Returning scientists and the emergence of China’s science system

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Abstract

China’s approach to developing a world-class science system includes a vigorous set of programmes to attract back Chinese researchers who have overseas training and work experience. No analysis is available to show the performance of these mobile researchers. This article attempts to close part of this gap. Using a novel bibliometric approach, we estimate the stocks of overseas Chinese and returnees from the perspective of their publication activities, albeit with some limitations. We show that the share of overseas Chinese scientists in the USA is considerably larger than that in the European Union. We also show that Chinese returnees publish higher impact work and continue to publish more and at the international level than domestic counterparts. Returnees not only tend to publish more, but they are instrumental in linking China into the global network. Indeed, returnees actively co-publish with researchers in their former host system, showing the importance of scientific social capital. Future research will examine the impact of length of stay, among other factors, on such impact and integration.

1. Introduction

For the past 40 years, China has made investments in building domestic research capacity, in prioritising advancements in targeted areas of science and technology (S&T), and in seeking opportunities of attracting foreign investment and knowledge. Against such backdrop and the unprecedented entrance of a huge nation into the global science system, this study examines the rise in the number of Chinese scientific personnel, their international engagement, the number of overseas Chinese scientists and returnees, and the contribution of such a pool of talent to Chinese and to global science.

This article discusses and analyses China’s human resources development amid its policy-driven process of globalisation and internationalisation. The article starts with a discussion of human capital development in the Chinese research and innovation system. This is followed by an examination of Chinese overseas study in the reform and open-door era, and especially the cross-border mobility of highly-skilled Chinese talent. China has implemented the largest and most intense campaign to attract overseas Chinese scientists to return. Due to a lack of reliable statistics, it is difficult to estimate the exact number of overseas Chinese scientists and engineers and returnees (especially from the European Union (EU)). Rather than assessing the success of any specific return migration programme, this article extracts data from S&T publications to offer a conservative estimate of the number of Chinese scientists in Europe and in the USA, as well as estimate of the number of returnees to China from these countries. These estimates are based on a novel bibliometric approach explained in the methodological section. The article proceeds with an assessment of the role which these overseas Chinese scientists and returnees have played in the formation of transnational ties among China, Europe, and USA and, thus, in embedding the Chinese science system in transnational collaborative networks.

We expect to show that increasing numbers of Chinese researchers have returned home over time, that those who return home are more likely to contribute to higher impact science and that they are more prone to engage in international collaboration. These international collaboration patterns are furthermore expected to be shaped by past mobility experience: that is, we expect to be able to measure the effect of scientific social capital aspect of scientific and technological human capital (Bozeman et al. 2001; Jonkers and Tijsen 2008; Jonkers and Cruz-Castro 2013).
2. Growth of Chinese science

In the span of four decades, China has evolved from a peripheral player to become one of the world’s most productive science systems (Zhou and Leydesdorff 2006). A variety of indicators suggest that China’s S&T capabilities are on a sharply rising trajectory. The Organization for Economic Cooperation and Development (OECD 2010) reports that since the 1990s, spending on S&T and research and development (R&D) in China has been increasing at a rate faster than that of overall economic growth. In 2017, China reported to spend RMB1.75 trillion ($259 billion), or 2.12 per cent of its increasing gross domestic product (GDP), on R&D (NBS 2018). This is higher than that of EU, which, with 317 billion euro ($358 billion), arrives at 2.06 per cent of GDP, while still lower than that of the USA, whose respective figures were estimated at $510 billion and 2.74 per cent of GDP in 2016 (Van Noorden 2014; NSF 2018; ESTAT 2018). China’s exponential rise in the S&T terms can be attributed to reform and open-door policies, especially the reform of the S&T system since the mid-1980s (Appelbaum et al. 2018). The leadership’s vision on the role of S&T in the country’s modernisation and government’s commitment to S&T also are contributing factors, evidenced in increasing public expenditure in S&T and R&D.

In the recent decade, there has been a steady rise in the contributions of Chinese scientists to international publications (NSF 2018). Measured by the number of papers published in journals indexed by Scopus, China ranked second in the world in number of publications, accounting for some 19 per cent (18 per cent fractional) of the world’s total in 2017, up from 10 per cent (9 per cent fractional) in 2005. Leydesdorff et al. (2014) showed that the yearly growth for China’s in the top 1 per cent of highly-cited articles was 0.85 percentage points per year between 2000 and 2012. As shown in Table 1, 5 per cent (4 per cent fractional) of China’s publications were among the top 10 per cent most highly-cited papers (field normalised); but in 2017, that statistic rose to 9 per cent (8 per cent fractional: that is fractionalised and field normalised). That is, based on this measure, China is still somewhat below the world average of 10 per cent in terms of high-impact publications as a share of its total output, but it has shown a remarkable increase in the share of impactful papers while expanding its total publication output exponentially.1 (FWCI stands for Field Weighted Citation Impact, a widely accepted method of normalising citation measures across fields (Purkayastha et al. 2019).) Taking the non-field normalised measure of the share of the top 10 per cent most highly-cited papers (field normalised); but in 2017, that statistic rose to 9 per cent (8 per cent fractional: that is fractionalised and field normalised). That is, based on this measure, China is still somewhat below the world average of 10 per cent in terms of high-impact publications as a share of its total output, but it has shown a remarkable increase in the share of impactful papers while expanding its total publication output exponentially.1 (FWCI stands for Field Weighted Citation Impact, a widely accepted method of normalising citation measures across fields (Purkayastha et al. 2019).) Taking the non-field normalised measure of the share of the top 10 per cent most highly-cited papers, the rise is even more spectacular: tripling rather than doubling between 2005 and 2017. The reason why China’s share of field weighted top 10 per cent papers grows slower than the absolute number is that in chemistry and engineering, fields in which China is heavily specialised, citations receive a lower weight when normalised by subject field.

International co-publications also have played a considerable role in the rise in impact. An increasing share—from 14 per cent (8 per cent fractional) in 2005 to 22 per cent (14 per cent fractional) in 2017—of the rapidly rising number of Chinese publications are the result of international co-publications. China’s international co-publications with the EU and USA on average receive considerably more citations than China’s articles more generally. One also observes that international co-publications with China receive more citations on average than the average publication from the EU28 and the USA (see also Leydesdorff et al. 2014). The rapid development of China’s international collaboration is thus mutually beneficial for both China and its partners (Adams 2012). As shown in Fig. 1, the numbers of co-publications between China and the USA have outpaced EU-US co-publications, while EU-China co-publications have grown less rapidly than EU-US co-publications (see also Wagner et al. 2015; Preziosi et al. 2019).

Funding intensity and the level of institutional for research systems affect the scientific performance of research systems (Cimini et al. 2016; Sandstrom and van den Besselaar 2018); the performance is also influenced by the presence of high-quality scientific human capital, scientific mobility, and international research collaboration (Sugimoto et al. 2017; Wagner and Jonkers 2017). Scientific mobility can be characterised ‘as a way to augment the scientist’s professional network and the resources available, thus increasing the scientist’s scientific and technical human capital’ (Edler et al. 2011: 792).

The literature has suggested theoretically (Borjas 1994) and shown empirically (Gaule and Piacentini 2013) that people are positively selected into migration: the most talented obtain education abroad or get job offers abroad. It is therefore expected that returnees outperform natives who did not move. Depending on the circumstances, the choice to return may also be subjected to selection (Borjas and Bratsberg 1996). Returnees may be either positively selected: that is, the best of the best return; or negatively selected: that is, the worst of the best return. Overall, if scientific potential would be an innate—non-context dependent—quality, both groups of returnees may be expected to outperform the natives that never migrated.

Smaller-scale studies suggest that returned scientists indeed publish high-impact papers than those domestic counterparts without foreign work experience (Jonkers and Tijsen 2008; Baruffaldi and Landoni 2012; Jonkers and Cruz-Castro 2013). Gibson and McKenzie (2014) do not find the same effect on high-impact publications (for small island countries), but do share the aforementioned authors’ findings on the greater propensity of returnees for international collaboration. Van Holm et al. (2018) found that Chinese scientists in the USA maintain more robust and productive networks than their US-born counterparts. Diaspora scientists tend to cooperate to a relatively large extent with those in the home system (Jin et al. 2007; Wagner 2008; Scellato et al. 2015) either spontaneously or in response to scientific diaspora policies implemented by the government of their home system (Meyer 2001; Jonkers 2008). Through this channel, they may thus help in the further development of their home research system (Agrawal et al. 2011; Wagner et al. 2018).

Table 1. Bibliometric indicators of China’s scientific performance.

| Year | PP10 FWCI, full | PP10 FWCI, frac | PP10 CITS, full | PP10 CITS, frac | WLD share, full | WLD share, fractional | Intl. share of CHN pubs, full | Intl. share of CHN pubs, frac |
|------|----------------|----------------|----------------|----------------|----------------|------------------------|-----------------------------|-----------------------------|
| 2005 | 5%             | 4%             | 5%             | 4%             | 10%            | 9%                     | 14%                         | 8%                          |
| 2010 | 6%             | 5%             | 7%             | 6%             | 16%            | 15%                    | 14%                         | 8%                          |
| 2017 | 9%             | 8%             | 15%            | 13%            | 19%            | 18%                    | 22%                         | 14%                         |
3. Public policy changes to improve the quality of China’s scientific workforce

Underlying the impressive performance taking place in the Chinese S&T system is the emergence of a very large talent pool whose quality has been improving. As a concept, talent (rencai) has gained increasing popularity and significance in China since the turn of the 21st century, when the leadership realised that ‘empowering the nation with talent’ (rencai qiangguo) is key to ‘rejuvenating the nation with science, technology, and education’ (kejiqiao xingguo), a strategy introduced in the mid-1990s. Despite possessing the world’s largest number of scientists and engineers and having a very full pipeline in higher education, China has been facing a serious talent challenge, especially at the high end. Critical concerns proliferated from the political and scientific leadership to enterprise chief executives, including the country heads of multinational corporations operating in China, about whether China’s potential could be realized, given the uncertainties surrounding the demand and supply, quantity and quality, and effective utilisation of China’s current and future S&T workforce (Simon and Cao 2009).

In 2006, China launched the Medium- and Long-Term Plan for the Development of Science and Technology (2006–20) (MLP), signalling the nation’s commitment to rely more on ‘brain’ than ‘brawn’ to bring China into a strong leadership position (Cao et al. 2006). The Central Leading Group for Coordinating Talent Work (CLGCTW), a high-level task force newly established by the organisation department within the Central Committee of the Chinese Commmity Party (CCCPCC), led the implementation of the Plan on National Medium- and Long-Term for the Development of Talent (2010–20). The formulation of the plan highlighted the urgency that China placed on achieving five goals: (1) transforming China’s population dividend into a talent dividend; (2) pursuing a shift from a ‘made in China’ to a ‘created in China’ model; (3) focusing less on attracting foreign capital and more on attracting human capital; (4) emphasising the importance of ‘software’ rather than ‘hardware’; and (5) shifting from an investment model to an innovation model. In addition to providing guiding policies and strategic goals, the plan recommended national talent development targets; specified sectors in which talent is in great demand; called for establishing national programmes to support and nurture the development of talent in various fields; and prioritised areas in which improvements in policy and institution-building are necessary to better employ talent (CCPCC 2010; Simon and Cao 2011; Wang 2011).

In 2015, the CCPCC and China’s State Council released the innovation-driven development strategy. In 2016, the CCPCC issued the ‘Opinions on Deepening the Reform of the Institutional Mechanism for Talent Development’ to accelerate the talent-driven nation-building, stimulate fully Chinese people’s innovativeness, creativity, and entrepreneurship, and attract talent from all walks of life to fulfil the cause of the party-state.2

These policy actions were the culmination of those in the 1990s when the Chinese government started making large investments in the reform and upgrading of the country’s universities through its 211 and 985 Programmes (Simon and Cao 2009; Wang et al. 2011; Zhang et al. 2013). In 2017, these higher education programmes were merged to become the ‘Double First-Class University Programmes’ aiming to raise rankings of 30 Chinese universities to the list of the top 100 leading universities worldwide (Wang 2017; Zhang 2018 ). The Chinese Academy of Sciences (CAS), the country’s leading research institution, has also experienced large-scale reform and investments (Suttmeier et al. 2006; Cao and Suttmeier 2017). As a consequence, China has not only been able to train increasingly larger volumes of scientists, but these investments and reforms have also made China a more attractive point of return for overseas Chinese scientists.

Domestically, between 2000 and 2016, the total number of Chinese postgraduate students with a master’s degree increased by ten-fold while the percentage of those in science, engineering, agriculture, and medicine (SEAM) showed a slight decline in the early 21st century before stabilising in recent years at 57 per cent of all students. Similarly, entering the 21st century, there was an initial decline in the number of doctoral students majoring in SEAM; but the trend was reversed. In 2016, 77 per cent of Chinese doctorates were awarded in SEAM. The annual number of SEAM PhDs graduating from Chinese universities has grown by 450 per cent since 2000. At around 40 000 SEAM doctorates graduating annually, China is currently close to the USA in number, while still being well behind the number of STEM PhDs graduating from EU universities (see Table 2).

Table 2. Number of STEM PhD graduated.

| Year | China | EU | USA |
|------|-------|----|-----|
| 2000 | 9038  | NA | 27 862 |
| 2005 | 20 269| NA | 34 468 |
| 2010 | 34 801| NA | 36 711 |
| 2015 | 40 963| 60 223 | 44 521 |

Sources: NSF (2018); CBS (2018); ESTAT (2018).

The expansion of China’s higher education system offers only a partial view into the processes leading to the strengthening of China’s scientific human capital base. A key part of this development has included the very large number of outbound students and scientists who travelled to the USA, Europe, and other countries to study and work (Simon and Cao 2009; Jonkers 2010). The outward mobility of Chinese students and scholars began immediately after the Cultural Revolution which ended in 1976. At that time, the Chinese leadership realised the negative impacts of a ‘missing generation’ of young and middle-aged, well-trained scientists, engineers, and other professionals on the nation’s modernisation in agriculture, industry, S&T, and national defence. In addition to resuming formal higher education, the leadership put the training of high-quality personnel overseas higher on its agenda. As early as 1978, Deng Xiaoping, who would become China’s paramount leader, proposed sending thousands and even tens of thousands students and researchers abroad as one of the important ways to raise the level of Chinese science and education. He did not perceive ‘brain drain’ to be a problem, as long as 10 per cent of the dispatched would return.

The open-door policy (Zweig 2002) also marked an important cultural shift, which accompanied a more ‘technical’ or development policy driven shift. This cultural shift was started by the strong statements in support of S&T and scientists made by Deng Xiaoping at the first National Science Conference in 1978. Not only were science and scientists respected again. Possibilities were also created to go and learn abroad, with the idea that they would bring this experience back to China. The process of opening up continued apace until the 1989 pro-democracy movement; thereafter, some restraints were added. In 1993, the twelve-word policy was adopted that again supported the outflows of students and scholars. These twelve words refer to ‘support study overseas, encourage returns and guarantee freedom of (international) mobility’ (zhichi liuxue, guli huigou, laiqu ziyou), with four more words, ‘allowing them to play a role’ (fabui zuoyong) being added recently by Xi Jinping, the current...
general secretary of the CCPCC and state president (for an analysis of the evolution of policy developments alongside a description of outbound and return flows, see Zweig and Chen (1995), Zweig (2002), Xiang (2003), and Cao (2008)).

Consequently, by 2017, a stock of 5.2 million Chinese had gone abroad and 3.1 million had returned; the return rate appears to be about 60.3 per cent. Taking into consideration that 1.45 million were still students, 83.7 per cent of those who had finished their overseas studies had returned. By comparison, by 2000, there had been only 340,000 and 130,000 overseas students and returnees. In terms of flow, in 2017, 608,400 Chinese went abroad and 480,900 returned, representing a return rate of 79 per cent in the year. By comparison, in 2000, only 38,989 and 9,121 Chinese went abroad and returned, respectively, with a rate of return of 23.4 per cent in the year (see Table 3).

Over time, some of these scientific émigrés returned to China. Indeed, the two processes are seen as interlinked: the large investments in the higher education and research system, coupled with its qualitative upgrading, have made China attractive for returnees. Upon return, they were expected to help strengthen China’s research and innovation system.

The bulk of the returnees earned bachelor’s- and master’s-level degrees in STEM. The return rate for Chinese with EU doctorates is thought to be higher than that from the USA. This is corroborated by the ‘stay rates’ found among the Chinese who have earned American doctorates, reported by the US National Science Foundation. Between 2006 and 2016, US universities awarded 50,439 doctoral degrees to Chinese nationals (NSF 2018) (see Table 4). In 2015, 22 per cent of the 464,000 foreign born S&E doctorate holders in the USA. Between 2012 and 2015, the vast majority of US science and engineering (S&E) doctorate recipients from China (83 per cent) reported plans to stay in the USA, and approximately half of these individuals reported accepting firm offers for employment or postdoc research in the USA. By country of citizenship at time of degree, China, the country that is the source of more S&E doctorate recipients than any other foreign country, had the highest 5- and 10-year stay rates. For those who received their doctorates in 2005, the 5-year stay rate was 90 per cent; for those who received their doctorates in 2010, the 5-year stay rate was 85 per cent, while the 5- and 10-year stay rates for all the S&E doctorates were both 70 per cent in 2015 (NSF 2018). In the life sciences in 2007, there were 2,500 Chinese origin scholars serving as faculty members in US universities (Wang 2007). In contrast to the USA, there are no systematically collected statistics on the number of Chinese students, scientists and returnees in the EU, limiting the potential for comparative analysis. This is one of the gaps that this study aims to address.

To counter the perceived ‘brain drain’ and to further encourage return, China has implemented a series of programmes to attract back highly skilled overseas talent to strengthen its universities, research institutes and high-tech companies. As policy background to this paper, Table 5 provides an overview of these programmes as well as the number of researchers involved.

A rough sum of the number of people attracted back through the various return programmes suggests that by 2018, the Chinese government had recruited back at least 16,000 scientists and high-tech entrepreneurs. Others may have returned following less well-known but presumably more extensive provincial or institutional programmes or on their own accord. Entrepreneurs and highly-skilled employees beyond academia have also taken advantage of the opportunities offered by China’s growing economy and high-tech development within the special economic zones (SEZs), introduced in the 1980s, as well as many high-tech parks in cities, such as Beijing, Shanghai, Guangzhou, Shenzhen, Hangzhou, and beyond. Here policies granted benefits to returnees and their dependents to encourage highly-skilled workers to locate in SEZs and high-tech parks (Liu and van Dongen 2016). These benefits have since been expanded to other areas and, indeed, competition for talent has driven mobility policies at the regional level.

The impact of some of the return programmes is being studied. For example, Li and Tang (2019) examined the return and advancement patterns for Chang Jiang/Cheung Kong Scholars (n = 1447) (Table 5) and found that international mobility had a heterogeneous effect on career progression within China, with overseas experience slowing down the advancement of some late-phase careers and appeared to make little difference to early stage careers, but local connections appear to be more important to advancement. Li et al. (2015) analysed differences in the publication behaviour of Chang Jiang Scholars finding that those who returned to their alma mater collaborated less intra-institutionally and tended to publish higher impact publications. The results of the current study are also in line with a recent analysis of the Young Thousand Talent programme (Yang and Marini 2019).

A full assessment of the relative success of the individual programmes described in Table 5 is beyond the scope of this article, as it would require, among others, detailed personnel data on the successful and unsuccessful applicants to these respective programmes. This article addresses the significance of the mobility of scientists between the Chinese as well as the US science system and European science system. At present no comparable statistics exist

### Table 3. Students going overseas and returning.

| Year | Number of students going overseas | Number of returnees | Cumulative number of students going overseas | Cumulative number of returnees |
|------|---------------------------------|--------------------|---------------------------------------------|-------------------------------|
| 2000 | 38,989                          | 9,121              | 340,000                                     | 130,000                       |
| 2005 | 118,515                         | 34,987             | 933,400                                     | 232,900                       |
| 2010 | 284,700                         | 134,800            | 1,905,400                                   | 632,200                       |
| 2017 | 608,300                         | 480,900            | 5,194,900                                   | 3,132,000                     |

Source: Compilation on the basis of data released by China’s (First two columns: National Bureau of Statistics, China Statistical Yearbook, Beijing, China Statistics press, various years. Last two columns: author’s research) Ministry of Education.
of the number of overseas Chinese scientists working in the USA and Europe, nor of the number of Chinese scientists who have returned to work in the Chinese science system following training and work abroad.

### 4. Methodology and data

In the absence of reliable statistics, scientific mobility patterns have been studied using microdata from surveys (Baruffaldi and Landoni 2012; Franzoni et al. 2012, 2015; Cruz-Castro et al. 2016; Scellato et al. 2015) or collected from targeted samples of returnees (Jonkers and Tijssen 2008; Jonkers and Cruz-Castro 2013). Microdata collected through surveys have well-known drawbacks. For example, given the need for anonymisation, it is often impossible to link microdata to objective measures of productivity or collaboration. In the early 2000s, scholars started to explore the potential of bibliometric data to study scientific mobility and its effects (Laudel 2003; Jonkers 2008).

A new bibliometric approach offers an alternative possibility to address both issues (Moed and Plume 2013; OECD 2017; Sugimoto et al. 2017; building on Wagner et al. 2018). An analysis of the microdata on publications contained in Elsevier's Scopus database allows us to track researchers from the moment of first publication. It is thus possible to trace Chinese researchers who first published in China and subsequently published in a different country. The number of researchers who started their publishing career in China, followed by publications in a host country, and who then continue to publish at the time of the analysis (i.e. contained in the Scopus database per 29 January 2019) is used as a proxy for mobility. This measure has limitations. In 2003, 75 per cent of Chinese origin PhD holders working in the USA had received their PhD degree from US universities (Cao 2008). This share may be lower at present but it is expected to be substantial. Many of these researchers will not have published in journals indexed in Scopus before moving to the USA and are therefore not captured in our analysis. However, the measure does offer an important improvement/alternative over current surveys. As the same approach is followed for the USA and EU, the statistics are comparable, thus addressing the problem that in many European countries no comparable data are available on scientists with a Chinese origin. The method also allows us to identify active scientists, excluding those overseas Chinese PhD holders who pursue a different career that does not involve publishing.

A proxy for returnees to China is calculated in a similar fashion. Of the scientists publishing with a Chinese address, a subgroup of authors is identified who had previously published with a US or EU address, respectively. While this group of authors may include researchers with a US or EU origin, the vast majority are expected to be returned overseas Chinese scientists (Jin et al. 2007).

### Table 5. Programmes related to the talent attraction, retaining, and utilisation (by 2018).

| Programme                                      | Agency in charge | Target of the programme                                                                 | Year initiated | Total affected number |
|------------------------------------------------|------------------|----------------------------------------------------------------------------------------|----------------|-----------------------|
| Hundred Talent Program                         | CAS              | Scientists under 45 years old (i)                                                      | 1994           | n.a.                  |
| National Science Fund for Distinguished        | NSFC             | Academic leaders under 45 years old; frontier sciences and technology (d)              | 1994           | 3454                  |
| Young Scholars                                 |                  |                                                                                       |                |                       |
| Chunhui Program                                | MOE              | Chinese expatriates for short-term services (i)                                        | 1996           | n.a.                  |
| Cheung Kong/Changjiang Scholar Program         | MOE              | Endowed professorships for under 45 years old; extended to 55 years old in social sciences and humanities (d & i) | 1998           | 2948                  |
| 111 Program                                    | MOE and SAFEA    | 1000 foreign scholars from the top 100 universities and research institutions (i)       | 2005           | n.a.                  |
| Thousand Talent Program                        | CLGCTW           | 1000 academics, corporate executives, and entrepreneurs under 55 years old to return from overseas (i) | 2008           | n.a.                  |
| Young Thousand Talent Program                  | CLGCTW           | Academics under 40 years old with three plus years of postdoctoral research (i)        | 2010           | 3335                  |
| Science Fund for Emerging Strong Distinguished | NSFC             | Researchers under 38 years old to work in academia (d)                                 | 2011           | 2398                  |
| Young Scholars                                 |                  |                                                                                       |                |                       |
| Ten Thousand Talent Program                    | CLGCTW           | To support high-end talent residing in China (d)                                        | 2012           | 3454                  |
| New Hundred Talent Program                     | CAS              | Renewal of Hundred Talent Program (d & i)                                              | 2014           | n.a.                  |
| Young Cheung Kong Scholar Program             | MOE              | Endowed professorships for young scholars at Chinese universities (d)                   | 2015           | 440                   |
| Science Fund for Emerging Distinguished Young  |                  |                                                                                       |                |                       |
| Scholarship Program                            |                  |                                                                                       |                |                       |
| Science Fund for Emerging Young Talent Program |                  |                                                                                       |                |                       |

**Notes:** MOE—Ministry of Education; NSFC—National Natural Science Foundation of China; SAFEA—State Administration of Foreign Expert Affairs; CLGCTW—Central Leading Group for the Coordination of Talent Work (i = international focus; d = domestic focus).

**Source:** Author’s research.
Publishing authors in the Scopus database (Schotten et al. 2017) are defined by their author profile. Scopus is among the largest curated abstract and citation databases consisting of metadata of over 76 million scientific publications published since 1788 to date (Baas et al. 2019, in press). Author profiles in Scopus are a combination of curated and system-generated profiles. All author profiles are originally generated by an ‘author profiling’ algorithm. This results in profiles that are optimised for precision (publications merged in a profile belong to one and the same person) over recall (all publications of the same person are merged into one profile). About 1.8 million profiles in Scopus have also undergone manual curation. The current reported precision and recall by Scopus is 98.1 per cent, at an average recall of 94.4 per cent (Baas et al. 2019, in press). The database captures links between authors and their affiliations on papers throughout the database historically. This allows for longitudinal researcher-mobility studies: allowing to track publications of the same researcher, their affiliations over time, using a comprehensive and curated database. This provides the basis of the mobility data presented in this article.

In order to determine the flow of researchers, this study builds further on the methodology of the OECD (OECD 2017: 71) by tracking author flows in Scopus using the first publication in each year and assigning authors fractionally to countries if that publication has multiple affiliation countries for that author (for instance, if an author has a guest position, it can be practice to list multiple affiliations). Having a sequence of countries per author over time allows tracking of movement of that author. It also provides a point-in-time identification after which an author has moved to a tracked destination. For example, a researcher publishing in China first in 2005, moving abroad and publishing in the USA in 2007, and then returns to and publishes in China in 2014, is classified as a China returnee. We then track publications of this returnee after 2014. Similarly, if an author moves from the EU to China and back to the EU and back to China, the returnee contribution to international publications for China is measured from the first move to China onwards, and publications authored while not in China (back in the EU) are not counted.

Using this approach, it is possible to determine, for instance, the contribution of returnees from the USA to co-publications between China and the USA, and to map their relative impact against the total of international publications. Movements between two countries are registered in this study only if they are subsequent. This means that if an author moves from the USA to EU and eventually to China, only the movements from the USA to the EU and from the EU to China are reported, and a movement from the USA to China is not taken into consideration. Contributions to publications after moving into a destination are measured at the time of the first publication at the destination.

In order to estimate stocks of overseas researchers and returnees, it should be taken into consideration that some researchers do not publish every year. To be able to count those authors even when they are not publishing in a given year, there are two different scenarios to take into account: (1) a researcher does not publish for a while and then publishes again; these authors are counted towards the last year available until they publish again, that is, the missing years in between are filled using the last known data point and (2) a researcher that stops publishing and does not publish again (until today); for these, an arbitrary threshold of 2 years is used in which they are still counted until eventually they are classified after that period as ‘retired’ and no longer counted. This is mainly relevant for the more recent years where it is important to be able to count stocks of researchers that have not published in the last year, but for which it is not certain if they are retired or just temporarily inactive.

Access to microdata on overseas Chinese scientists and returnees allows us to engage in a further analytical step that sheds insight on the contribution these scientists have made to the Chinese, EU, and US science systems and on the relations between them. The first step is to assess the relative share of the top 10 per cent most highly-cited papers from different science systems co-authored by overseas Chinese and returnee authors. Apart from contributing to the human resource in S&T (HRST) stocks in the US, EU, and for returnees the HRST stocks in China, scientific mobility flows are also thought to play an important role in transnational knowledge transfer and to be closely related to international collaboration (Wagner 2008). The scientific social capital, that is, the scientific networks that scientists had built up during their stay in a foreign country, is expected to shape collaboration patterns at later stages in their career—including upon return (Jonkers and Tijsen 2008; Jonkers 2010; Jonkers and Cruz-Castro 2013). The second step is therefore to assess the share of international co-publications between the USA and China as well as between the EU and China, respectively. If co-publications are more prevalent in the direction of the former host system, then this substantiates the often referenced hypothesis that scientific social capital influences collaboration patterns. If we cannot show tendency towards co-publications, then this longer term effect of scientific mobility may not occur. International co-publications tend to receive more citations than the average paper published in each of the science systems (Royal Society 2011). The participation of overseas Chinese scientists and returnees in co-publications with their EU and US counterparts, respectively, thus sheds light on the mechanisms underlying the sustained contribution of scientific mobility flows to the performance of advanced and emerging science systems.

5. Results: assessing the size and impact of overseas Chinese scientists and returnees

Using the approach described in the methodological section, it is possible to make an estimated assessment of the stocks of people who returned to China, as well as recent mobility. Figure 2 and Table 6 present these data.

Figure 2 shows estimates of the number of people who left China and now publish in the EU or the USA, and the number of people who left the EU or the USA and now publish in China. Column 1 in Table 6 under Fig. 2 shows the number of scholars who had previously published in China and now publish in the USA (5222) and the number of new authors in this category in 2010 (3019), and the same data for 2017, that is prior mobile scholars in the USA at 9321 (including all previous years, including the 2010 data), and those new in 2017 (4453). The top section of the bars in Fig. 2 shows the new inflows in 2010 or 2017; the ‘existing stock’ (prior mobility) is shown in the bottom part of the column. Those authors who began publishing in the USA prior to 2010 and returned to China are shown in Table 6, column 3, at 2279, and those US authors newly publishing in China in 2010 (2703) and the same data for the EU in that year. The data showing those authoring first in the USA and EU and moving to China (approx. 9630 and approx. 5260, respectively) primarily involves Chinese researchers who published in the USA or the EU and then returned to China.
One observes from Fig. 2 that between 2010 and 2017 an increasing number of Chinese researchers returned home from the USA and EU, but the number of publishing Chinese researchers moving to the USA and EU is higher than those returning home. In 2017, the number of researchers who had started their publication career in China and subsequently moved to the USA is around three times higher (approx. 13,770) than the number who moved to Europe (approx. 4,860). In 2017, the number of new Chinese entrants to these regions had grown in both the USA and the EU.

The number of Chinese researchers going to the EU has grown faster than those going to the USA, albeit from a lower base. The number of new entrants in the USA in 2017 is 2.3 times higher than the number of new entrants in the EU. The ratio between overseas Chinese and returnees provides us with an insight in the relative return rates from the EU and USA. Whereas for every returnee from the USA, 1.4 overseas Chinese scientists remain in the USA; this ratio is 1 to 0.9 in the case of the EU.

Using the same approach, it is also possible to estimate the relative impact which returnees and overseas Chinese have on the Chinese science system. These data also provide insight into the performance differences between the researchers that remain overseas and those who return. Figure 3 shows that the total population of returnees (ALL → China) published nearly 14 per cent of China’s publications in 2005. This share remains relatively stable over time at 13 per cent in 2010 and 2017. (The supplement provides the entire time series.) Returnees from the USA (USA → CHN) published a larger number of indexed publications than Chinese researchers returning from Europe (EU → CHN). Returnees from the USA are responsible for 5.1 per cent of all China’s publications, whereas returnees from Europe are responsible for 2.9 per cent. The publication productivity of overseas Chinese scientists in the USA or EU are not counted as part of the Chinese output.

The columns CHN → USA and CHN → EU28 depict the productivity of this overseas Chinese population relative to the total Chinese output. For Chinese scholars in the USA, productivity over-performance was 3.5 per cent in 2005 and 2.3 per cent in 2017. The over-performance of Chinese scholars in the EU was 1.4 per cent in 2005 and 1.15 per cent in 2017. In other words, Chinese researchers in the EU published 1.15 papers for every 100 papers made in China in 2017.

Returnees make a substantial contribution to the impact of Chinese science. Figure 4 shows, as expected, that the average impact of the work of overseas Chinese is considerably higher than that of those who have not moved abroad. Chinese scientists who remain in the USA and EU meanwhile not only publish a relatively high and larger number of articles, the share of these publications that are among the top 10 per cent worldwide is at over 20 per cent and 17 per cent in the USA and EU28, respectively, considerably higher even than that of the returnees, at 13 per cent for returnees from both the USA and EU28. However the share of high impact publications from returnees is increasing over time.

The share of China’s publications that is among the top 10 per cent most highly-cited worldwide (adopting fractional counting) was 4 per cent in 2005. This is well below the worldwide average of 10 per cent. Over time, the percentage of highly-cited publications by Chinese authors has been increasing and can be expected to grow further. In 2010, the share of Chinese papers in the world’s top 10 per

### Table 6. Estimates of the number of overseas Chinese scientists and returnees.

| Year | Chinese authors now publishing in the USA | Chinese authors now publishing in EU | US authors now publishing in China | EU authors now publishing in China |
|------|------------------------------------------|-------------------------------------|----------------------------------|-----------------------------------|
| 2010 | Preceding stock (movement prior to 2010) | 5222                                | 1386                             | 2279                              | 1163                              |
|      | New movement                            | 3019                                | 1175                             | 2703                              | 1141                              |
| 2017 | Preceding stock (movement prior to 2017) | 9321                                | 2957                             | 5058                              | 2889                              |
|      | New movement                            | 4453                                | 1905                             | 4569                              | 2371                              |

Figure 2. Stocks of mobile Chinese scientists in China, the EU, and USA.
cent most highly cited (PP10) was 9 per cent. As expected, the citation impact of papers by returnees is considerably above those who never left China. In 2005, this share was 2 per cent higher, at 6 per cent and in 2017 it was already 5 per cent higher at 14 per cent, that is, 4 percentage points above the world average.

One of the factors related to the stronger performance of returnees is their participation in internationally-co-authored papers. Such papers are known in general to attract more citations and returned scholars use the connections built up during their stay abroad to continue publishing with foreign colleagues (Jonkers and Tijssen 2008). Indeed, if one considers the total share (fractional counting) of China’s international co-publications published by researchers with foreign work experience, one observes that these shares are between 29 per cent and 27 per cent of China’s total output of international co-publications, double the share of China-only publications. In other words, these researchers tend to publish a much higher share of papers as a result of international connections. The difference in the share of China’s international co-publications by researchers who returned from the USA, and those from the EU, is likely to be mainly a reflection of the different number of researchers returning from these parts of the world. What is striking is that a considerable share of the international co-publications is made by researchers who came to China from other parts of the world; in 2017, 27 per cent of China’s international papers were authored by returnees. This can be split into 16 per cent USA/EU and 11 per cent from elsewhere. It suggests that flows of researchers from other East Asian countries, Canada, Australia, Singapore, and the global south have had a considerable impact—also considering that a high share of these papers is among the top 10 per cent most highly cited (PP10).

Chinese researchers who remain overseas also play an important role in forging ties between their host country and home system. As is clear from Fig. 5, overseas Chinese scientists working in the USA and EU are involved in 8 per cent and 5 per cent, respectively, of China’s international co-publications in 2017. Figure 6 shows that researchers who moved to China after work experience in Europe predominantly co-publish with researchers in EU research systems,
whereas researchers who moved to China from the USA continue co-publishing predominantly with the USA.

6. Discussion and conclusion

The Chinese government’s policy and programmes to build a world-class science system have borne fruit given the impressive rise of high-impact science it produces. As shown in the data presented in this article, the mobility (in and out) of foreign-bound students and scientists has had a major impact on the development of both the Chinese science system and the global science systems. Recognising that the most highly talented of the overseas Chinese remained overseas, the Chinese government has actively sought to build and improve a national system to attract them back and then has gone on a campaign to recruit them. While return migration programmes would in the best case scenario be able to attract back the best of the best, they might also claim success if they manage to attract people who substantially outperform those who have remained: given that their objective is to raise the performance of the domestic system. Even those who remain abroad appear to be an asset to China as co-authors. Countries facing large outbound flows of scientists may draw lessons from the Chinese experience.

One of the main challenges in assessing the impact of outbound and return flows of Chinese scientists to Europe and the USA is the lack of comparable data on the population of overseas Chinese scientists. Data on returnees from these respective host systems are

**Figure 5.** International co-publications by overseas and returnees as a proportion of China’s international co-publications.

**Figure 6.** The direction of co-publications by returnees.
even less available. This article, rather than attempting to assess government return migration programmes, provides an insight in the relative dimensions of these stocks of scientists. As expected, we show that the share of overseas Chinese scientists in the USA is considerably larger than that in the EU. Over time, flows of researchers from these destinations back to China have increased, although more so from the EU than the USA. We also show that Chinese researchers who have returned from overseas both publish higher impact work and continue to publish at the international levels and collaborate with the colleagues in the science systems in which they once participated.

As expected, Chinese scholars return to China in increasing numbers. We find that their publications have a higher relative impact than domestic researchers. Furthermore, we find that both the overseas Chinese and returned scientist population have contributed to the Chinese science system. It shows that over 12 per cent of mainland China’s total number of publications is published by people with overseas experience and, as explained in this article, this number is likely to be a substantial underestimation. The share of high-impact publications by scientists is considerably higher than that of their colleagues who remained in China throughout their scientific careers, as expected.

The impact of publications by overseas Chinese is higher than those of researchers in China (including returnees). This continues to be the case. In combination with a growing net outflow of Chinese researchers to the USA and EU, this suggests that China may not yet attract back its ‘best’ expatriate scientists, or is perhaps not offering an environment for top-quality science (Cao 2008). Many factors—not just talent—influence the quality and impact of publications. This includes the quality of the research environment, which though improving in China may still be less conducive to the high-impact science China would like to conduct. Nevertheless, we show that overseas Chinese contribute to China through international collaborations. In the future, China may succeed in capitalising further on the quite considerable contribution that overseas Chinese scientists make to the scientific effort of the USA and EU: in any case, there appears to be some scope for this.

Part of the explanation for the relatively-high impact of publications by returnees relative to their domestic counterparts is that they tend to engage more in co-publishing with foreign-based collaborators. This tendency is common among many mobile researchers and we found it to be true of China. Both returnees and overseas Chinese scientists play an important role in embedding China in international collaboration networks. The observation that returned Chinese scientists co-publish predominantly with researchers in their former host system is important for two reasons. First, it shows the importance of scientific social capital (Jonkers and Tijsen 2008; Jonkers and Cruz-Castro 2013); it is the contacts that people have built up in their host systems during their foreign work experience which continue to influence collaboration patterns upon return. Secondly, it also shows the broader significance for any country of attracting foreign scientists. Mobile scientists play an important role in forging international collaboration ties, so a relative lack of attractiveness can influence long-term integration with China and by extension the global science system.

In the analysis presented here, we have not distinguished between scientists on the basis of their length of stay and the stage of their career: the only criterion of foreign work experience was having published in a host system. This means returnees include junior scholars (such as the large number of doctoral students funded through the China Scholarship Council) as well as established ones who returned home after perhaps years away. This limitation should be kept in mind. Future research will seek to address this gap. As suggested in the return migration literature, this time factor can be important both for the accumulation of various forms of capital and for the successful reintegration upon return (King 1986; Cassarino 2004; Jonkers 2010; Andújar et al. 2015). Cassarino (2004) classified different types of returnees as well as motivations to return. Whereas other methods are required to understand return migration decisions it may be possible to use the method described in this article to perform further quantitative analysis of different types of returnees, by analysing, for example, those who return permanently or those who engage in multiple moves between their home and host system.

Outbound scientific mobility and return are shown in this article to have an impact on both the host and the home system in terms of the production of high-impact science and in shaping international collaborative ties. China is unique among late industrialisers in the scale and scope of mobility as a strategy for development. The idea of advancing through learning is common to these countries, seen in Korea and Japan, but China is focused more on talent than on import substitution and imitation seen in other Asian nations. China’s model has included an emphasis on basic science that was not a part of early actions of other ‘Asian Tigers’. This feature—described here as mobility—may be a signature of China’s rise as they have sought to benefit not only from the human scientific and technical human capital that these scientists constitute but also from those benefits that accrue from greater integration in collaborative international networks (Wagner 2018).

The large mobility flows and international collaboration patterns between China, the USA, and the EU have developed in a political context, which allowed for these patterns of interactions to emerge in the decades since 1978. This political context might now be changing in particular with respect to the USA and China. The Trump administration has singled out specifically China’s Thousand Talent Program for scrutiny. There is a concern in the academic community on both sides of the Pacific regarding the potential ramifications of these changes, although it is too early to tell whether they will have an impact on mobility, return, and international collaboration.

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Conflict of interest statement

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Notes

1. Source: Scopus; extracted and indexed dataset on 29 January 2019.
2. ‘The CCPPC issued the Opinions on Deepening the Reform of the Institutional Mechanism for ‘Talent Development’ (in Chinese) <http://www.xinhuanet.com/politics/2016-03/21/c_1118398308.htm> accessed 30 June 2018.

3. In Chinese statistics information is collected on doctoral students majoring in SEAM. This classification is similar to the disciplines of science, technology, engineering, and mathematics (STEM) referred to in the context of other countries.

4. As an indication of the importance given to this issue at the highest level of government, Xi Jinping also praised Chinese studying overseas to be ‘the valuable treasure of the party and the Chinese people as well as the effective strength to realize the great rejuvenation of the Chinese nation’. ‘President Xi Jinping’s Speech at the 100th Anniversary of the Founding of the Western Returned Scholars Association’ (in Chinese) <http://www.xinhuanet.com/politics/2013-10/21/c_117808372.htm> accessed 28 Sept 2019.

5. National Center for Science and Engineering Statistics, Directorate for Social, Behavioral and Economic Sciences (comp.), 2016 Doctorate Recipients from U.S. Universities, NSF 18–304 (Alexandria, VA: U.S. National Science Foundation, March 2018). Table 26. Doctorates awarded for ten largest countries of origin of temporary visa holders earning doctorates at US colleges and universities, by country or economy of citizenship and field: 2006–16.

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