Effects of international collaboration and knowledge moderation on China's nanotechnology research impacts

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Abstract

Purpose – Recent studies report that China is becoming a leading nation in the quantity of scientific output, including in the emerging field of nanotechnology. In nanotechnology, bibliometric measures based on citations also indicate improvements in the research impacts of Chinese scientific papers. The purpose of this paper is to examine the effects of international collaboration, including the role of knowledge moderation through Chinese researchers who collaborate in both domestic and international scientific cooperation, on the impacts of Chinese nanotechnology research publications.

Design/methodology/approach – Using a nanotechnology publication dataset, bibliometric analysis and statistical testing are adopted to explore the issues raised in the study.

Findings – International collaboration, through direct collaboration and indirectly through Chinese knowledge moderators, has a positive impact on the quality of Chinese research, controlling for language, discipline, research capacity, and other factors.

Originality/value – The concept of a Chinese knowledge moderator is introduced to identify Chinese researchers who bridge scientific worlds by publishing scientific papers with both domestic and international colleagues. This concept is operationalized to capture the indirect impacts in China of international knowledge linkages and spillovers including those associated with overseas Chinese researchers and with overseas returnees.

Keywords China, Innovation, Technology management, Research work, Nanotechnology, International collaboration, Knowledge moderation, Knowledge spillover

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Introduction

A growing body of evidence confirms China's emergence as a major producer of scientific research (Porter *et al.*, 2008; Zhou and Leydesdorff, 2006; Adams *et al.*, 2005; Kostoff *et al.*, 2007; Shapira *et al.*, 2010). Although there are variations in the methods of these recent studies, the key findings have been consistent. China is now the world's second largest producer of scientific publications, and is predicted to overtake the USA (the current leader) in the next few years (Royal Society, 2011). To date, the research impact of China's rapidly increasing publication output – as measured by citations – still lags that of the leading developed economies. However, the gap is closing, with an increase seen in recent years in total citations to Chinese scientific publications and in the number of highly cited papers produced annually by Chinese authors (Zhou and Leydesdorff, 2006; King, 2008). In the domain of nanotechnology, to take one example, the average number of citations to Chinese nanotechnology articles was only 0.31 in 1990 or about 16 percent of the US. By 2005, this number had risen to 0.78, or about 45 percent of the equivalent USA figure[1].

R&D spending has grown dramatically in China, from 1.3 percent of GDP in 2005 to 1.7 percent of GDP in 2009, with a gross increase of more than 900,000 full-time equivalent R&D personnel over this period (OECD, 2011; Shapira and Wang, 2010). Much of this R&D growth is publicly financed and directed to research institutes and universities. The expansion of funding and personnel, paralleled by incentives to publish in international journals, undoubtedly underwrites the quantitative growth of China's scientific publication output. However, China's progress in terms of research citation impact, as seen in nanotechnology as well as in other leading-edge fields, requires further probing. In particular, we seek to determine the extent to which the narrowing of the gap in scientific research quality between China and other developed nations is the result of knowledge absorption and spillover due to international collaborations, and what role is played by internally driven quality improvements? These forms of scientific quality improvement are not mutually exclusive, and indeed are likely to be reciprocally reinforcing. Moreover, determining the relative importance of externally driven versus internally driven improvement is complicated not only by the existence of a large Diaspora of overseas Chinese researchers but also by reverse migration of Chinese researchers trained overseas back to the Chinese mainland. This has led some observers to emphasize the role of international knowledge diffusion entering the Chinese science system through overseas returnees (Chen, 2003; Li, 2006; Jin *et al.*, 2007). Yet, assessing the relative parts played by domestic, international, and returning researchers in China's recent scientific development has been hampered by the common practice of using currently reported affiliations when determining the nature of scientific collaborations. This can lead to a significant under-reporting of the role of international knowledge acquisition.

In this article, we develop the concept of a Chinese knowledge moderator (CKM) – representing a Chinese researcher who has collaborated with colleagues both inside and outside of China. CKMs complement the direct international collaboration reflected by country affiliation in order to capture the concealed indirect knowledge spillover across national borders. Our statistical testing shows that international collaboration and moderation have a positive effect on the research impact of Chinese articles after controlling for the other explanatory variables. Articles associated with international collaborators and CKMs are more likely to be published in journals with higher journal impact factor (JIF) and that have a higher number of citations.

This paper uses the CKM concept to advance discussion and measurement of the role of international collaboration and its impact on China's research performance by taking into account the growing phenomenon of reverse migration of overseas-trained Chinese scientists back to China. We introduce a two-dimensional coding mechanism to identify Chinese scholars who collaborate both with domestic and international researchers. This allows us to empirically examine the role of Chinese overseas and returning researchers on China's knowledge accumulation. Rooted in the notion of structural holes (Burt, 2004), we argue that networks associated with CKMs allows them to explore and fuse the ideas of two heterogeneous groups, thus increasing the likelihood of producing research that has relatively greater impact.

The paper is organized as follows. After briefly reviewing evidence on international collaboration and research quality, we introduce the CKM construct and discuss its operationalization. We then test the influence of CKMs on China's research impacts by examining publications in the domain of nanotechnology. The paper concludes with a discussion of the results, implications and limitations of this study, and suggests potential directions for future work.

Literature review

The available literature on the impacts of international collaboration on research performance offers divergent findings. Research collaboration is generally presumed to valuable and useful, particularly by policymakers (Katz and Martin, 1997), and indeed there are a series of studies that indicate a positive correlation between collaboration and research performance. Narin and Whitlow (1990) and Narin *et al.* (1991) find that biomedical papers with international co-authors have greater citation impacts than either single-or nationally co-authored papers. Bordons *et al.* (1996) assert that among Spanish biomedical publications, articles authored by international collaborators are higher quality and international collaborators are more productive than their domestic partners. A study by Barjak and Robinson (2007) demonstrates positive impacts from international collaboration on the quantity and quality of European life sciences research. In the field of nanotechnology, Kostoff and his colleagues at the Office of Naval Research show that international co-authorship is positively correlated with the number of citations (Kostoff *et al.*, 2006, 2008). Positive relationships between international collaboration and research impact have been similarly reported by other studies (Cesaroni and Gambardella, 2003; Glanzel and Thijs, 2004; Lee and Bozeman, 2005; Persson *et al.*, 2004).

However, some studies that have looked at the effects on international collaboration on research impacts have found contrasting results and trade-offs between on research productivity quantity and research impact. Using panel publication data from 110 leading US universities, Adams *et al.* (2005) find that foreign collaboration is positively correlated with the number of citations but negatively correlated with the productivity of research institutes. In a study of one European university, Carayol and Matt (2004) observe no evidence of an impact of international collaboration on research productivity at the laboratory level. In a study of ecological papers published in the journal *Oecologia* from 1998 through to 2000, Leimu and Koricheva (2005) report that while multi-authored paper receive higher citations, international collaboration has no effect on citations. Gonzalez-Brambila and his colleagues find that after controlling for individual heterogeneity and network variables, the effect of a structural hole on knowledge creation is either negative or non-existent (Gonzalez-Brambila *et al.*, 2008).

What might be the causes of these contrasting findings? One issue in prior bibliometric studies of the impact of international co-authorship is that alternate explanations for higher (or lower) number of citations are not fully examined. For example, it is plausible that internationally co-authored articles are more likely to:

- occur in basic scientific fields (Frame and Carpenter, 1979) where there is a larger "invisible college" (de Solla Price, 1963) of researchers in multiple countries working on same or similar topics who may have propensity to cite; and
- be written in English and hence more readable and citable than those written in other languages.

Without controlling for such factors, studies of international collaboration and research impacts will remain inconclusive.

A second issue in prior research is that typically only reported affiliations and author countries at the time of publication are recorded and analyzed in determining international collaboration. This is not inaccurate in and of itself, but it can lead to misestimating the role of international linkages and knowledge spillovers associated, for example, by expatriate returnees. Scientists who have been educated and who have worked abroad may bring back with them a series of existing linkages that are subsequently denoted as international when that scientist takes up a domestic post, even though nothing much has changed in the nature of that scientist's collaborations. Equally, a returning scientist may incorporate new domestic collaborations which appear as domestic, but which may actually be linked, albeit indirectly, to a network of international knowledge relationships. The concept of an international knowledge moderator is helpful in identifying and measuring such relationships. It is particularly useful in the Chinese case, given the increasing role of returnees in the Chinese science system and the extent of the overseas Chinese scientific Diaspora. The next section further discusses the application of the international knowledge moderator concept for China and our methodological approach.

Methodology

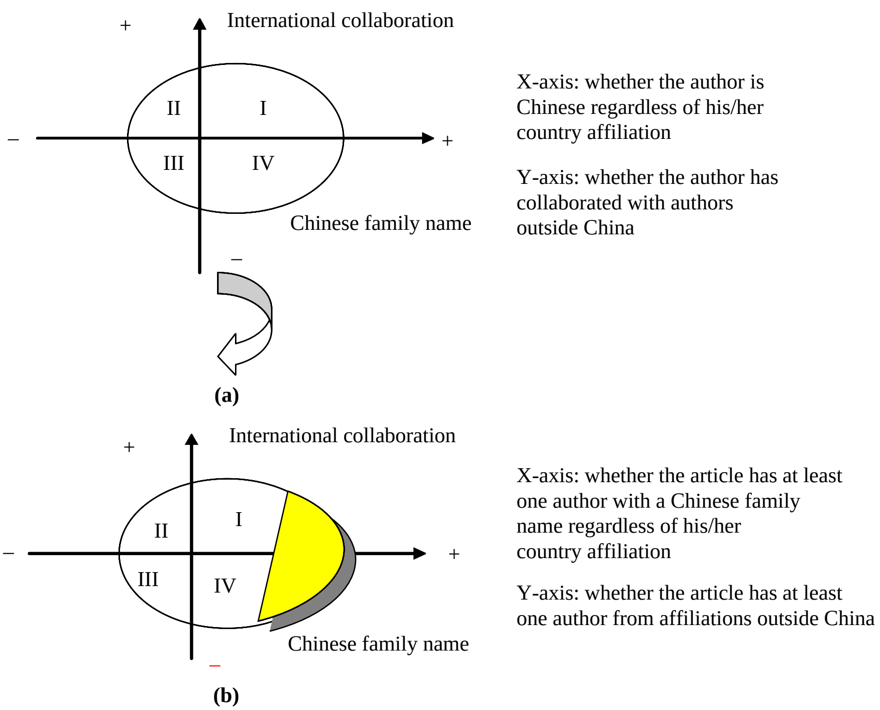
CKMs – definition and operationalization

According to the *Merriam-Webster* dictionary, a moderator is someone who mediates between parties at variance[2]. The key roles of a moderator include facilitating, intermediating, and managing relationships among different parties. In the case of scientific research, moderators are themselves typically active participants in research collaborations. For this paper, we employ a specific definition which addresses both international and domestic research collaboration: we define a CKM as a Chinese researcher who has co-authored with both domestic and international scientists. For empirical testing, we focus on the domain of nanotechnology, using the Georgia Tech global nanotechnology publication database of nanotechnology papers published between 1990 and mid-2006 (Porter *et al.*, 2008).

The CKM concept is operationalized drawing on data included in a paper's publication record, including the family name of the author and his or her country of affiliation. Specifically, we regard a researcher as a CKM if these three criteria are met:

(1) a Chinese family name;
(2) co-authorship on at least two papers with foreign collaborators during the period of investigation; and
(3) reprint authorship on at least one domestically collaborated article.

The conceptual framework we use to allocate researchers is shown in Figure 1. The author family name (x-axis) and international collaboration status (y-axis) are used to discern four types of authors. In Quadrant I are Chinese authors who have collaborated with foreign peers; Quadrant II contains foreign colleagues who have collaborated with Chinese scholars; Quadrant III denotes foreign scholars who have collaborated with their domestic scholars[3]; and Quadrant IV contains Chinese scientists who have collaborated with Chinese-affiliated researchers. In other words, for eligibility to become a CKM, an author's name has to appear in both Quadrants I and IV but not in Quadrants II and III. Once CKMs are identified, we code the variability of knowledge moderation such that all articles associated with the CKM are coded as 1 (the yellow areas of Figure 1) regardless of whether the affiliations listed on that article include two countries or not. In other words, a CKM belongs in a subset of international collaborators, but articles associated with the CKM do not represent a subset of articles associated with the international collaborator. Combining both variables of international collaboration and CKM, we can capture a more comprehensive picture of both the direct and indirect effects of knowledge spillover via Chinese returnees.



Notes: (a) Ellipse is the set of author names; (b) Ellipse is the set of articles

Figure 1.
Illustration of categories of international collaboration and knowledge moderation

In categorizing authors, we differentiate Chinese from non-Chinese researchers based on the unique spelling of the Chinese Hanyu Pinyin system. We constructed a Chinese family name database, which includes all Chinese names collected from Chinese name dictionaries. Using VantagePoint data-mining software, we used this database to develop a thesaurus of Chinese family names which was then applied to the database of nanotechnology publications for China. Once CKMs were identified, we linked them to their co-authored articles and coded each article for the variables of international collaboration and Chinese knowledge moderation.

Our approach to coding CKMs is based on the following considerations. A CKM is a researcher who bridges two scientific communities, respectively, located within and outside China via meaningful collaboration with both sides. Given the tacit nature of knowledge diffusion, it is reasonable to believe the role of knowledge moderation is embedded in the process and the result of joint publication in internationally peer-reviewed journals. Requiring collaboration on two or more publications is a subjective determination; this was introduced to exclude sporadic, one-time interactions, and also to reduce CKM verification tasks to manageable levels. This approach also reflects the idea that trust and knowledge exchange is cultivated by more frequent interaction (Coleman, 1990). Additionally, China's language and culture continue to present substantial obstacles to non-Chinese researchers pursuing careers in China (Reynolds, 2006). While there are a small number of non-Chinese researchers active in China who are not only fluent in Chinese but also embedded in the Chinese research system, the vast majority of researchers in China are native Chinese. Limiting the CKM definition to researchers with Chinese family names ensures a high probability that this researcher is able to communicate well with other Chinese researchers. Indeed, less than 1 percent of the authors who appear in the publication dataset of authors with Chinese affiliations have non-Chinese family names. Finally, focusing only on Chinese researchers allows us to observe the effects of China's human capital policies of sending domestic Chinese researchers out (pinyin: *gongfei chuguo kaocha*) versus attracting self-sponsored expatriates back (pinyin: *xiyin zifei haigui huiguo*).

Dataset construction and description

All Chinese publications were extracted from the Georgia Tech global nanotechnology publication database (for discussion of the definition and approach used to identify and collate nanotechnology publications (Porter *et al.*, 2008 and Youtie *et al.*, 2008). The Georgia Tech dataset includes more than 400,000 Web of Science (WoS) nanotechnology publication records between 1990 and mid-2006. By volume, the most productive countries are the USA, Japan, China, Germany, France, and the UK, constituting over 60 percent of all nanotechnology articles globally[4]. Other studies (using differing search strategies) have found a similar publications levels and distribution (Kostoff *et al.*, 2007).

A Chinese publication is defined as WoS article containing at least one author with a Chinese address[5]. The WoS collects various types of documents, including articles, reviews, corrections, and letters. We analyzed only articles (98 percent of all records) and excluded the other types. Geographical information data for Chinese regions was obtained from Chinese Government web sites. Before undertaking analysis, we cleaned each field to reconcile typographical errors and variations in names, including geographical fields such as cities and zip codes (for a detailed description, please refer to Tang and Shapira, 2011a). VantagePoint data-mining software was used for cleaning, managing and analyzing the database. The resulting dataset contained 43,767 Chinese nanotechnology publication records. We matched these publication records with the 2005 ISI JIF measure. Our dataset included publications that appeared in some 1,295 journals with JIF measures. The final dataset contained 41,847 articles with no missing data in any fields. Data variables were developed and then imported into STATA for model testing.

China has emerged as one of the largest producers of nanotechnology research, with exponential growth in total nanotechnology publications. However, China's internationally co-authored collaborations show only linear growth. This suggests the importance of domestic activity in raising the quantity of China's nanotechnology research output (Tang and Shapira, 2011b). Our dataset indicates that Chinese nanotechnology publications accrued 4.4 citations per article for the period 1990 through to mid-2006), with a normalized average citation rate of 0.86 per year. As might be expected, a small proportion of these articles garner frequent citations, while most articles receive few or no citations. The top 15 percent most frequently cited articles account for 70 percent of the citations, and the most frequently cited 50 percent account for 90 percent of the citations. These percentages are larger than those found by Seglen (1992). A further examination reveals that the normalized average percentage of citations of articles without foreign collaborators is 0.79, compared with 1.26 for those with international collaboration. It thus appears that there is a disproportionate effect of international collaboration in contributing to the upgrading of the quality of China's nanotechnology research. Our key research question is thus:

RQ1. How does international collaboration contribute to raising the research impact of China's nanotechnology articles and what role do CKMs play in this process? We explore this question through the model described in the following section.

Analytical model

Variables and hypothesis testing

The dependent variable in our analysis is research impact[6]. This is measured by two citation-based indicators: the journal impact factor, denoted by JIF_i, and accumulative citations received, denoted as $\Sigma Cite_{it}$ (Baldi, 1998; Phelan, 1999)[7]. We use the 2005 WoS JIF to capture the overall impact of academic journals. The accumulated article citations are for the nearly 16-year period of 1990 through to mid-2006.

Explanatory variables

To explain the factors associated with differences in research impacts of Chinese nanotechnology publications, the following explanatory variables are identified.

International collaboration and international knowledge moderation. From 1990 to mid-2006, Chinese scientists internationally co-authored 6,928 articles in the field of nanotechnology; that is, almost one out of six Chinese articles indexed in WoS had at least one overseas co-author. By contrast, about one-third were associated with a CKM. We anticipate that both international collaboration and CKM moderation have positive impacts on the research impacts of Chinese nanotechnology research. This leads to two hypotheses:

H1. Internationally collaborated articles are more likely to be published in higher ranked journals and to receive more citations.

H2. CKM internationally moderated articles are more likely to be published in higher ranked journals and to receive more citations.

Language. In our dataset, 86.4 percent articles were written in English, 13.5 percent in Chinese, and a small remainder in Japanese and other languages. The annual number of non-English WoS nanotechnology articles has increased from just a handful in the mid-1990s to more than 1,300 in 2005. This finding is consistent with that of Lin and Zhang (2007). An important prerequisite for scientific visibility and impact is communication and readability. It is reasonable to assume that articles published in Chinese have less opportunity than those published in English to be cited among global scientific community, leading to this hypothesis:

H3. Articles written in Chinese are less likely to be cited or published in highly ranked journals.

Control variables

In addition to the above explanatory variables, we also include four sets of controlling variables.

Scope of research collaboration. Our dataset indicates that research collaboration is very common in the China nanotechnology domain: 98 percent of articles are collaborated research, and the average number of authors is as high as 4.7 per article. Some previous studies argue that the size of the collaborative network has a positive influence on the number of article citations and journal publications (Lawani, 1986; Baldi, 1998; Leimu and Koricheva, 2005), but other research suggests that associated transactions costs have a negative effect (Bacal, 2006; Raab and Milward, 2003; Herbertz, 1995; Avkiran, 1997). In this study, we do not have prior expectations as to the direction of influence, but we do test the scope of collaboration using four variables: the number of co-authors, the number of affiliations, the number of authorship countries, and the number of Chinese cities involved (Goldfinch *et al.*, 2003)[8].

Research capacity. In their examination of the impact of collaboration, most other studies (an exception is Adams *et al.*, 2005) do not address the problem of the self-selected characteristics of the collaborators. For example, it is plausible that international collaborators are inherently different from others in terms of their research capacity. There is an unequal distribution of research capacities among the large number of Chinese institutions engaged in nanotechnology research. To reduce the effect of self-selection, we distinguish three types of privileged institutions. First, universities based in Hong Kong, where there are historically well-established relationships with developed countries, particularly those speaking English. The second and third types are mainland institutions comprising the Chinese Academy of Sciences (CAS) and elite Chinese universities which have traditionally attracted the best Chinese researchers.

Scientific community size. As Moed and Van Leeuwen (1995) observed, the "composition of the contents" matters, and the characteristics of the research field also influence citation and JIFs (Jappe, 2007). These factors are particularly important for an interdisciplinary subject such as nanotechnology. Some subfields within nanotechnology research such as nanomaterials science may have different citation patterns from others subfields such as nanobio, which directly influences the JIF and citation factors. To control for this discrepancy, we adopt a classification method developed by the Fraunhofer Institute for Systems and Innovations Research to further differentiate nanotechnology research into 24 research fields based on subject codes[9].

Time period. It is evident that elapsed time from publication influences citation-based indicators. In this study, we include 17 publication-year dummies and publication-elapsed time to control for time period variations.

The names and descriptions of the variables are listed in Table I. Descriptive statistics for each variable are indicated in Table II. As indicated in the correlation matrix (Table III), the independent variable for international collaboration is highly correlated with the number of collaborated countries ($r = 0.93$). We drop the latter variable in our model to remove multicollinearity.

Results

Given the censored nature of the two outcome variables (Maurseth and Verspagen, 2002; Wooldridge, 2006), Tobit regressions are used to test our hypotheses[10]. The main estimates are summarized in Tables IV and V. The first columns in Tables IV and V are base models and include only the following three sets of controlling variables: research field dummies, year time dummies, and years lapsed since the article was published. We then add other variables into the model in a stepwise manner[11]. In Table IV, we add variables of the research collaboration scope to Model 2. In Model 3, we also control for research capacity measured by whether authors are affiliated with the CAS, elite Chinese universities or Hong Kong institutions. We further add the language variable to Model 4,

	Construct	Variable name	Anticipated direction	Description
DV	Research impact	JIF ΣCitation counts		2005 JIF Number of citations, to mid-2006
IV	Language	Chinese	(−)	1 if the article is written in Chinese; otherwise, 0
	International collaboration	International collaboration	(+)	1 if there is at least one authorship with an affiliation in the USA; otherwise, 0
	Research collaboration scope	Num_ Affiliation	(+/−)	Number of affiliations associated with co-authorship
		Num_PRC_ City	(+/−)	Number of Chinese cities associated with co-authorship
		Num_Author	(+/−)	Number of co-authors
		Num_Ctry	(+/−)	Number of co-authors' country of affiliation
	Research capacity	Hong Kong	(+)	1 if the article has one or more authors from Hong Kong; otherwise, 0
		CAS	(+)	1 if the article has one author from CAS; otherwise, 0
		Elite Univ.		1 if the article has one author from a top 10 Chinese university; otherwise, 0
CV	Scientific community size	Sub Domain		A set of subject dummies indicating the subfield of nanotechnology
	Scientists	Scientist		A set of dummy variables of scientists
	Time period	Pub_age		Pub_age = 2007-publication year
		Y1990–2006		Y1990 = 1 if article was published in 1990; Y1991 = 1 if article was published in 1991

Table I.
Description of variables

Variable	Mean	SD
Citations	4.44	12.35
2005 Journal impact factor	1.87	1.75
International moderator (CKM)	0.32	0.47
International collaborator	0.16	0.36
Chinese language	0.14	0.35
Hong Kong	0.14	0.35
Chinese Academy of Sciences	0.29	0.45
Chinese elite universities	0.36	0.48
No. of Affiliations	1.57	0.78
No. of Cities	1.24	0.49
No. of Countries	1.18	0.44
No. of Authors	4.72	1.97
Publication age	4.30	2.87

Table II. Descriptive statistics

which indicates that articles written in Chinese are more likely published in low-impact journals. Note that after we added the language variable in Model 4, its Pseudo-R^2 more than doubled. Combined with the substantial coefficient of the variable Chinese, we can say that language is factor that most influences the JIF. Journals which publish Chinese-language nanotechnology articles tend to have lower JIFs than journals which publish English-language nanotechnology articles. Models 5 and 6 test the influence of international knowledge diffusion. Model 5 shows a positive sign for international collaboration. After we added the variable CKM (international moderator), Model 6 shows that the impact of international collaboration remains but shrinks, and the moderator has a positive and statistically effect on research impact. We thus find that there is a partial effect on China's nanotechnology research impacts from collaborations involving overseas returnees.

The full JIF Model 6 (Table IV) conveys the following results. First, international collaboration has a positive impact on the quality of China's nanotechnology research. *H1* is supported. Second, holding constant international collaboration, written language, publication date, research field, research collaboration scope, and previous collaborating intensity, articles associated with CKMs are more likely to be published in journals with high JIFs[12]. In other words, among the internationally collaborated articles (i.e. holding the variable of international collaboration constant at the value of 1), those with a CKM have a higher quality than those without. Furthermore, among the non-international-collaborated articles (i.e. holding the variable of international collaboration constant at the value of 0), those with a CKM have a higher influence than those that do not. This finding indicates the bridging role of the knowledge moderator and is consistent with the notion of structural holes (Burt, 2004): collaborators who connect two otherwise disconnected homogeneous groups are able to explore and exploit resources on both sides. Chinese scholars who collaborate in bridging international and domestic research perform positives role in knowledge exchange across national borders. *H2* is supported. Third, holding other variables constant, articles written in English are more likely to be published in journals with higher impact factors than those written in Chinese. This finding supports *H3*.

The full citation Model 6 (Table V) tells a similar story in terms of the impact of explanatory variables. Two additional findings are reflected in the citation model.

Table III.
Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. ΣCitation counts	1.00												
2. JIF	0.37	1.00											
3. Knowledge moderation (CKM)	0.04	0.06	1.00										
4. International collaboration	0.07	0.15	0.24	1.00									
5. Chinese language	−0.10	−0.29	−0.06	−0.13	1.00								
6. Hong Kong	0.08	0.11	−0.02	0.04	−0.10	1.00							
7. Chinese Acad. Sci.	0.03	0.07	0.04	0.00	−0.04	−0.10	1.00						
8. Elite Chinese Univ.	0.03	0.05	0.01	−0.04	−0.04	−0.12	−0.29	1.00					
9. No. of affiliations	0.03	0.09	0.12	0.55	−0.06	0.13	0.10	0.06	1.00				
10. No. of cities	−0.03	−0.02	−0.02	−0.09	0.02	0.16	0.13	0.06	0.50	1.00			
11. No. of countries	0.08	0.15	0.21	0.93	−0.12	0.06	0.00	−0.04	0.60	−0.09	1.00		
12. No. of authors	0.05	0.12	0.05	0.11	−0.05	−0.01	0.14	0.04	0.25	0.11	0.15	1.00	
13. Publication age	0.26	−0.06	0.02	−0.01	−0.04	0.04	0.08	0.02	−0.03	−0.04	−0.01	−0.01	1.00

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Knowledge moderation (CKM)						0.086
						(3.54)**
International collaboration					0.678	0.649
					(16.53)**	(15.55)**
Chinese language				−3.704	−3.636	−3.632
				(77.74)**	(76.49)**	(76.42)**
Hong Kong			1.333	0.965	0.978	0.981
			(30.48)**	(23.33)**	(23.74)**	(23.81)**
Chinese Acad. Sci.			0.709	0.568	0.595	0.592
			(25.42)**	(21.26)**	(22.31)**	(22.20)**
Elite Univ.			0.579	0.447	0.490	0.488
			(22.22)**	(17.86)**	(19.53)**	(19.43)**
No. of affiliations		0.271	0.232	0.164	−0.091	−0.089
		(15.30)**	(13.30)**	(9.92)**	(4.02)**	(3.94)**
No. of cities		−0.417	−0.626	−0.476	−0.240	−0.241
		(15.22)**	(22.71)**	(17.99)**	(7.99)**	(8.05)**
No. of authors		0.124	0.108	0.097	0.101	0.101
		(20.18)**	(17.69)**	(16.79)**	(17.53)**	(17.45)**
Publication_age	−0.031	−0.031	−0.035	−0.061	−0.063	−0.063
	(0.83)	(0.84)	(0.97)	(1.80)	(1.86)	(1.84)
Pseudo-R^2 %	1.58	2.14	3.07	8.19	8.37	8.38
Observations	41,487	41,487	41,487	41,487	41,487	41,487

Notes: Significant at: *5 and **1 percent; ABSOLUTE value of t-statistics in parentheses

Table IV.
Tobit regression on JIF

First, the Pseudo R^2 of the base model, which consists of time-only dummies and subject dummies[13], is high. Moreover, even though we continue to add new explanatory variables, the Pseudo R^2 does not change much. Until Model 6, only a 0.7 percent increase occurs, indicating that the date of publication and the size of the scientific community are the two most significant factors for the number of citations an article receives.

Discussion

This paper experiments with identifying the impact of international knowledge spillover by differentiating the role of CKMs from general international collaboration activities reflected by authorship country affiliations. From the perspective of quantity, the rapid growth of Chinese nanotechnology research is mainly internally driven. However, international collaboration, through direct links or through the indirect route of collaboration through a CKM, has effects on raising the research impact of Chinese nanotechnology publications. Although the growth of international collaboration lags behind the production of domestic articles in China, the impact and importance of international research collaboration is disproportionately high, including through the process of moderation by CKM researchers in China who can link both international and domestic scientists.

As in other developing countries, China has suffered from a loss of talent in the past as its brightest students went abroad and never returned. However, this situation is changing: China is beginning to benefit from brain circulation (Saxenian, 2007). With the rapid development of the domestic economy, the expansion of R&D spending, and the

	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
Knowledge moderation (CKM)						0.858 (4.50)**
International collaboration					3.396 (10.44)**	3.103 (9.36)**
Chinese language				−7.815 (27.98)**	−7.527 (26.86)**	−7.489 (26.72)**
Hong Kong			6.316 (19.41)**	5.338 (16.46)**	5.407 (16.69)**	5.442 (16.80)**
Chinese Acad. Sci.			1.716 (8.18)**	1.336 (6.40)**	1.487 (7.11)**	1.452 (6.94)**
Elite Univ.			2.334 (11.84)**	1.963 (10.00)**	2.175 (11.03)**	2.148 (10.90)**
No. of affiliation		1.197 (9.00)**	1.028 (7.75)**	0.845 (6.41)**	−0.428 (2.38)*	−0.406 (2.26)*
No. of city		−2.327 (11.22)**	−3.165 (14.98)**	−2.738 (13.02)**	−1.549 (6.48)**	−1.563 (6.54)**
No. of author		0.541 (11.82)**	0.518 (11.26)**	0.481 (10.53)**	0.502 (10.99)**	0.497 (10.88)**
Publication age	0.846 (3.28)**	0.841 (3.26)**	0.852 (3.32)**	0.798 (3.14)**	0.789 (3.11)**	0.799 (3.15)**
Pseudo-R^2 %	1.58	2.14	3.07	8.19	8.37	8.38
Observations	41,487	41,487	41,487	41,487	41,487	41,487

Notes: Significant at: *5 and **1 percent; absolute value of *t*-statistics in parentheses

Table V.
Tobit regression on citations

growth of technology-oriented industries, China is increasingly attracting skilled Chinese returnees into academia and industry. The Chinese Government has launched various policies to attract overseas talent and retain those who return. For example, the Ministry of Education of China launched the Scientific Research Foundation for the Returned Overseas Chinese Scholars program in the early 1990s, allowing returnees who received PhD degree(s) outside of China to apply for special funding after two years of work in China. The National Science Foundation of China (NSFC) also initiated a "Specific Fund for Chinese Scholars Abroad Returning for Short-period of Work or Lecture" to encourage various types of contributions from overseas Chinese. In addition, the "Chun Hui Plan" opens up another opportunity for overseas returnees to contribute to Chinese economic development. At the regional level, realizing the important role of overseas returnees to their economic development, provincial and municipal governments have also launched policies and programs to attract overseas talent, including start-up funds, subsidies for housing, and child care. Our study provides some justification for such policies. These programs are stimulating the growth of a class of CKMs in China who bridge international and domestic research collaborations and who are contributing to the improvement of the quality of the Chinese scientific research system.

We note that our study has several limitations. Our dataset is drawn from peer-reviewed journal articles indexed in WoS. While this is an internationally recognized resource, this database does not include other types of publications such as books or reports (although these may be less relevant than articles in scientific fields). The WoS is also weaker in its representation of non-English language publication sources. In addition, international collaboration takes place through multiple channels. Co-authorship does not capture all aspects or outcomes of research collaboration. We also did not examine whether the effect of CKMs is temporal and whether it diminishes after more years of residence in China (this would be an appropriate topic for future research).

Our study has focused on CKMs in China. We suggest that the concept of international research moderators is worthy of further exploration both in China and in other countries. Thus, could include further work on the characteristics of these researchers and the avenues by which they have gained their international linkages.

Notes

1. Citation figures calculated from the Georgia Tech global nanotechnology publication database, 1990-mid 2006 (Porter *et al.*, 2008).
2. The definition of "moderator" can be found at: www.merriam-webster.com/dictionary/moderator.
3. Since the population consists of articles with at least one Chinese affiliation, the area of Quadrant III is consequently very small.
4. In this article, China refers to mainland China, Hong Kong and Macao.
5. The whole counting method is used to credit publications to countries and affiliations. For example, in counting authorship at the country level, a nanotechnology paper co-authored by researchers affiliated with two reported unique affiliations in the USA and three unique affiliations in China will be recorded as one paper for the USA and one for China. In terms of authorship counting at the organization level, each unique affiliation will be counted once.
6. In the bibliometric community, research quality is often interchangeable used with research visibility and research impact. In this paper, we tend to use the term research impact, given our reliance on JIFs and citation counts. We recognize that these quantitative measures, by themselves, do not fully capture the quality of a research publication.
7. We elected to use normalized annual citation counts over other alternatives, such as a five-year citation window. We did not use this later indicator because it would only allow us to analyze articles published in the period of 1990-2001 publications, meaning that we would miss all observations for the years from 2002 onwards when nanotechnology publication levels greatly expanded.
8. We experimented with a quadratic term for the scope of collaboration, but found no distinguishable impact separately and collectively. We dropped this approach so as to simplify the model.
9. This method initially targeted all articles included in the WoS. Applying it to our dataset, we found 24 out of 26 research fields were covered by Chinese nanotechnology publications.
10. For robustness, we also conducted a negative binomial test for modeling with citations as a dependent variable. The results were similar. We did not try Poisson modeling – a widely used regression in event count data – because the two assumptions of Poisson modeling (no unobserved heterogeneity and time-independence of event occurrence) are rarely met in research of publication activity. In addition all alphas in our regression are greater than 0.5 suggests that Poisson is poorer than NBRM approach in dealing with over-dispersion.
11. Due to space limitations, the results of control variables are not displayed here.

12. Interaction terms between CKM and the other explanatory variables were examined. All interaction terms are statistically insignificant separately. Wald tests were conducted to test their effects collectively. We could not reject the null hypothesis that all interaction terms have no effect on the dependent variable. Thus, to simply the model, we drop these interaction terms.
13. In total, 16 year dummies and 25 research field dummy variables are coded to control for the heterogeneity of the dependent variable over 17 years and 26 research areas.

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