Jointly published by Akadémiai Kiadó, Budapest
and Springer, Dordrecht

Scientometrics, Vol. 77, No. 2 (2008) 309–333
DOI: 10.1007/s11192-007-1971-x

Chinese researchers returning home: Impacts of international mobility on research collaboration and scientific productivity

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The aim of this study is to contribute to the debate on the relationship between scientific mobility and international collaboration. This case study deals with leading Chinese researchers in the field of plant molecular life sciences who returned to their home country. A correlation analysis of their mobility history, publication output, and international co-publication data, shows the relationship between scientific output, levels of international collaboration and various individual characteristics of returned researchers. The outcome of the analysis suggests that while host countries may loose human capital when Chinese scientists return home, the so-called "return brain drain", they may also gain in terms of scientific linkages within this rapidly emerging and globalizing research field.

Introduction: when brain drain becomes brain gain

A significant part of the current 'brain drain/brain gain' phenomenon is a result of planned governmental initiatives that were launched during the last 10–20 years in which several of the leading developing countries, with 'catching-up' economies, were actively encouraging their brightest graduate students and talented young researchers to spent time abroad in order to complete their education and training, and to gain relevant international experience in R&D. After a certain period of time these researchers where

Received November 5, 2007

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0138–9130/US $ 20.00

expected to return to their home country. The return migration of such skilled science and engineering workers is seen as a major determinant of the quality and flexibility of the labor force. Data from the US shows that some countries/territories have higher rates of return than others. For example, in the case of Korean and Taiwanese doctoral candidates who graduated in 1996, only 21% and 40%, respectively, were still working in the US in 2001, whereas 86% and 96% of the 1996 cohort of doctoral graduates from India and the People's Republic of China, respectively, were still working in the US in 2001 [FINN, 2003]. Part of the success of the first two countries can be attributed to the already well-resourced and advanced R&D environment that the respective governments were able to provide in order to lure back their scientists; in other words, the 'absorptive capacity' of the home country is a necessary condition to a successful reverse migration [SONG, 1997]. In the 1990s, China appeared to have been less successful in its efforts to promote the return of its skilled expatriates, despite the government's incentive systems. Some authors have argued that the return incentives, as a policy lever for governments to improve the quality of their domestic science base, has failed since it is based on the questionable assumption, premised on theoretical foundations of the human capital framework, that governments can successfully manipulate the mobility of highly skilled R&D staff (e.g.: [CAO, 1996]).

One may also argue that the chances of the return option being successful, in terms of scientific productivity and research performance of the returnees, are increased when they are embedded in transnational professional networks in their home country, or when they are enabled to retain professional linkages with their co-workers and supervisors in the former host country, thus tapping into existing knowledge-producing networks and promoting (sustainable) international scientific cooperation (see e.g.: [JIN & AL., 2007]). This phenomenon could also be of interest to policy-makers in their former host countries as the forging of professional linkages with the emerging Chinese research system could help off-set some of the perceived costs in terms of the loss of human capital to the host system associated with the *return brain drain*. This may be of particular interest for European policy makers as the return rate of Chinese students and researchers trained in Western European countries is reportedly much higher than from the US [ZHANG & LI, 2002; ZHANG, 2003]. Since the beginning of his century increasing numbers of overseas Chinese researchers have returned from the US as well to take up positions in Chinese leading research institutes. The size of the US' overseas Chinese community of leading researchers in e.g. the molecular life sciences is still far larger and as a group more productive than the Chinese scientific community in this field (see e.g.: [WU, 2004; WELLS, 2007; JONKERS, 2007]). Nonetheless, the faculty of China's leading research organizations in Beijing and Shanghai is nowadays formed for around 70% by researchers with research experience in North America, Western Europe, or Japan and these researchers are considered to have been an important driver for the increase in productivity and quality of the Chinese research effort.

This paper addresses this relationship between scientific mobility and international collaboration. It studies the extent to which returned Chinese plant molecular life scientists remain embedded in international co-publication networks after their return to mainland China. The structure of this paper is as follows. It starts with a brief review of the literature on international research collaboration, scientific mobility, and highly skilled return migration. Next, a brief introduction is given of the general development and internationalization of the Chinese plant molecular life science system, based primarily on bibliometric analysis as well as the responses of 40 interviewed professors based in leading plant molecular life science research organizations in Beijing and Shanghai. This general introduction is followed by the main research questions and a brief discussion of the methodology. The results of a correlation analysis are discussed, which is followed by a concluding section.

International scientific cooperation and mobility

Cooperation and co-publications

The increasing trend in the last two decades towards international scientific cooperation and associated co-publication behavior has been documented in numerous studies (see e.g.: [LUUKKONEN & AL., 1993; MOED & AL., 1995; WAGNER & LEYDESDORFF, 2005]). Most of these studies used quantitative data on the collective scientific publication output in all scientific subfields. Some of these studies showed that while an upward trend is visible in all scientific subfields the dynamics of international co-publication behavior appears to differ from field to field (see e.g.: [YOSHIKANE & KAGEURA, 2004; WAGNER, 2005]). For this reason this paper studies a single scientific subfield only, namely the Plant Molecular Life Sciences, focus on domain specific characteristics of scientific cooperation.

International co-publications are often used as an indicator for international research collaboration – the strongest form of scientific cooperation referring to those activities where scientists work together on a specific research project with the aim of disseminating their findings together in jointly authored research articles [SMITH & KATZ, 2000; LAUDEL, 2001; WAGNER, 2005]. In comparison to weaker forms of research-driven communication and interaction, collaboration involves a larger expenditure in time, resources and effort of the individual actor who must engage in intensive communication and coordination of activities – in some cases over large distances. It is therefore not surprising that several analysts have stressed that the potential partners have to know and trust each other as a prerequisite for researchers to engage in collaboration in research together [SMITH & KATZ, 2000; LAUDEL, 2001].

Research collaboration comes in many shapes and sizes; the connectivity spectrum ranges from closely interacting R&D staff working on a joint research project to loosely connected people who are involved to some degree (sometimes almost negligible) to joint research-related efforts. This study focuses on research-intensive, academically successful, and output-oriented research projects; the kind of joint project in which contributing researchers aim at co-publishing their findings (for a discussion of this concept see: [KATZ & MARTIN, 1997; LAUDEL, 2001]).[1]

These joint authored research publications are amenable to large scale quantitative ('bibliometric') analysis of (inter)national scientific cooperation. Bibliometric analysts recognize that co-publications constitute a partial indicator of (successful) research collaboration and collaborative networks because not all joint research is published and not all co-authors need to have contributed equally. They don't even need to have worked together, or even know each other, as became clear during some of the interviews carried out amongst the Chinese contributors to these co-publications. For a review on the pros and cons on the use of co-publications as an indicator for research collaboration see [KATZ & MARTIN, 1997; GLÄNZEL & SCHUBERT, 2004] for reviews of the bibliometric literature on the use of co-authorship to measure scientific networks. The analysis in this paper will focus on international co-publications. In contrast to intramural and extramural domestic co-publications, wherein local power structures often determine the inclusion and ordering of authors in joint research publications, co-authorships of international co-publications are considered to better reflect 'genuine' research collaboration and the contributions of individual authors [GLÄNZEL & SCHUBERT, 2004].

Tracking the mobility of researchers

Apart from the bibliometric approach, with its statistical analysis of co-publication frequency data, this paper incorporates concepts on scientific mobility and highly skilled return migration, a topic of intense interest nowadays for academics, analysts and policy-makers alike as this pervasive development appears to challenge the long standing concerns over the so-called *brain-drain* (see e.g.: [ZWEIG, 1997; IREDALE & GUO, 2001; CERVANTES & GUELLEC, 2002; LI, 2004; CAO, 2004; SAXENIAN, 2005]). Whereas in the *brain drain* approach it is argued that countries loose human capital when their students and scholars go overseas to study or work and decide to remain there, the more sophisticated "mobility perspective" emphasizes a two-way flows and connectivity where scientists and other highly skilled professionals return to their home

[1] The ongoing rise of international co-publications reflects an increase in the magnitude and intensity of worldwide cooperation in science, but also the benefits of a common language of science (English), cheap transport and e-mail, all of which facilitate long distance communication and meetings. Other factors influencing the increasing tendency towards international co-publication include the increasing complexity and differentiation of research, increasing scientific mobility [LUUKKONEN & AL., 1993] and the launch of large scale multinational research programs and associated research networks.

countries and bring back scientific human and social capital. This constitutes a *brain gain* for the home country, a *return brain drain* for the host country, but also creates a mobility-based connection between both countries in which the open ended nature of these migration processes is recognized to offer a more nuanced and comprehensive view of the *brain gain/brain drain* issues.[2]

This study focuses on a specific form of highly skilled return migration, namely that of actively publishing Chinese scientists. Scientists in general are among the most internationally mobile groups of highly skilled professionals as in many research systems a stay abroad is often an integral part of a scientist's (early) career. Students and researchers often leave their home system with the intention to return in the short or medium term future – even though some remain in their host systems for ever. For studies focusing specifically on the phenomenon of *scientific mobility* (see e.g.: [PIERSON & COTGREAVE, 2000; MAHROUM, 2000; LAUDEL, 2003; MOGEROU, 2006]).

A researcher's mobility, and his/her ability and opportunities to engage in research collaboration, are thus not only affected by their level of knowledge and scientific expertise, but also by his/her *scientific social capital*; the sum of his/her relationships to other scientists. This *scientific social capital* is one element of what BOZEMAN & AL. [2001] termed *scientific and technical human capital* which they defined as the sum of a researcher's professional network ties and their technical skills and resources. This definition of *S&T human capital* differs considerably from the human capital concept as it is used in the classical human capital or *"brain drain"* literature, because of its emphasis on the relational aspect of scientific and technological knowledge and resources (for a discussion see: [MEYER, 2001]). The actor model adopted in this project is closer to the social network approach than to the human capital approach to highly skilled migration. The reason for this choice is twofold, first scientific knowledge has an important relational component which is ignored in the human capital approach [MEYER, 2001]. Second the scientific behaviour of interest in this study explicitly deals with this interaction between scientists. For these reasons this project introduces the compound concept of *scientific social and human capital*.

In this compound concept: scientific social capital refers to a researcher's stock of relevant professional ties, while scientific human capital refers to the stock of a researcher's scientific and technological knowledge and skills. A researcher's scientific social capital increases when the number of scientists with whom he/she is in contact increases and also when the quality or intensity of this relationship is stronger. In view of the focus on the international cooperation and collaboration activities of Chinese returnees, it is particularly interesting to adopt the concept of international scientific

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[2] For example, recent studies by Saxenian on "brain circulation" and the development of "transnational innovation systems", in which highly skilled migrant entrepreneurs set up high tech businesses in California as well as in China, Taiwan, and India, and in doing so forge connections between these regions, seem to be resulting in 'transnational systems of innovation' [SAXENIAN, 2002; 2005]

social capital rather than scientific social capital and human scientific capital separately which are difficult to disentangle empirically. A researcher's propensity and ability to collaborate with foreign peers is thought to be influenced both by his scientific social capital and scientific human capital. The definition of this compound concept is basically identical to the BOZEMAN & AL. [2001] concept of scientific and technical human capital, although its scope is limited to scientific skills and contacts with active scientists. The formulation of this compound concept will also aid in highlighting the contribution of the stock (and direction) of international ties which Chinese researchers accumulated during their stay in a host country in exploring the effect of foreign research experience on international collaboration with researchers in a former host system.

Data gathering and analytical methodology

Sampling of researchers

The sample of Chinese researchers, all at senior level of professor/principal investigator (PIs), consists of plant molecular life scientists who are mainly employed by China's elite research organisations in Beijing and Shanghai:[3]

- National Key Lab of Protein Engineering and Plant Genetic Engineering (Beijing University);
- National Key Lab of Plant Physiology and Biochemistry (China Agricultural University);[4]
- National Institute of Biological Sciences (Beijing);
- Institute of Genetics and Development Biology (Chinese Academy of Sciences);
- Institute of Botany (Chinese Academy of Sciences);
- National Key Laboratory of Plant Molecular Genetics of the Institute of Plant Physiology and Ecology (Shanghai Institutes of Biological Sciences of the Chinese Academy of Sciences).

Three plant molecular life science PIs from Tsinghua University and one based in Wuhan were also included. These four were added because several interviewees included them in the group of 50–70 leading plant molecular life scientists in China. The total sample of 76 PIs is believed to capture a large share of the leading plant molecular life scientists in China, as confirmed by several interviewees. 43% of these

[3] Two researchers in these organisations who spent on average more than five months a year abroad were not included in the sample. Researchers who returned to China less than two years ago in 2007 were also excluded.
[4] This lab also has three PIs based in *Zheijiang University* who were also included.

researchers had research experience in North America (primarily the USA), 31% in Western Europe, and 14% in the Asia pacific region half of which in Japan. The remainder of 14% had no or less than two years of foreign work experience.[5]

The main data sources used in this analysis are the mobility data contained in (a) the curricula vitae of the scientists and (b) international (co-)publications indexed by Thomson's ISI's Science Citation Index (SCI). Many of the CVs were published in annual reports and official websites of their organisations. In several cases complete employment history data could be retrieved from these two sources. To complement some of the missing mobility history data, and to collect further information on their background and research activities, 40 PIs were interviewed which included questions on their previous affiliations and the time they had spent in various host countries.[6] This sub-sample was more or less equally distributed among returnees from the USA and Western Europe, complemented by a small share of respondents who returned from Japan (7%). It is only in recent years that researchers have started to use CVs as a data source for the evaluation of research programs [GAUGHAN & BOZEMAN, 2002; GAUGHAN & AL., 2007], the study of scientific mobility [LAUDEL, 2003; BOZEMAN & CORLEY, 2004; CAÑIBANO & AL., 2008] and career development [DIETZ & AL., 2000; DIETZ, 2004; DIETZ & BOZEMAN, 2005; LEE & BOZEMAN, 2005].[7]

Variables in the analysis

According to the literature on return migration, the dimension of 'time' is a critical factor in the analysis of successful return migration [KING, 1986; DUSTMANN & KIRCHKAMP, 2003; CASSARINO, 2004]. The 'time-dimension' is especially significant with regard to the *time spent abroad*, which is expected to influence the potentiality of building up of social capital, but also important in terms of the *timing of return* as the Chinese research system has been rapidly evolving during the last 10–15 years and the situation experienced by returnees in the early 1990s differs considerably from the situation experienced by more recent returnees.

The time researchers spent abroad – in total, and per host country – was entered into a database with data points for each year since their return for the period 1994–2006.

[5] Since some of the PIs had work experience in two or more of these regions, the total sum of shares is higher than 100%.

[6] The directors of the National Key Laboratories included in this study, helped to complete some of the data for those faculty members who could not participate in these interviews due to practical constraints or language problems.

[7] Especially in the case of using large numbers of CVs the likelihood of mistakes in coding and entering the data can be a problem. The sample used for this study is relatively small. For this reason the coding and database formation did not have to be outsourced which increased the possibility of quality control. It is not unlikely, however, that some small errors have been made.

The variable *length of time spent abroad* was transformed into a dichotomous dummy variable representing whether or not a scientist had worked at least two years abroad, in the US, in Western Europe, or in Japan.

For each year another data-point was entered representing *the number of years a researcher had spent in China since his/her return*. For each of those years a data-point was included representing the number of articles published in journals included in the Science Citation Index [THOMSON SCIENTIFIC, 2007], which is used as an indicator of the productivity of the researcher. This indicator is a proxy because not every co-author contributes equally to a paper nor does every co-author receive equal credit from the scientific community.[8] With the increasing level of quality of the Chinese research system over time researchers have become more and more able to publish in higher impact SCI-covered journals; Chinese researchers within the top level research organisations are actively stimulated to publish in these international journals. A final important reason why the quantity of SCI publications is an imperfect measure for scientific productivity is that Chinese researchers also have the possibility to publish in the well-developed domestic scientific press. These publications are not taken into account because, aside from practical difficulties in accessing and analysing this data, this project focuses on international visibility and international collaboration for which this data is less relevant as these publications are hardly visible to researchers outside the Chinese research system.

The CV data on the age of the researchers was incomplete and due to problems with accessing the Chinese language Science Citation Database, which holds this information, another measure had to be used which was available: namely the *time at which researchers completed their PhD*. For a small number of Chinese researchers the data included for time after completion of PhD actually represents the number of years after the year of graduation plus six year: (a) those that completed their PhD at a relatively late age; (b) researchers graduating before 1980 who often did not obtain a PhD degree at all, as this degree was not offered in China at that time.

The output variable entered for each year includes *the number of international co-publications in total and per host country/region*, which is used as an indicator for international collaboration. As explained in the bibliometric literature, this again is a partial indicator although the limitations of co-publications as an indicator for research

[8] For example, if a researcher publishing two articles in the journal *Plant Cell Tissue and Organ Culture* which in 2005 had an impact factor of 1.1 is considered more productive than a researcher publishing one article in the journal *Plant Cell* which had an Impact Factor of 11 (THOMSON SCIENTIFIC ISI [2005]). Clearly many, if not all, researchers working in this field would not agree with productivity measure. On the other hand, for a large part of the period under study this hardly applies as very large as Chinese researchers used to publish primarily in lower impact SCI journals – if they published in them at all. What is more, the output based evaluation mechanisms introduced in the past decade initially focused on the number of papers rather than on their impact, thus providing an incentive for high quantity rather than high quality. According to respondents this is still common practice in lower level universities but has been replaced in the top level research organisation by an approach which takes into account the impact factor of journals as well.

collaboration are less severe as compared to domestic or intramural collaboration [KATZ & MARTIN, 1997; WAGNER, 2005; GLÄNZEL & SCHUBERT, 2004]. Still, as some of the interviewed researchers mentioned, co-authors do not necessarily have to have worked with, or even know each other. It might therefore be more appropriate to use international co-publications as an indicator of the extent to which a researcher is embedded in international research networks, rather than for actual international research collaboration as such.

Results

The internationalization of Chinese plant molecular life science

Over the past 10 years the Chinese plant molecular life science community has become increasingly visible at the international stage. The share of publications (articles, letters, notes and reviews) published by these researchers in plant molecular life science[9] journals increased rapidly as shown in Figure 1, up to almost 11% of the worldwide total in 2006. The R^2 of a (exponential) curve estimation is 0.85. Over this period the average impact of Chinese papers has increased as well, as exhibited in Figure 2. The growing numbers of Chinese research articles in the SCI contributes to its international visibility. A further measure of how pervasive Chinese science has become in this field is to look at the international scientific impact, which can be gauged by counting the number of citations (references) to these articles with the SCI-covered journal literature. The number of citations to each cited article is normalized to ease comparisons across fields and time. The field-normalized average number of citations per article (denoted by the acronym CPP/FCS) equals a value of 1 when the citation frequency is on par with the worldwide average [MOED & AL., 1995]. Scores of more than 1 indicate a relative high citation impact; below 1 is relatively low by global standards. The trends exhibited in Figure 2 clearly indicate that during the last 10 years the Chinese research system has steadily improved its performance up to a 'world average' development level.

[9] This custom made category was compiled by the CWTS on the basis of journal-to-journal co-citation relationships with "plant science" as a source journal. Citation data used for this project was sourced from Thomson's *Journal Citation Reports*. The subfield category consists of the following journals: *Acta Physiologiae Plantarum, Biologia Plantarum, Environmental and Experimental Botany, Journal of Experimental Botany, Plant Physiology, Physiologia Plantarum, Phytochemistry, Plant Cell, Plant Cell and Environment, Plant Cell Reports, Plant Cell Tissue and Organ Culture, Plant Growth Regulation, Plant Journal, Plant Molecular Biology, Plant Physiology, Plant Physiology and Biochemistry, Plant Science, Plant Species Biology, Plant Soil and Environment, Planta, Scientia Horticultura, Theoretical and Applied Genetics, Trends in Plant Science, In Vitro Cellular Development Biology Plant, Current Opinion Plant Biology,* and *Plant and Cell Physiology*.

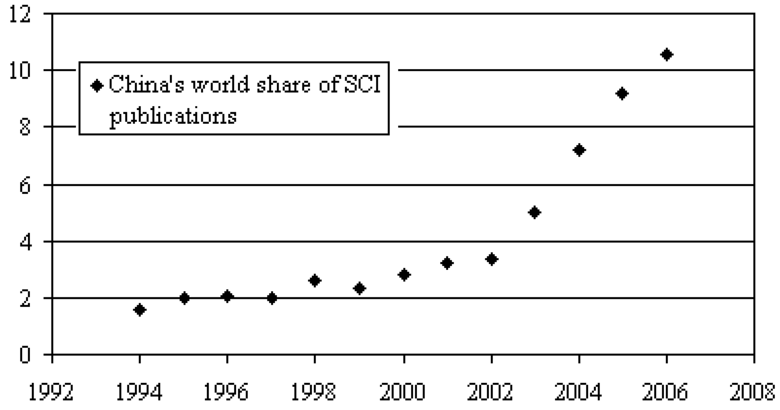


Figure 1. National shares of worldwide publication output in Plant Molecular Life Science

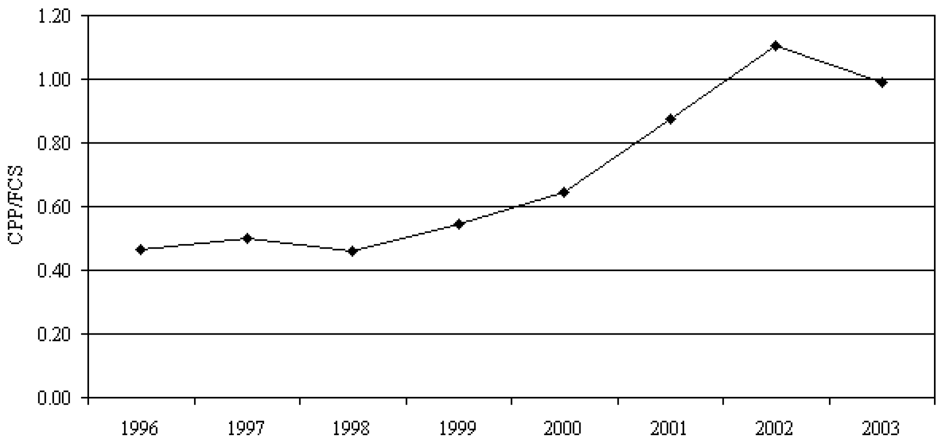


Figure 2. Trend in citation impact performance of Chinese research in Plant Molecular Life Science: Field normalised citation impact score (CPP/FCS)

A significant part of the rise in publication output and improvements in visibility and impact is due to international cooperation. For each year between 1998 and 2003, over 30 % of Chinese SCI publications in this field are international co-publications and well over 30% of the citations received by publications published by authors in mainland China in a two year time interval after publication refer to co-publications between China and the main partner countries shown in Table 1. As shown in Table 1 the number of international co-publications published by Chinese researchers in this scientific subfield amounts to a third of the output; it has increased over the years at a rate similar to China's total publication output.

Table 1. Chinese publication output and international co-publications in the Plant Molecular Life Science

	1996	1999	2002	2005	1996–2005
Total publication output of China	104	115	167	526	2052
*Output of international co-publications**	*37 (36%)*	*41(36%)*	*58(35%)*	*166(32%)*	*695(34%)*
China-US	16	14	20	70	271(39%)
China-Canada	1	0	5	12	39
China-EU(17)	*13*	*15*	*16*	*60*	*225(32%)*
China-UK	4	6	5	21	80
China-GE	4	6	3	18	75
China-FA	0	1	3	8	33
China NL	1	3	0	12	30
China-JPN	8	10	16	29	178(26%)
China-SG	2	0	3	7	22

Source: (Thomson Scientific ISI, 2007).
* This data refers to international co-publications between China (including Hong Kong) and the 50 countries with the highest GDP according to the IMF in 2005.

When queried about these changes in international collaboration behavior during the past ten years all interviewees responded that there had indeed been a major increase in activity. Compared to the 1990s, international collaboration is now less driven by the need to acquire funding and more by a desire to share resources and skills. They provided the following mix of possible reasons and explanations for this development, some of which are generic for worldwide science, others are particular to the field or specific to the Chinese research system in general:[10]

- *Technological development* – internet has dramatically increased the possibilities for and the ease of long distance communication needed for cooperation and collaboration;
- *Changing nature of research in this field*, which is becoming more complex;
- *Increasing quality of Chinese research* in this field;
- *Need to publish in English* language international journals – in part because of evaluation pressure which favours journals included in Thomson ISI's Science Citation Index. As a result Chinese researchers also have an increasing need for (English) editing of papers;[11]

[10] All of the above factors may have, to some degree, influenced the magnitude and nature of collaboration, but not necessarily the intensity or effectiveness of international collaborative links.
[11] This latter factor may, however, be more important in stimulating international contacts in general than the more narrowly defined international collaboration.

- *Increasing numbers of visitors* to China from Western Europe, the US, and Japan;
- *Significant increase in the funding of scientific research* by the Chinese government. Nowadays, recently returned researchers no longer depend on foreign sources as a way to attract research funding as sufficient funding is supplied within the Chinese research system itself;
- *Promotion and support* of the Chinese government and intermediary organisations for international cooperation and collaboration. This is related to *changes in the research culture* and the increasing openness of Chinese research organisations externally, as well as internally within the Chinese research system;
- *Social capital of returned foreign trained researchers*.

The remainder of this paper focuses on the last mentioned factor. It addresses the issue whether and to which extent returned scientists remain embedded in international research networks, and whether differences in the nature of their overseas experience have an influence on their propensity to be so.

Mobility and scientific performance

A first in the analysis was to examine whether differences in the nature of their overseas experience has noticeably influenced their scientific productivity. The explanatory (independent) variables in this analysis are:

- *Overseas research experiences and host country* (are there differences between researchers who have worked in North American, Western European or East Asian research systems?);
- *Time spent abroad* (does the length a researcher spent abroad influences his/her stock of international scientific social capital? And is this reflected in his/her propensity to co-publish internationally?);
- *Year since return* (did the amount of time spent in the Chinese research system influences their productivity and their propensity to co-publish internationally?);
- *Year since PhD* (to what degree has the academic seniority of the researcher affected the productivity?);
- Y*ear number* (is there a positive relationship between point in time and productivity of research articles, especially international co-authored ones?).

One of the reasons for expecting a significant positive correlation between these variables and the two dependent variables (*number of publications* and *number of international co-publications*) is that the quality of the research conditions in the

Chinese research system has been increasing over time, not only in terms of the availability of research funding (in total and for individual researchers), but also in terms of research infrastructure, as well as the overall visibility and internationalisation of the system. Furthermore, it was assumed that such a positive relationship will partly depend on the age of researchers [VAN HEERINGEN & DIJKWEL, 1987; JIN & AL., 2004]. In the course of a scientific career a researcher tends to become more experienced and skilled expert in the field with a greater access to resources (staff, students, research funding, etc.), which tends to have a positive effect on their scientific productivity and visibility which in turn increases their access to resources further. This process of cumulative advantages enjoyed by leading senior researchers within scientific communities is often referred to as the Matthew Effect [MERTON, 1973].[12]

Based on the literature on (highly skilled) return migration the expectation is that people have to have spent a certain amount of time in a host system to build up human and social scientific capital and mobilize these resources before returning (see e.g.: [KING, 1986; DUSTMANN & KIRCHKAMP, 2003; CASSARINO, 2004]). Our expectation is that the longer a researcher has spent time abroad, the higher his/her propensity to co-publish internationally – though there may be an optimal migration period after which potential benefits of the time spent abroad decrease [KING, 1986; DUSTMANN & KIRCHKAMP, 2003]. For this reason one would assume a positive correlation between the variables *time spent abroad* and *number of international co-publications*. This correlation is expected to be host system specific, i.e. a researcher who has spent time in North America is expected to co-publish primarily with researchers based in North America. The same is expected to hold for Western Europe and Japan. The reason for this expectation is that the social scientific capital a researcher builds up during the time (s)he spends in a foreign research system is specific to this host system and that this influences his collaboration behaviour upon return. A positive correlation is also expected between *time spent abroad* and *number of publications* assuming that the longer a Chinese researcher has spent in more developed research systems the larger his stock of *scientific human and social capital* which will be reflected in his productivity.

[12] However, the effect of age and seniority on scientific productivity is not necessarily always a positive one; in the course of their career successful scientists often face increasing administrative responsibilities, managerial tasks or teaching loads. Also for active researchers increasing age does no longer have a positive effect after a certain point in time and productivity may even start to decline towards the end of a researcher's scientific career. As shown by JIN & AL. [2004] for the case of Chinese language publications, the relationship between age and productivity is different for the older generation of Chinese researchers as a result of the Cultural Revolution and its aftermath in which the Chinese higher education and research system could not provide high quality training to its students. They showed that the productivity of the generation trained in this period is considerably lower than the productivity of the generations coming after that as well as that of the generation of researchers which has now mostly retired.

Foreign experience is also expected to have an effect on the researcher's English proficiency which influences his ability to publish in English language international journals and collaborate with foreign partners.

As for the variable *year since return* the expectation is that productivity in the early years since return is low because of a lag period in which a researcher needs to set up a new lab and research lines, that international co-publications in this first years may be high as a result of carry-on projects with researchers in his former host system, that productivity increases over time and that the positive effect of overseas experience on both productivity and international co-publication behaviour may wear off after ten to fifteen years. It is therefore expected that overall the correlation between this variable and both productivity and the number of international co-publications is positive but that this is a non-linear relationship. Figure 3 presents a schematic graphical model of the expected relationships between the variables.

A series of bivariate correlation analyses was performed to examine and explore the relational structure between the various variables as they occur within the dataset of the 76 Chinese researchers. Given the non-parametric nature of the data, Kendall's tau correlation coefficients were computed. The findings are shown in Table 2.

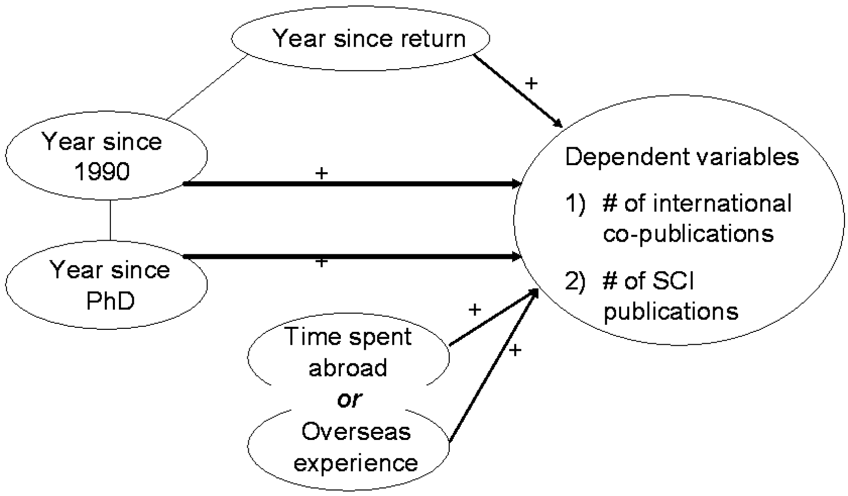


Figure 3. Models of expected relationship between dependent and independent variables

Table 2. Correlations between variables (Kendall's tau_b correlations)

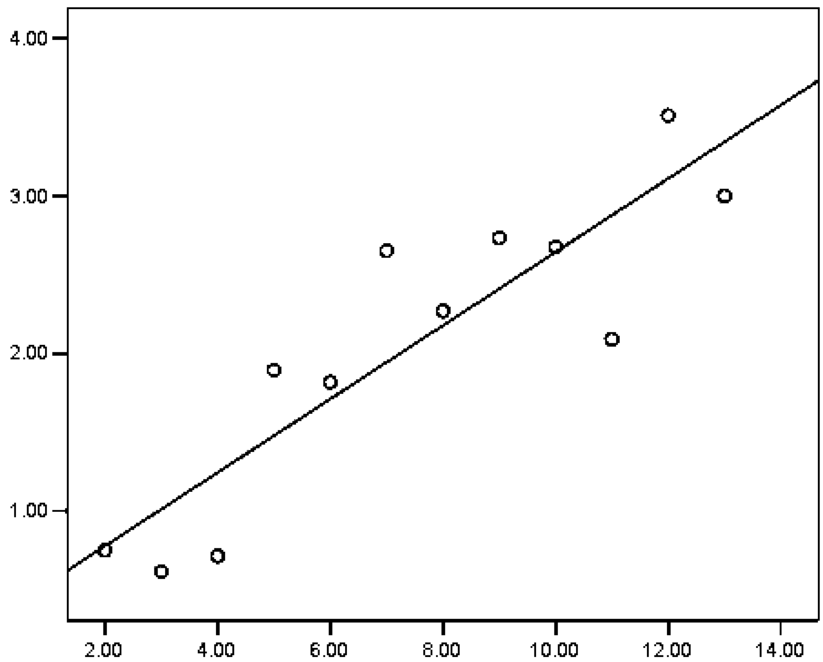
	Year	Output sci pub	Output int co-pub	US	EUR	JPN
Year	1.000	0.302(**)	0.233(**)	0.231(**)	0.079(*)	0.081(*)
Years since PhD	0.223(**)	0.312(**)	0.144(**)	0.157(**)	0.056	0.015
Time since return to China	0.170(**)	0.383(**)	0.193(**)	0.130(**)	0.130(**)	0.058
Overseas experience	0.154(**)	0.107(**)	0.195(**)	0.157(**)	0.107(**)	0.087(*)
Experience USA	0.136(**)	0.078(*)	0.245(**)	0.332(**)	0.021	0.009
Experience W.Europe	0.025	0.029	0.016	–0.050	0.109(**)	–0.020
Experience Japan	0.071(*)	–0.044	–0.033	–0.058	–0.071	0.149(**)
Time spent abroad	0.154(**)	0.025	0.133(**)	0.101(**)	0.095(**)	0.063
Time spent in the USA	0.114(**)	0.053	0.198(**)	0.279(**)	0.021	0.012
Time spent in W. Europe	0.025	0.019	0.000	–0.070	0.099(**)	–0.029
Time spent in Japan	0.070(*)	–0.049	–0.030	–0.056	–0.069	0.155(**)

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

While most coefficients are fairly low, thus hinting at the existence of additional (causal) factors that may help to explain the relationships between these variables one can observe many statistically significant positive coefficients that substantiate several of the expectations. Such is the case for the expected positive correlation coefficient between *year number* and the *number of publications*, as well as *year number* and the *number of international co-publications*. Considering the strong correlation between the researchers current age (in 2006), *years since PhD* and the *year number*, it is not clear whether the improvement of the research conditions in China has resulted in an increasing number of publications by the authors, or whether this is more related to their increasing age and seniority. There appears to be an effect of the point in time upon the number of international co-publications published by these researchers. This could indicate an increasing openness of the Chinese research system as well as an increase in the institutional support for international research collaboration. It could also be an indirect effect of the increasing quality and visibility of Chinese scientists which is likely to make them more interesting collaborative partners for foreign researchers. Considering the nationality of the foreign partners in the international co-publications it would seem that both the number of years since 1994 and the number of years since the obtaining of a PhD have a positive correlation with co-publications with foreigners, especially in the case of those Chinese returnees who spent time in North America.

A next step is to study the correlation between the three time variables and the scientific productivity as measured by the *average number of SCI publications per year*. The results are displayed in Figures 4–6. For all three figures only average data-points were included were data was available for over at least 10 individuals. As shown in Figure 4 there appears to be a positive linear relationship between *year number* and the average number of SCI publications. A similar, though potentially more complex relationship appears to exist between the *time since return* and the *average number of*

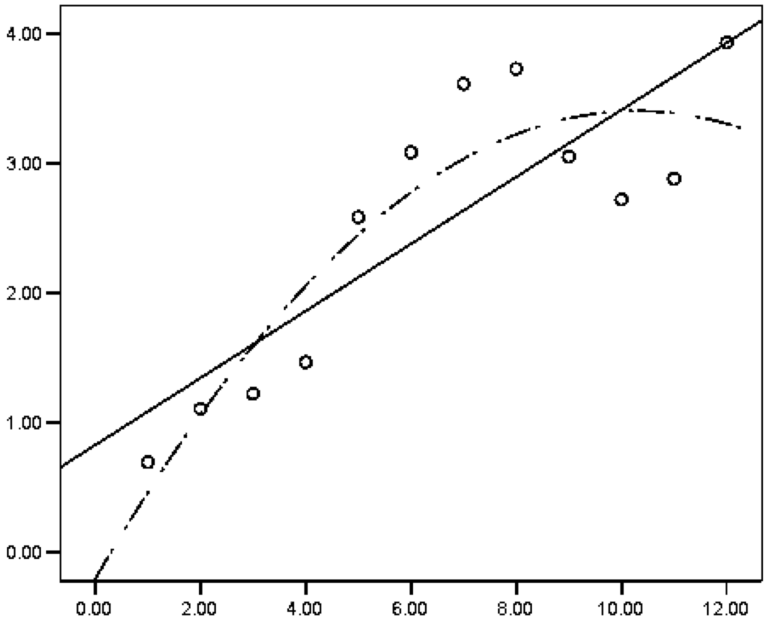
SCI publications. As expected the *time since return* is positively correlated to both dependent variables (see Figure 5). Part of this correlation can probably be explained by the correlation between year number and time since return. As shown in Figure 5, a non-linear curve provides a slightly better fit of the relationship between *time since return* and the *average number of publications* compared to the a linear relationship.



Relationship between year since 1994 and average number of SCI publications		
R^2	Constant	β_1
0.785	0.311	0.233

Figure 4. Plot of the relationship between year since 1994 and average SCI publication output per year

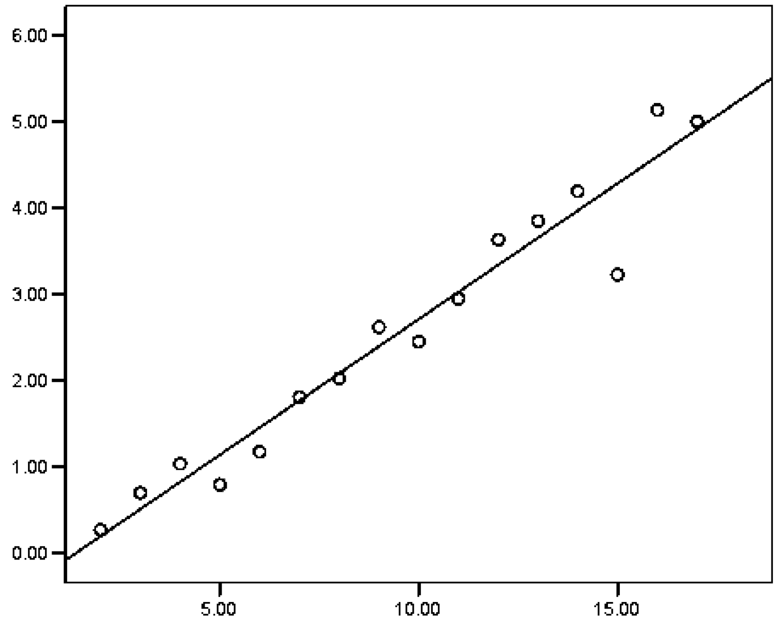
The curve as such does not provide a sufficiently clear indication that positive effects of foreign experience tends to wear off after its initial positive effect during the years immediately after return.



Relationship between year since return and average number of SCI publications				
	R^2	Constant	β_1	β_2
Linear	0.706	0.826	0.259	
Quadratic	0.820	–0.207	0.702	–0.34

Figure 5. Plot of the relationship between year since return and average SCI publication output per year

Figure 6 shows that the average number of SCI publications per year also appears to be increasing with academic experience and seniority (i.e. years after completing the PhD). Note that data point averages were only included for data based on more than ten researchers. The plot clearly indicates a linear statistical relationship between *year since PhD* and *average number of SCI publications* per year. Introducing an extended timeline with individuals, who have over 18 years experience after their PhD, produces a more scattered distribution with a significant dip in the publication productivity between 17 and 23 years experience after receiving their PhD. Several possible reasons may explain this phenomenon such as retirement and managerial responsibilities, but in view of the small size of the sample (5–7 individuals) for this age group no (statistically) robust conclusions can be drawn from this finding.



Relationship between year since PhD and average number of SCI publications (vertical axis)		
R^2	Constant	B_1
0.944	–0.431	0.314

Figure 6. Plot of the relationship between year since PhD and the average number of SCI publications per year

As the three time-related variables *year number*, *year since return*, and *year since PhD* are not independent a partial correlation analysis is performed to explore how the factors contribute to the increase in annual research productivity, i.e. the *average number of publications per year*. When controlling for *year number* and *year since PhD,* the correlation between *year since return* and *number of SCI publications* is 0.316, which is relatively high but slightly lower than the correlation coefficient when controlling for the other time related variables. The *variable year number*, when controlling for the other two time variables, produces a correlation coefficient of 0.230. The correlation between the age variable *year since PhD* and the *number of SCI publications* is only 0.113 when controlling for the other two time variables. Hence, a large share of the observed positive correlation between this variable and the number of SCI publications can be attributed to the *year number* and the *time since return.*

Controlling for these two variables separately suggests that the *time since return* contributed strongly to the observed positive correlation (controlling only for *year number* leads to a correlation between *year since PhD* and *number of SCI publications* of 0.241). While both *year number* and *time since return* independently have a relatively strong independent positive correlation with research productivity, this is true for a considerably lesser extent for the variable *year since PhD* in this sample of researchers.

As expected there is a positive correlation between whether someone has worked abroad for two years or more (*overseas experience*) and the publication output – both in terms of the number of publications as well as the number of international co-publications. The effect on international co-publications appears to be stronger. The choice of *host country* clearly impacts on international co-publication behaviour; there is a strong positive correlation between having been in either North America, Western Europe, or in Japan and the number of international co-publications with researchers located in these respective regions/countries. Note that the observed correlation is much stronger for researchers with experience in North America – explanations for this phenomenon are provided in the next section.

Similar observations can be made about the relationship between *time spent abroad* and international co-publications. Somewhat contrary to expectations, there does not seem to be a positive effect of the time spent in these three regions and the number of international co-publications beyond what was explained by the above variables. Also contrary to what one might expect, *having foreign experience* is positively correlated to the *number of publications*, whereas no such positive correlation is found between the *years spent abroad* and the *publication output*. One possible explanation for this somewhat counter intuitive finding is that most scientists with a foreign experience of more than ten years have only returned during the last three to four years. It may be too early to tell. Since it may take them some years to establish their lab and develop new research lines, significant positive effects on productivity (if any) are likely to emerge only after several years time. Another possibility is that researchers who have spent a long time abroad (especially in the highly competitive US "publish or perish" research culture) are more likely to focus on quality rather than quantity and therefore tend to produce international level high-quality publications – a crucial distinction that unfortunately is not captured in this study.

The observed correlation between the variable *having [over two years of] foreign experience* and the *number of publications* per year merits a caveat as well. The number of researchers in the sample without foreign experience is relatively low (i.e. 14 out of 76 researchers); most researchers at top level Chinese research organisations nowadays have had several years of foreign work experience. More often than not researchers without foreign experience belong to the "old generation" of researchers approaching retirement whereas the population of returned Chinese scientists tend to be between 35 and 50 which is generally considered to the most productive age of researchers.[13]

Feedback from interviewed Chinese researchers

When queried about the observed effect of host regions on the correlation between *time spent in a host region* and *propensity to collaborate with this region*, respondents replied that this may be due to differences in the pool of active researchers which was believed to be larger in North America (the USA) than in Western Europe. Yet, based on the number of *plant molecular life science* publications published by researchers in these two regions, see Figure 1, it is more likely that the opposite is the case. However, at the level of national science systems it is certainly true that the pool of US researchers is far larger than that of any European country. The dominance of the US was also present when respondents were asked about their number of contacts abroad "*people with whom you cooperate in the broad sense of the word",* i.e. those with which they *"exchange data, samples, advice, comments, or other professionally relevant information or resources, or consider cooperating with in the future"*. The respondents could choose from one of five classes for each country: 0, 1, 2–5, 6–10, or 11–25 contacts. The median number of US contacts they reported was 11–25, while the median for the UK, Germany and Japan was 2–5 and for France only 1 contact. Several of the respondents indicated that they had over 50 contacts in the USA. When asked about the frequency with which they contacted researchers in various foreign research systems, the median of the responses was "*monthly*" for the USA, "*several times a year*" for the UK, around "*once a year*" for both France and Germany, but "*almost never*" for Japan. As for their contacts with overseas Chinese, or of Chinese descent, the US share ranged from 30 to 80%, with 10–30% shares for the UK and Germany. Contacts in Japan tended to be non-Chinese (0%). When asked whether or not this difference in the number of overseas Chinese researchers in the US and Western European research systems could play a role in the greater propensity of returnees to collaborate with researchers in the US, respondents denied that such ethnic or cultural factors played an important role. A typical reply would be: "*I am in contact with them because they are good scientists and I'm interested in their work, not because they are*

[13] While Jin et al. found that this is a relatively unproductive age contingent in China, the long term negative influence of historical events which they observed is not expected to have affected the population of returned researchers to the same extent. Returned researchers still make up only a small proportion of the Chinese researcher population and their productivity profile is likely to differ as they did have access to good training in contrast to the population trained during the Cultural Revolution and its aftermath. Even if these researchers would have had a large productivity they may not have influenced the results of Jin et al.'s analysis which took into account only publications in the domestic Chinese press while returnees may be expected to be more prone to publish in international journals. [JIN & AL., 2004].

Chinese" (Respondent 29).[14] However, these responses are not sufficient to discard the potential influence of this factor as the response may have been socially desirable. Recent empirical work shows that a high share of Chinese international co-publications, over 70% of US-China co-publications, have at least one US based co-author with a Chinese surname ([JIN & AL., 2007], see also: [JONKERS, 2007]). This is a clear indication of the important role of overseas Chinese scientists as collaborative partners for researchers in mainland China.

Another factor that could help explain the stronger correlation between *time spent in the US* and *international research collaboration with US based researchers upon return,* are the differences in the way research is organised in the various host systems. Several respondents mentioned that Western European research groups tended to be more 'focused', where the whole group works on a particular topic which is relatively narrowly defined.[15] Upon return a former post-doc trained in Western Europe would therefore often have to change his research topic to avoid direct competition with his former colleagues. In contrast, respondents viewed the US working environment to be often characterised by larger research groups that include post-docs working on several related but different research lines. Such a diversified and more 'open' organisational set-up could be more conducive for establishing a larger and broader range of contacts, which might help explain the stronger correlation.[16]

General discussion and conclusions

The results of the analysis presented in this paper supports the general expectation that having benefited from *overseas experience* has a distinctive positive impact on the publication productivity of Chinese plant molecular life scientists in top level research organisations. This in turn impacts on the extent to which they are embedded in international collaborative networks as indicated by their international co-publications. The main finding of this paper is the observed positive correlation between foreign experience in a particular host region/country and the number of international co-publications with researchers from this region. This finding itself is not very surprising,

[14] Some respondents did mention the programs set up by the NSFC and recently also by the CAS, specifically designed to link up research groups of overseas Chinese scientists (in the USA) with researchers in mainland China. Several respondents considered applying for these programs, but they said it was unlikely these programs would have a large effect on the observed differences between Western Europe and the USA.

[15] Note, this response was not restricted to researchers trained in Germany, as might perhaps be expected, but responses in the same line were also given by a researcher trained in another Western European research system and two researchers who were trained in the USA.

[16] Apart from the difference in the post-doc system mentioned above, the differences in the financing of PhD students could have an influence. In the USA overseas students are often forced to pay their way by doing work for their professors while in Europe they often have access to grants. The situation in the USA might foster stronger linkages between Chinese PhDs and their former supervisor.

given the importance of close personal interactions and associated accumulative *scientific social capital* as a prerequisite for, and a driver of, successful international research collaboration. However, this empirical study is one of very few to provide quantitative support for this assumption, which was so far based primarily on qualitative work.

This finding is also important because of its implications for the debate on the *return brain drain*; it shows that while the return of scientists to China may constitute an outflow in human capital to the former host system, this *loss* may be partially off-set by new and intensive relationships between these Chinese researchers and their former supervisors and co-workers abroad. The net benefit is the strengthening of ties between the Chinese research system and other countries, thus embedding China more firmly within the global science system. Again, several commentators, analysts, and scientists have pointed out this mutually beneficial positive effect of returnees, but so far no (semi-)quantitative studies on scientific co-publication have been done showing this effect.

Both the positive correlation between *foreign experience* and the *number of SCI publications* and the general *number of international co-publications* can be explained with reference to a combination of both the *human* and *social* capital dimension of the *scientific human and social capital* gained abroad. Since researchers with a higher international visibility also tend to be more likely to co-publish internationally and it is therefore difficult to disentangle the importance of the *scientific knowledge and skills* gained abroad from the *relevant professional ties* build up during this period. There is an indication that this latter dimension does indeed contribute to the propensity to co-publish internationally as the correlation between *foreign experience* and the *number of international co-publications* is higher than the correlation between this independent variable and the *number of SCI publications*. The importance of *scientific social capital* becomes clearer when looking at the direction of international co-publications. As there is a strong positive correlation between time spent in a particular host system and co-publications with this system, while this correlation does not exist for co-publications with other research systems.

Returning to the key notion of *scientific social capital*, it is less clear from the results whether the length of time spent in a host country has a significant positive effect on the number of international co-publications with researchers in this country. There are several possible explanations for this finding. Firstly, it may result from the sample which was used; most of the researchers who have spent a long time (over 10 years) abroad have returned during the last four years and may not have had sufficient time to build their lab and set up new research lines that could result in international co-publications. Second, there may be an 'optimal time' for researchers to spend in a host system, after which there are no perceivable additional gains in *scientific social capital*.

Thirdly, there may be distinctive differences in the accumulation of social capital gained by researchers depending on the stage of their career in which they moved abroad; those who went abroad as a post-doc may acquire more, or a different kind, of scientific social capital compared to researchers who go abroad to do a PhD and return immediately, or those that decide to stay abroad for a longer period of time.

As for the geographical dimension of the results, there is a strong positive case to be made for the beneficial accumulation of scientific social capital of those who spent time in North America, but less so for those who worked in Western Europe or in Japan. Most likely, a host of interrelated factors may explain this, more specifically differences in (a) the organisation of research systems, (b) the available pool of potential collaborative partners in the former host systems, and their international visibility, (c) the interest of collaborative partners to collaborate with the returnees in China, (d) the population of overseas Chinese scientists in the different host systems, (e) the institutional support for international collaboration between China and foreign research systems, as well as (f) a potential bias of Chinese researchers to collaborate with researchers in English speaking countries.

The findings are derived from a very restricted frame of reference: only one subfield of science (plant molecular life science) and only the cream of the returned Chinese researchers within this field. One may assume that the dynamics, nature and size, and rationale for international collaboration differ significantly from one subfield to the other, the scope for generalisation of these findings to other fields of Chinese science is therefore limited. While similar positive correlations are likely to exist across fields of science as to foreign experience and international co-publications, some cautionary notes should be made in the case of plant molecular life sciences where international collaboration is expected to be driven mainly by access to skills and resources (such as mutant lines, germplasm, and test-fields), while in other fields, such as for example nuclear physics and to a lesser extent biophysics, international collaboration may be driven more by the need to have access to expensive equipment. Moreover, Chinese science is relatively strong in plant molecular life sciences; the same can not be said for many other subfields and it is therefore not unlikely that the nature of international collaboration differs in other scientific subfields as well, especially in those in which China is well below the international average development level.

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The authors are grateful to Rikard Stankiewicz for comments and feedback on earlier versions of this paper. It has also benefited from comments and suggestions from the participants in the workshop on the Global Political Economy of the Research System held at the European University Institute in San Domenico di Fiesole on May 18, 2007 and the workshop on "Methodological Issues in the use of CV data for Research Evaluation and Assessment" at the 11th ISSI conference in Madrid on June, 2007. The final version of the paper has furthermore benefited from the comments of two anonymous reviewers. This research is part of a PhD project: "Scientific Mobility and the Internationalisation of the Chinese Research System – The Case of Plant Molecular Biology" funded by the Dutch Ministry of Education Science and Culture at the European University Institute.

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