International Collaboration and Research Quality: Evidence from the Us-China Collaboration in Nanotechnology

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Abstract -- **China's status as a scientific power, particularly in the emerging area of nanotechnology, has become widely accepted in the global scientific community. The role of international collaboration in China's nanotechnology development is generally assumed albeit without much evidence. Based on a longitudinal publication data of 77 Chinese nanoscientists, this study empirically examines the impact of US-China collaboration on the research performance of Chinese researchers. The study found that US-China collaboration has a positive effect on China's nano research quality. And such impact demonstrates a time-decaying pattern at the level of individual paper, but not at the level of journal.**

Keywords -- **Research evaluation, international collaboration, nanotechnology, panel regression**

I. INTRODUCTION

Evidence is accumulating that China is an emerging scientific powerhouse in terms of research output. The findings of numerous studies are robust despite their diverse search strategies [1-3]. Measured by the number of research articles, China is now the world's second largest producer. In terms of citation, the relative quality of China nano-research is also increasing over year. When bench mark with the US, in 1990, the difference of mean citation per article between the US and China was 1.69. And in 2009, the statistic dropped to 0.44. [1] In light of both countries' huge investments in nanotechnology, the existence of the Chinese Diaspora, and the growing phenomenon of reverse immigration, this narrowing gap in the number of citations likely stems from unbalanced knowledge spillover due to international collaboration, albeit without much supporting evidence.

The impact of international collaboration on research performance is not a new topic, having been extensively explored in prior research. In spite of the rich volume of results in the literature, they are in disagreement. Since the seminar work of Katz and Martin [4], the amount of evidence supporting the positive *correlation* between collaboration and research performance has been accumulating. Narin and his colleagues [5] found that biomedical papers with international co-authors have a larger impact than both single-authored and nationally co-authored papers. Bordons and his co-authors [6] claimed that in Spanish biomedical publications, internationally co-authored articles were higher quality and international collaborators more productive than their domestic counterparts. A recent study led by Barjak and Robinson [7] demonstrated the positive impact of international collaboration on the quantity and quality of a European Union research group. Other studies reported similar findings [8, 9].

The conflicting evidence has been reported recently. For example, Leimu & Koricheva [10] found that internationally co-authored articles do not receive more citations than domestically co-authored papers in the field of ecology. In a comparative study conducted by Duque and his colleagues [11], they found that in the context of developing countries, collaboration is not related to "any general increment in productivity." Findings in support of the trade-off effect of international collaboration on quantity and quality has also been reported. Using the panel publication data of 110 top US universities, Adams *et al*. [12] argued that foreign collaboration among research institutes was positively correlated with citations but negatively correlated with productivity. In another study on one large European university, Carayol and Matt [13] reported no evidence of the impact of international collaboration on research productivity at the lab level. Table 1 summarizes the methods and results of some selected work whose findings on the effects of general scientific collaboration and international collaboration in particular were inconclusive in terms of both direction and impact on research performance.

Prior research, while insightful, suffers from three interrelated, mutually influencing drawbacks. One is the ignorance of self selection when individual heterogeneity is not controlled for in most studies. If the saying "birds

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[1]The citation figures were calculated based on the latest Georgia Tech Nanotechnology Publication Database (1990-2009) which was updated in January 2010.

of a feather flock together" has any validity, then higher research performance, i.e., more publications and greater citations, do not necessarily result from collaboration. Second, but also related, is that many studies focus on only aggregate-level analysis rather than individual-level analysis. Among those adopting micro-level analysis, the omission of variables in model specification is problematic. As noted by Garfield, the founding father of Thomson Scientific, a citation itself is a function of many other variables in addition to scientific quality [14, 15]. It is for this very reason that more recent studies have begun to adopt statistical modeling to exclude competing explanations. Unfortunately, important variables such as language and size of the scientific communities are still missing. The third problem is that many studies have adopted cross-sectional data rather than dynamic longitudinal data. The few that have adopted longitudinal data have all assumed a constant impact of collaboration over the years, which is highly inconsistent with absorptive learning and knowledge accumulation.

Table 1 summarizes the methods and results of some selected work whose findings on the effects of general scientific collaboration and international collaboration in particular were inconclusive in terms of both direction and impact on research performance.

TABLE 1:
SELECTED EMPIRICAL STUDIES: COLLABORATION VS. RESEARCH PERFORMANCE

Article	**Data Source**	**Country**	**Research Scope**	**Method**	**Unit of Analysis**	**Results**	**Collaboration level**
Narin *et al.*, 1991	WoS	EU countries	Biomedical Papers	Descriptive	Paper	+ Quality	International collaboration
Bordons *et al.*, 1996	WoS	Spain	Biomedical Research	Descriptive	Individual Scientist (Team Leader)	+Productivity; + Quality	International collaboration
Barjak and Robinson, 2007	Survey	10 EU countries	Life Sciences	Modeling	Research Team	+ Productivity; + Quality	International collaboration
Persson *et al.*, 2004	WoS	Global	All Fields	Descriptive	Paper	+ Quality	General collaboration
He, *et al.*, 2009	WoS	France	Biomedical Research	Modeling	Individual Scientist	+Productivity; + Quality	International collaboration
Leimu and Koricheva (2005)	Oecologia	EU and America	Ecology	Modeling	Individual Scientist	Not Correlated With Quality	International collaboration
Glanzel & Schubert 2001	WoS	Global	Chemistry	Descriptive	Paper	+ Quality	International collaboration
Duque *et al.*, 2005	Survey	Less developed areas (Ghana, Kenya, and the south-western India)	All Fields	Modeling	Individual Scientist	Not Correlated With Productivity	General collaboration
Adams *et al.*, 2005	WoS	USA	12 Selected Research Fields	Modeling	University Department	- Productivity; + Quality	General collaboration
Carayol and Matt , 2004	University administrative reports	France	All Fields	Modeling	Lab Level	Not Correlated With Productivity	International collaboration

Unfortunately, important variables such as language and size of the scientific communities are still missing. The third problem is that many studies have adopted cross-sectional data rather than dynamic longitudinal data. The few that have adopted longitudinal data have all assumed a constant impact of collaboration over the years, which is highly inconsistent with absorptive learning and knowledge accumulation.

As illustrated in Table 1, in addition to various disciplines, the studied country context seems also related to the mixed results pertaining to collaboration. In the case of China, while the role of international collaboration in scientific development is widely assumed [16-18], empirical evidence of such collaboration remains sparse. Therefore, to augment the literature, this article refers to data obtained from Chinese nano publication data, a panel publication of CKM and their curricula vita (CVs) to explore the impact of China-US collaboration on the research quality of Chinese nanoscientists.

II. HYPOTHESES

Built upon past studies the first hypothesis follows:

H1: *International collaboration has a positive impact on the quality of China's nanotechnology research.*

During the period of 1990 to 2006, China collaborated with 70 countries in nanotechnology and co-published 7,000 papers. In addition to collaborating with American researchers, Chinese researchers also collaborated extensively with their Asian and European counterparts. Given that the US has been the number one knowledge producer in nanotechnology, I further hypothesize the following:

H2: *Research collaboration with US researchers has a larger positive impact on the quality of research in China than other international collaboration without US researchers.*

The above two hypotheses test the impact of international collaboration on research quality under a strong assumption of a constant effect over the years. However, it is reasonable that the accumulation of knowledge and collaborative experiences over time has enhanced Chinese researchers' absorptive capacity. That is, the comparative returns from international collaboration relative to non-international collaborative research decrease over time, leading to the third hypothesis:

H3: *The impact of US-China collaboration on China's nano research quality diminishes over time with less impact in more recent years.*

Hypothesis 3 relaxes the assumption of a constant effect of international collaboration by allowing it to vary over time. To test this hypothesis, interaction terms between international collaboration and publication year are included in the estimation model, and the impact dynamics can be identified by the signs of the interaction term. So if the impact of collaborating with US nanoscientists does demonstrate a time-decay pattern, the interaction term, i.e. the expected *difference* of *increased* quality of US-China collaborated paper and Chinese domestic paper by each additional year would show a positive sign. [2] In other words, the increased JIF is larger for CKM's domestic papers than the increase for CKM papers (hereinafter CKMS) involving the US scholars.

III. DATA

This study utilizes a specially constructed longitudinal publication data of 77 Chinese knowledge moderators. The publication data are extracted from the Chinese nanotechnology publication dataset (1990-2006). For more details on constructing and cleaning this dataset please refer to [19] and [20].

Selection of Chinese knowledge moderators

For the purpose of this article, a nano scientist is considered a Chinese knowledge moderator (CKM) in China-US research collaboration if he or she satisfies the following criteria:

1) A Chinese family name
2) Co-authorship on at least two papers with the U.S. affiliation during the period of investigation
3) Co-authorship on at least two papers with Chinese affiliation during the period of investigation.

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[2] This is due to the coding of publication time: more recent years have smaller value.

Chinese knowledge moderator is a researcher that bridges two different scientific communities of China and the U.S. via *intensive* collaboration. Given the tacit nature of knowledge diffusion, it is reasonable to believe the role of knowledge moderation is embedded by the *process* and the *result* of joint publication on international peer-reviewed journals. Thus, the publication dataset can be used to identify knowledge moderators. Requiring that each side collaborate on two or more publications is arbitrary, but the main idea is to exclude sporadic or opportunistic collaboration and to reduce CKM verification tasks to a manageable level. It also embraces two conflicting notions in social network theory: the structural hole and trust cultivation via frequent interactions [21-23].

Restricting knowledge moderators to only scholars with Chinese family names is justified for the following reasons. First, to facilitate knowledge moderation, knowledge moderators must be able to communicate with all the *co-authors*. As noted in previous study, China's language and culture remain substantial obstacles to a non-Chinese researcher pursuing a career [24]. Thus, assume individuals with a Chinese family name embed both cultural and language factors, they can communicate more effectively with scholars in China either psychologically or behaviorally. In fact, less than 1% of the authors in the Chinese nano publication dataset have non-Chinese family names. Last, which is also related to the first reason, restricting knowledge moderators to only Chinese scholars allows me to compare China's different human capital policies on exporting domestic Chinese researchers and then luring expatriates back.

In this study, I was able to differentiate Chinese from non-Chinese researchers based on the unique spelling of the Chinese *Hanyu Pinying* system. Empirically, two steps were used to code the variability among knowledge moderators. We first constructed a Chinese last name database, which includes all Chinese names collected from the Chinese name dictionary. Built on the database, a thesaurus of Chinese family names was constructed and applied to the Chinese nanotechnology publication dataset. Once the CKMs were identified, we linked them to their coauthored articles and coded each article for the variables of international collaboration and Chinese knowledge moderation.

Figure 1 depicts how the CKMs were identified from a specifically constructed nanotechnology publication database. Since all the CV data of the CKMs and all their affiliations had been collected, this study relied on the author name + the manual cleaning method to extract CKM articles. I started with the names appearing twice in the China-US co-publication dataset. The field of "author" was first cleaned following the most conservative approach. With the idea of casting a wide net first, a false positive was temporarily allowed at this stage.[3] Authors with Chinese family names who appeared at least twice in different articles were considered CKM candidates. This CKM thesaurus was then applied to the fields of author names in the Chinese publication dataset to extract publication records. This returned 374 potential CKMs associated with 10,191 articles were retrieved from the 43,767 Chinese nano dataset. In the second stage, starting from the most productive CKM candidates, the information of 96 potential CKMs was collected. In addition to the full record of their publications and cited references, comprehensive information about a CKM consisting of both academic and professional activities, if applicable, was compiled. More specifically, information such as gender, the subspecialty within nanotechnology, the institution of affiliation, and professional experience outside of China [25] were collected. Based on CV information (both geographical information[4] and publication lists), both false negatives[5] and false positives were identified and dealt with separately. In addition, a cross checking via the Scopus database [6]and fifteen verification emails were sent out with only one non-response. After the manual checking process, 2,186 records were identified as those written by the 77 CKMs. Once the CKMs were identified, the CKMAs, i.e. the articles that the CKM coauthored, were retrieved. Then a subset of publications was constructed for each CKM candidate.

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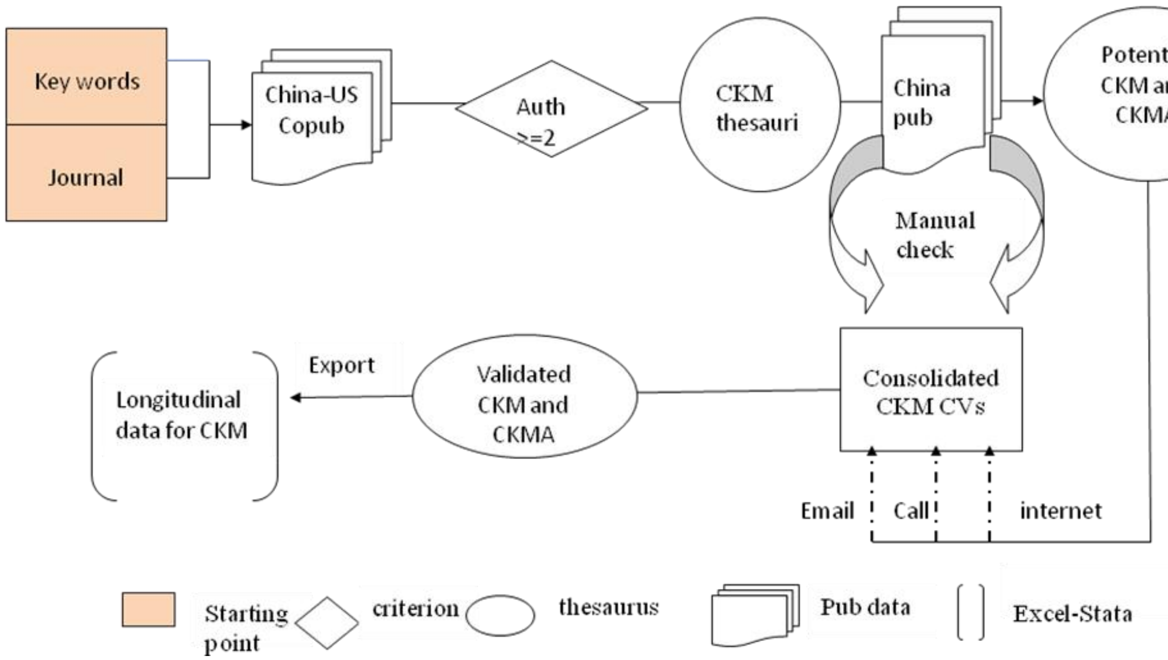
[3] If middle names were available and different, the authors were not considered the same. For example, in the first stage, "Pashley, DH" was considered the same author as "D H Pashley," "Pashley D," Pashley H," or "Pashley, HD," but not "Pashley, DD." Along the same vein, articles reporting either An, L N" or "An, L" were considered the same author as "An, Li Nan" at this stage.

[4] One rule of thumb is if an author "Wang, Jin" never worked at or was affiliated with Florida State University, then the article with "Wang, J" appearing as the reprint author who reported Florida State University as his/her affiliation should not be included as Wang, J's paper.

[5] A false negative occurs if inconsistent names of the same authors were reported, for instance, if a CKM named "Luo, Guo An" reported both "Luo, G A" and "Luo, G" in his publications, or If "Zhang, Jin" reported "Zhang, J Z" rather than "Zhang, J" in all his publications. These cases were verified with CV of the CKM with and WoS nano publication lists.

[6] Searching the same articles in Scopus dataset can provides me with information on authors with their reported affiliations and email communications

Figure 1: Flow Chart of Identifying CKMs and Their Authored Articles



IV. VARIABLES

To test the above hypotheses, this research utilizes two publication databases. The full dataset, pooled cross-sectional data, includes all nano articles reporting at least one Chinese affiliation published in the years 1990 to 2006. The limited dataset is a panel data set of 77 CKM nanotechnology publications from these years. All of the hypotheses except are tested in both the full and panel datasets.

The unit of analysis is a nanotechnology research article published in a peer-reviewed international journal. The *dependent variable* of research quality[7] is measured by two citation-based indicators: the journal impact factor, denoted by *JIF*, and the number of citations received, denoted as *CITATIONS.*

Journal Impact Factor

The journal impact factor is a proxy indicator of the importance of journals, indicated by the *average* number of citations that an article in that journal received. According to Thomson ISI, it is calculated by dividing the number of current citations to articles and reviews published in the two previous years by the total number of articles and reviews published in the same two years.[8] In general, articles published in a journal with higher JIF suggest greater visibility.

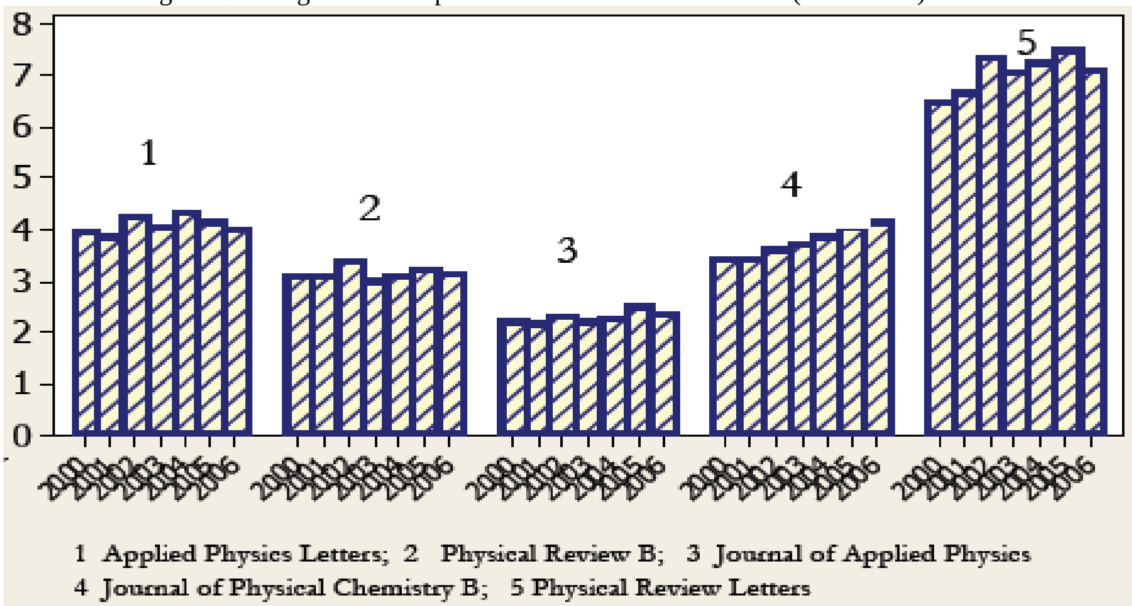
Given its formula, the impact factor of each journal may change from year to year. A plotting of the JIF of the top five journals that contain published nano research (Figure 2), however, shows no significant differences among JIFs over the period of 2000 to 2006.[9] Thus due to data availability, the 2005 Journal Impact Factor, is used as a proxy indicator that captures the quality of an academic journal. To ensure data consistency, the analysis excludes journals that do not have a reported 2005 JIF (such as new journals established after 2005). This left 41,487 in the full dataset and 2,186 in the CKM panel dataset. The descriptive statistics show that the mean journal impact factor of Chinese nano papers is 1.4 with a standard deviation of 1.78. On average 50% of papers were published in journals with an IF of above 1, about 25% were accepted by journals with an IF of greater than 2, while 10% were accepted by journals with an IF of greater than 3.

[7]This term research quality was used interchangeably with research impact in some previous studies.

[8]The definition and formula of journal impact factor is available at http://www.thomsonreuters.com/business_units/scientific/free/essays/impactfactor/

[9]The 2000-2006 JIFs of ISI indexed journals were compiled during my visit in Fraunhofer ISI, Karlsruhe.

Figure 2: Changes in the Impact Factors of Selected Journals (2000-2006)



SOURCE: The data were compiled based on ISI journal citation reports ranging from 2000 to 2006.

CITATIONS

The distribution of citations within the same journal, however, is highly skewed [26]. This leads to the second indicator of research quality, accumulative citations that an article virtually receives after it is published. Similarly, a higher number of citations indicates higher quality. In our database, the mean citation per year of Chinese nano papers is 4.4, ranging from 0 to 753. However, about two-fifths of the Chinese articles had not yet been cited as of June 2006, when the data was downloaded.

In addition to the journal impact factor and the summed citations, another common practice of measuring research quality is using an n-year citation window with n typically 3 or 5. This method has been adopted in previous studies [8, 12, 27, 28]. This study, however, does not adopt this method for the following three reasons. The first is a practical issue. The downloading of nano publications did not produce immediate results or calculate the n-year citation count for each article. However, the total number of citations without information about when the paper was cited was available. Secondly, the proper cut-off point of citations varies significantly according to the research area [29]. Given the multidisciplinary nature of nanotechnology, a single cut-off point of a citation is arbitrary. Although the probability of a research paper being cited falls off sharply after a certain number of years, citations with long lag times do occur. Last but not least, nanotechnology is still a nascent technology. If this study used, for example, a three-year citation window, only articles published during the years 1990 through 2003 would be available for citation analysis and thus exclude studies from the latest "boom" years. Not surprisingly, the use of both the journal impact factor and the citation number as indicators of research quality also poses limitations and caveats. Accepting their inherent limitations for now, I will attempt to examine both *JIF* and *CITATIONS* as dependent variables using both explanatory variables and control variables.

Explanatory Variables

International collaboration. Following common practice, this study adopts co-authorship involving researchers from different countries as an indicator of international research collaboration. Three dummy variables were generated based on whether or not and where a Chinese researcher outside of China became involved in the process of knowledge creation. If an article reports affiliations in two or more countries, the variable of *ICOLLAB* is coded as 1; if it reports only Chinese affiliation(s), it is coded as 0. Since this study focuses on China-US collaboration, the study further separates *ICOLLAB* into another two dummy variables: *USCOLLAB if* an American affiliation was reported in an international collaboration; and *NUSCOLLAB* if it was not.

Of worthwhile interest is that although joint publications are widely accepted nowadays, the validity of using co-authorship as a measure of research collaboration is being questioned. For example, based on research collaboration between firms and universities, Lundberg and his colleagues [30] argued that the "uncritical use" of either co-authorship or funding may mislead readers and policy makers. In the context of Chinese nano research, it is a reasonable assumption that most research collaboration is finally presented in the format of a co-authored paper for the following two reasons. First, the source of most research funding in China is the public sector, which is particularly true for emerging science (such as nanotechnology research), topping the list of government development priorities. Second, studies have found that most Chinese nano publications originate in universities and public research institutes, whose main goal is to publish [31, 32].

Knowledge moderation. As noted earlier, the positive *correlation* between internationally co-authored papers and *JIF/CITATIONS* in cross-sectional data suffers from "reverse causality and survivor bias" [33]. The causal effect requires the left side variable, i.e., *JIF/CITATIONS*, an indicator of a good researcher, is the *result* of the right side variable *ICOLLAB*. The presumed logic here is that international collaboration produces a "good paper" that is cited more often than other papers. The factor of more citations, no doubt, further promotes the author's reputation. Possible reverse causality, however, is that the denotation of a "good scholar," which is often measured by a higher number of *JIF/CITATIONS*, increases the probability that these scholars will be designated a *COLLAB* over others. Given the definition and operationalization of CKM, it would not be surprising to find that the average number of citations of CKM-related articles is higher than that of non-CKM-related articles. To test the individual specifics, the CKM variable *KMOD* was included in the testing of the full dataset. If the article involves any CKM, *KMOD* is coded as 1, otherwise 0.

Control Variables

To eliminate competing explanations, the model included the following five sets of *control variables*:

Language. Academic journals are important sources of communication within the scientific community. One prerequisite for such scholarly communication is readability [34]. Few researchers would cite scholarly work that they found difficult to comprehend. Although the number of indirect citations is increasing, articles written in English are more likely to be cited than others. In the past, this factor was probably disregarded because of the commonly acknowledged, even accepted bias towards English journals in the WoS. However, this situation is changing, so controlling for language is especially critical since the number of nanotechnology publications in the WoS written in Chinese has increased sharply.

Scope of research collaboration. One methodological issue marring the validity of using citation as an indicator of research quality is self citation [10], i.e. citations by an author to his/her previous work [35, 36]. Intuitively, multi-authored articles have higher probability of being cited by authors themselves [37-39], thus important to control for that *in the statistical analysis* on citation data. It is too costly in time and computational complexity to remove self-citations from about 43,000 publications. Three research collaboration scope variables are included in the model estimation.

Some studies found that the number of authors, institutions, and countries is positively correlated with the number of citations [40-42]. However, other studies suggest the opposite [43, 44]. Thus, this work includes the variables of number of article citations and placement in journals in the model, but without prior expectations as to the direction of influence.

Researcher capacity. In addition to Chinese knowledge moderators, another factor compounding the self-selection problem is the collaborator(s) of CKMs on the China side. As noted by previous research, different from the US researchers, the best Chinese researchers are concentrated within a few elite universities and research institutes. In mainland China, the Chinese Academy of Sciences (CAS) and elite Chinese universities (Appendix 1) have traditionally attracted the best researchers and students, who form and maintain extensive international collaborations with their counterparts overseas. For historical reasons, Hong Kong, with its English-speaking tradition, has formed close research exchange activities with developed western countries. To reduce the possible self-selection effect of co-authors, three dummy variables—*CAS*, *ELITE-UNIV*, and *HONG KONG*—are included in the models.

Research discipline. Another factor that influences the number of citations is research discipline. As Moed and Van Leeuwen [26] observed, both the "composition of the contents" and the characteristics of the research field influence citation and journal impact factors. For example, compared with papers in bioengineering, those in materials science may exhibit different citation patterns, directly influencing the JIF and number of citations. In fact, prior studies have found that some fields are "more amenable to scholarly interaction than other fields" [45, 46]. Papers published in biomedicine are usually published in journals with larger impact factors. Differences in the impact factor due to the size of the scientific community are important for an interdisciplinary field such as nanotechnology. Thus, this research will control for this factor by adopting the Fraunhofer ISI classification

[10] This is identified if at least one author in the citing paper is the author of the cited publication.

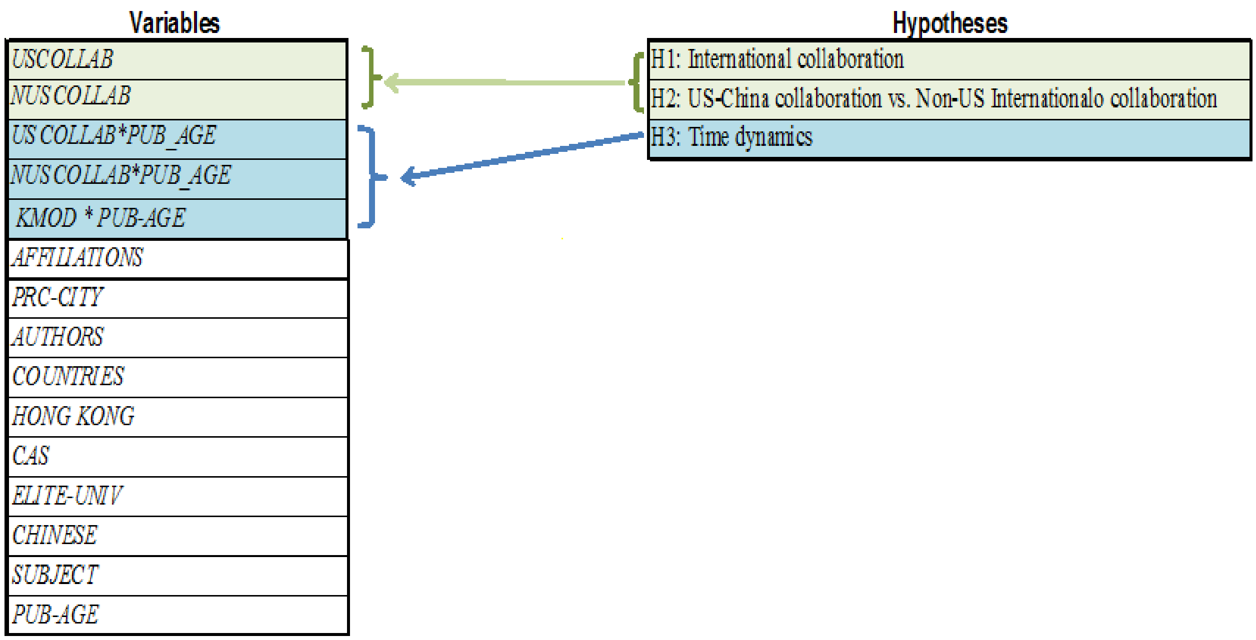
method, which differentiates nanotechnology research into 24 research fields based on subject codes.[11] Table 2 links the variables with the testing hypotheses.

Research experience. Based on the CVs of the CKMs, a numerical variable RES-EXP is constructed to indicate research experience of researchers. The value of RES-EXP is calculated by 2009 minus the year CKM got his highest degree. This variable is only used in the selection model of testing hypothesis 3.

Publication age. Publication date also influences citation-based indicators. Articles published earlier are more likely to be found and cited than later papers of the same quality. In this article, publication elapsed time is used to control for time period variations.

TABLE 2:

HYPOTHESES AND TESTING VARIABLES



[11] The categorizing method of the Fraunhofer ISI initially targeted *all* articles included in the SCI-WoS. Applying it to our nanotechnology dataset, I found that 24 out of 26 research fields were covered in Chinese nano publications, indicating the multidisciplinary nature of nanotechnology.

TABLE 3
DESCRIPTION OF THE VARIABLES

Type	Construct	Variable Name	Expected Direction	Description
D	Research quality/ visibility	*JIF*		Journal impact factor, 2005
D	Research quality/ visibility	*CITATIONS*		Times cited since publication
I	International collaboration	*ICOLLAB*	(+)	At least one author with an affiliation outside China = 1; otherwise = 0
I	International collaboration	*USCOLLAB*	(+)	At least one author with an US affiliation outside China = 1; otherwise = 0
I	International collaboration	*NUSCOLLAB*	(+)	At least one non-American affiliation outside China is reported =1; otherwise = 0
C	Scope of research collaboration	*AFFILIATIONS*	(+/-)	Number of affiliations associated with co-authorship
C	Scope of research collaboration	*PRC-CITY*	(+/-)	Number of Chinese cities associated with co-authorship
C	Scope of research collaboration	*AUTHORS*	(+/-)	Number of coauthors
C	Scope of research collaboration	*COUNTRIES*	(+/-)	Number of coauthors' countries of affiliation
C	Capacity of researcher	*HONG KONG*	(+)	Article has one or more authors from Hong Kong = 1; otherwise = 0
C	Capacity of researcher	*CAS*	(+)	Article has one author from the Chinese Academy of Sciences = 1; otherwise = 0
C	Capacity of researcher	*ELITE-UNIV*	(+)	Article has one author from a top 10 Chinese university = 1; otherwise = 0
C	Language	CHINESE	(-)	Written in Chinese = 1; other = 0
C	Research discipline	*SUBJECT*	(+/-)	F1-F26: A set of subject dummies indicating the subfield of nanotechnology. 26 subject categories based on key words of subject codes from Thompson ISI
C	Time	*PUB-AGE*	(+/-)	Pub_age=2006-publication year
C	Research Experience	*RES-EXP*	(+/-)	Years of research experience

Note: Variable type: D = Dependent; I = Independent; C = Control.

Detailed descriptions of the above variables and coding mechanisms are summarized in Table 3. Tables 4~ 7 provide descriptive statistics for the full dataset and the panel dataset.

TABLE 4
SUMMARY OF DESCRIPTIVE STATISTICS: FULL DATA

Construct	Variable	Observation	Mean	S.E.	Min	Max
Quality of research	*JIF*	41487	1.41	1.78	0.00	30.93
	CITATIONS	41487	4.44	12.35	0	753
International collaboration	*ICOLLAB*	41487	0.16	0.37	0	1
	USCOLLAB	41487	0.05	0.21	0	1
	NUSCOLLAB	41487	0.11	0.31	0	1
Knowledge moderation	*KMOD*	41487	0.05	0.22	0	1
Scope of research collaboration	*AUTHORS*	41487	4.72	1.97	1	14
	AFFILIATIONS	41487	1.57	0.78	1	9
	PRC-CITY	41487	1.24	0.49	1	5
	COUNTRIES	41487	1.18	0.44	1	7
Capacity of researcher	*HONG KONG*	41487	0.08	0.27	0	1
	CAS	41487	0.29	0.45	0	1
	ELITE-UNIV	41487	0.36	0.48	0	1
Language	*CHINESE*	41487	0.14	0.35	0	1
Time	*PUB-AGE*	41487	3.30	2.87	0	15

As indicated in the correlation matrix (Tables 4.7 and 4.8), the number of collaborating countries (*COUNTRIES*) is highly correlated with the international collaboration variable (*ICOLLAB*)[12] and are thus dropped from the models in an effort to eliminate multicollinearity.

[12]Pearson's "r" of the number of countries and international collaboration in both full and CKM panel data are 0.93 and 0.94 respectively.

TABLE 5

SUMMARY OF DESCRIPTIVE STATISTICS: PANEL DATA

Construct	Variable	Observation	Mean	S.E	Min	Max
Quality of research	*JIF*	2186	2.11	2.51	0.08	30.93
	CITATIONS	2186	7.44	21.53	0	753
International collaboration	*ICOLLAB*	2186	0.29	0.45	0	1
	USCOLLAB	2186	0.23	0.42	0	1
	NUSCOLLAB	2186	0.06	0.23	0	1
Connection with the US	*USWRK*	2186	0.41	0.49	0	1
	USVST	2186	0.33	0.47	0	1
	*USOTH**	2186	1.16	0.80	0	2
Connection with China	*CNWRK*	2186	0.96	0.20	0	1
	CNPRM	2186	0.01	0.11	0	1
	*CNOTH**	2186	0.03	0.17	0	1
Scope of research collaboration	*AUTHORS*	2186	5.28	1.96	1	14
	AFFILIATIONS	2186	1.75	0.89	1	7
	PRC-CITY	2186	1.24	0.50	1	4
	COUNTRIES	2186	1.31	0.51	1	4
Capacity of researcher	*HONG KONG*	2186	0.04	0.21	0	1
	CAS	2186	0.42	0.49	0	1
	ELITE-UNIV	2186	0.43	0.50	0	1
Language	*CHINESE*	2186	0.07	0.25	0	1
Research experience	*RES-EXP*	2186	15.0	9.94	1	51
Time	*PUB-AGE*	2186	3.11	2.45	0	15

TABLE 6
CORRELATION MATRIX: FULL DATASET

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*JIF*	1.00														
2	*CITATIONS*	0.37	1.00													
3	*ICOLLAB*	0.15	0.08	1.00												
4	*USCOLLAB*	0.13	0.07	0.51	1.00											
5	*NUSCOLLAB*	0.08	0.04	0.82	-0.08	1.00										
6	*KMOD*	0.09	0.06	0.09	0.21	-0.04	1.00									
7	*AUTHORS*	0.12	0.05	0.11	0.08	0.08	0.07	1.00								
8	*AFFILIATIONS*	0.09	0.03	0.55	0.34	0.41	0.05	0.25	1.00							
9	*PRC-CITY*	-0.02	-0.03	-0.09	-0.03	-0.08	0.00	0.11	0.50	1.00						
10	*COUNTRIES*	0.15	0.08	0.93	0.50	0.74	0.07	0.15	0.60	-0.09	1.00					
11	*HONG KONG*	0.11	0.08	0.04	0.06	0.01	-0.03	-0.01	0.13	0.16	0.06	1.00				
12	*CAS*	0.07	0.03	0.00	0.01	-0.01	0.06	0.14	0.10	0.13	0.00	-0.10	1.00			
13	*ELITE-UNIV*	0.05	0.03	-0.04	-0.01	-0.04	0.04	0.04	0.06	0.06	-0.04	-0.12	-0.29	1.00		
14	*CHINESE*	-0.29	-0.10	-0.13	-0.07	-0.10	-0.05	-0.05	-0.06	0.02	-0.12	-0.10	-0.04	-0.04	1.00	
15	*PUB-AGE*	-0.06	0.26	0.00	-0.01	0.01	-0.02	-0.01	-0.03	-0.04	-0.01	0.04	0.08	0.02	-0.04	1.00

TABLE 7

CORRELATION MATRIX: CKM PANEL DATA

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	*JIF*	1.00													
2	*CITATIONS*	0.36	1.00												
3	*ICOLLAB*	0.19	0.03	1.00											
4	*USCOLLAB*	0.18	0.00	0.87	1.00										
5	*NUSCOLLAB*	0.04	0.05	0.38	-0.13	1.00									
6	*AUTHORS*	0.10	0.01	0.10	0.07	0.06	1.00								
7	*AFFILIATIONS*	0.14	0.00	0.62	0.56	0.20	0.27	1.00							
8	*PRC-CITY*	-0.05	-0.05	-0.03	0.00	-0.06	0.13	0.46	1.00						
9	*COUNTRIES*	0.20	0.04	0.96	0.84	0.35	0.13	0.66	-0.04	1.00					
10	*HONG KONG*	-0.02	-0.02	0.01	0.03	-0.05	0.01	0.10	0.20	0.00	1.00				
11	*CAS*	0.06	0.00	0.01	-0.03	0.08	0.26	0.12	0.11	0.00	-0.06	1.00			
12	*ELITE-UNIV*	-0.01	0.02	-0.05	-0.04	-0.04	-0.10	0.05	0.11	-0.05	-0.10	-0.50	1.00		
13	*CHINESE*	-0.22	-0.07	-0.11	-0.09	-0.06	-0.01	0.02	0.10	-0.11	0.02	-0.03	-0.02	1.00	
14	*PUB-AGE*	-0.08	0.26	-0.11	-0.16	0.08	-0.06	-0.09	-0.04	-0.10	0.01	-0.06	0.14	-0.03	1.00

V. MODELS AND ESTIMATION RESULTS

This study uses STATA version 9.0 for estimation. The regression results are shown in Table 8 for the journal impact factor (*JIF*) and Table 9 for the number of citations (*CITATIONS*). All the models are statistically significant.

Journal Impact Factor

Full Dataset

Panel 1 in Table 8 lists the estimation results using a full dataset of Chinese nanotechnology papers, that is, cross-sectional data. Model 1 reports the results of testing the impact of international collaboration and China-US collaboration on research quality (H1 and H2). Model 2 lists the results including knowledge moderation and its interaction term with publication elapsed time. Given the distribution of dependent variables**,** both models adopt negative binomial estimation, which is typically considered a better choice than Poisson in the case of over dispersion. [13]

Column 1 shows that the regression coefficients of *USCOLLAB* and *NUSCULLSB* are positive and statistically significant, indicating that the average journal impact factor of internationally collaborative articles is higher than that of the reference group—Chinese domestic papers. The coefficient of *USCOLLAB* (0.55) is nearly twice as large as that of *NUSCOLLAB* (0.28), suggesting that China-US collaboration has a larger positive impact than international collaboration without a US affiliation. The numbers of both affiliations and cities involved in collaboration are negatively associated with *JIF*, suggesting that an increased scope

TABLE 8

REGRESSIONS ON THE JOURNAL IMPACT FACTOR

	Full Dataset (Panel 1)		CKM Longitudinal Data (Panel 2)		
	Model 1	Model 2	Model 3 (Main Model)	Model 4	Model 5
	Negative Binomial	Negative Binomial	Fixed Effect	Negative Binomial	FGLS
KMOD		0.21***			
*KMOD * PUB-AGE*		0.01			
USCOLLAB	0.55***	0.47***	1.07***	0.44***	0.65***
*USCOLLAB * PUB-AGE*	-0.01	0.00	-0.24**	-0.08***	-0.13***
NUSCOLLAB	0.28***	0.28***	0.25	0.33**	0.55**
*NUSCOLLAB * PUB-AGE*	0.00	0.00	-0.07	-0.05	-0.07
CHINESE	-2.41***	-2.40***	-1.80***	-3.40***	-1.72***
HONG KONG	0.48***	0.49***	0.30	0.00	-0.14
CAS	0.31***	0.30***	-0.23	0.12**	0.05
ELITE-UNIV	0.27***	0.27***	0.49	0.07	0.07
AFFILIATIONS	-0.06***	-0.06***	0.35**	0.09***	0.00
PRC-CITY	-0.11***	-0.11***	-0.42**	-0.16***	0.03
AUTHORS	0.05***	0.05***	0.11**	0.03***	0.05***
PUB-AGE	-0.04***	-0.04***	-0.05	-0.01	-0.01

Note: *** p<0.01, ** p<0.05, * p<0.1

[13] The variance is much larger than the mean.

domestic collaboration decreases the likelihood of publishing in better journals, perhaps due to the transaction costs of collaboration. As expected, articles written in Chinese are more likely published in low-impact journals than paper written in English, and papers authored by researchers from elite Chinese research institutes or universities are more likely to be accepted in good journals. Based on the values of the standardized coefficients of the variables, language is the most influential factor impacting *JIF*. [14] Indicated by the two interaction terms (*USCOLLAB* **PUB-AGE* and *USCOLLAB* **PUB-AGE*), the dynamic impact of international collaboration is statistically *in*significant.

The above pattern remains after the variable *KMOD* and its interaction term with time *KMOD*PUB-AGE* are added to the regression equation (Model 2 in Panel 1). In addition, the results suggest that holding international collaboration, language, research collaboration scope, public age, research capacity, and research discipline constant, papers associated with CKMs are more likely to be published in higher quality journals. This supports the role of knowledge moderators in upgrading China's research quality. However, the effect of time is not statistically significant.

Longitudinal Publication Data of CKMAs

The Sacred Spark Hypothesis suggests that scientists differ with regard to their research performance [47]. Arguably, the research quality of an internationally co-authored paper is higher, not because of the occurrence of transnational collaboration but because the authors themselves are better researchers. Providing more convincing evidence of the impact of international collaboration on individual research performance, the estimates from longitudinal data are presented in the second panel of Table 8.

Fixed Effect or Random Effect

In the analysis of panel data, one must first decide whether to adopt a fixed effect or random effect model. This decision depends on whether or not the individual effects correlate with the explanatory variables [48, 49]. Obviously, given the selection criteria of CKMs, the panel publications are not a random sample from a given population, so for the purposes of generalizability, a fixed effect model is preferred. In practice, the determination of which model to use requires the implementation of the Hausman-Wu specification test [50]. The STATA outputs shows that the Hausman test produces Prob>chi2 = 0.0033, providing strong evidence of a significant correlation between the unobserved person-specific random effects and the regressors. This suggests the existence of an individual effect, so the fixed effects model is preferred.

The fixed-effect model equation is

$Y_{it}=\beta_0+\beta_t+\beta_1 Xe_{it}+\beta_2 Xc_{it}+a_i+u_{it,}$, where

Y is the dependent variable (i.e., research quality),

β_t is the time effect,

Xe refers to the list of explanatory variables,

Xc includes the list of control variables,

a_i is the individual fixed effect or unobserved heterogeneity of each CKM, and

u_{it} is the idiosyncratic error.

The first column of Panel 2 in Table 8 provides the fixed-effect estimates obtained by the within-groups method. The following discussion focuses on the fixed effects. Like Panel 1, the reference group consists of Chinese knowledge moderated papers without authors from any institution outside of China.

The coefficients of international collaboration variables (both *USCOLLAB* and *NUSCOLLAB*) denote the expected difference between the impact factor of internationally co- authored articles and that of non-internationally co-authored articles with zero years of publication, i.e., 2006. These two statistically significant positive signs show that for CKM papers published in 2006, the expected journal impact factor of US researcher co-authored papers is about 1.07 higher than that of the reference group, i.e., CKM papers without authors outside of China; however, the journal impact factor of non-US internationally co-authored papers accepted by journals is an average of 0.25 higher than that of the reference group. So both H1 and H2 are supported in the longitudinal data.

The coefficient of the *PUB-AGE* (-0.05) indicates that on average the impact factor of CKM domestic papers is 0.05 higher than it was in the previous year. Notice that the coding mechanism of publication age is that later articles are associated with smaller values. The negative sign indicates that CKM papers without international co-authors also climbed up the ladder of journal visibility over time despite such annual increase is not statistically significant.

[14] The standardized beta coefficients which are not shown in Table 8 are available upon request.

The coefficient of the interaction term *USCOLLAB * PUB-AGE (-0.24)*, i.e., the difference between the differences, suggests that with each additional year, the journal impact factor for US-China collaborated articles is expected to be 0.24 higher than for Chinese domestic articles, indicating that the effect of US-China collaboration on the acceptance of Chinese-related papers (the journal impact factor) increases over time. This finding does *not* support Hypothesis 3, which predicts that the impact decreases over the years due to knowledge accumulation resulting from "collaborative learning."

This result could be explained by two factors. For one, "learning by doing" practices may not be as influential as we expect with regard to decisions by journals to accept a paper for publication. In other words, what CKMs learned by collaborating on publications with US colleagues would not have been transmitted to CKMs' work without the latter's input. On a more conservative note, the expected knowledge spillover may not have been recognized by the "gate keepers," possibly due to language barriers, a short observation period, selection bias, or other reasons.

From a scientific behavioral perspective, however, this finding is also plausible that only better ideas or novel methods facilitate successful international collaboration. Given the relative strength of the development of US and China nanotechnology, taking the two-sided nature of research collaboration beyond quid pro quo [51] into consideration, it is highly possible that only the most promising research of CKMs is recognized or acknowledged by US collaborators, which contributes to the widening gap between international and non-international collaboration at the individual CKM level.

Interestingly, the role of research capacity from the Chinese perspective disappears, contradicting the results of the full dataset (Panel 1). Individually and jointly, the regression coefficients of *HONG KONG*, *CAS*, and *ELITE-UNIV* are statistically *in*significant.[15]

For the testing of robustness, two more regressions-negative binomial and feasible generalized least squares (FGLS) regressions were carried out based on the nature and distribution of dependent variable. As shown in Models 4 and 5 of Table 8, the results are relatively consistent. From a comparison of Model 4 (the panel dataset) and Mode 1 (the full dataset), both of which use the negative binomial regression estimate, it should also be noted that the coefficient of *USCOLLAB* in the longitudinal data is about 20% smaller than it is in the full dataset: more evidence that supports the self-selection effect of international collaboration. More importantly, in Model 1, the regression coefficient of *PUB-AGE (-0.04)* is statistically significant at a 0.001 level, while in Model 4, not only was it statistically insignificant, but its magnitude had also shrunk to one-fourth its previous size *(-0.01)*. The diminished effect of time suggests that the increased visibility of Chinese nanotechnology research over the years was facilitated by CKMs.

[15] The Wald test could not reject the null hypothesis that they were jointly 0 (Prob > chi2 = 0.18).

TABLE 9

REGRESSIONS ON CITATIONS

	Full Dataset (Panel 1)		CKM Longitudinal Data (Panel 2)		
	Model 1	Model 2	Model 3 (Main Model)	Model 4	Model 5
	Tobit	Tobit	Fixed Effect	ZINB[16]	Tobit
JIF	0.24***	0.23***	0.13***	0.20***	0.13***
KMOD		0.10*			
*KMOD * PUB-AGE*		0.08***			
USCOLLAB	0.14***	0.08	-0.21**	-1.17***	-0.22**
*USCOLLAB * PUB-AGE*	0.04***	0.04***	0.22***	0.38***	0.22***
NUSCOLLAB	0.10***	0.10***	-0.02	-0.84*	-0.03
*NUSCOLLAB * PUB-AGE*	0.02***	0.02***	0.06	0.26***	0.06
CHINESE	-0.30***	-0.29***	-0.39***	-0.87***	-0.39***
HONG KONG	0.40***	0.41***	0.30**	-0.11	0.30**
CAS	0.10***	0.09***	0.05	0.06	0.05
ELITE-UNIV	0.20***	0.19***	0.15**	0.22**	0.15**
AFFILIATIONS	-0.04***	-0.04***	-0.08**	-0.07	-0.08**
PRC-CITY	-0.11***	-0.12***	-0.03	0.04	-0.03
AUTHORS	0.03***	0.02***	-0.01	-0.02	-0.01
PUB-AGE	0.25***	0.25***	0.22***	-3.40	0.22***

Note: *** p<0.01, ** p<0.05, * p<0.1

Paper Citations

Full Dataset

Table 9 lists the regression results on log (*CITATIONS*). [17] Panel 1 produces rather consistent results as those in Table 8. Holding other things constant, articles written in English are more likely to receive be cited than papers written in non-English. Articles authored by researchers from elite Chinese research institutes or universities are more likely to be cited by their colleagues. Knowledge moderated paper are cited more those without involving CKMs, and US-China collaborated paper on average receive higher citations than domestic Chinese nano research, but the effect becomes smaller both substantially and statistically after controlling for knowledge moderated paper. This also provides some evidence that CKMs drives the positive impact of US-China collaboration on China's research quality.

Longitudinal dataset

Similar to the estimation on journal impact factor, three regression models: fixed effect, zero inflated negative binomial, and Tobit regression were conducted for the longitudinal data. I also focus on the fixed effect (Model 3) to elaborate on the main findings here. Undoubtedly, papers published in journals with a larger *JIF* are generally cited more often. The premium of English still holds in and even more apparent in CKMA. The influences of collaboration scope and research capabilities from China side become ambivalent in panel data. All of these findings are consistent with those in Table 8.

[16] The value of Ln(alpha) is 0.15, statistically significant at 0.001 level.

[17] Considering that e log (0) is meaningless, the dependent variable is calculated by log (citations+1).

Surprisingly, the citation regressions tell a rather different story on the effects of international collaboration. The regression coefficient of *USCOLLAB (-0.21) (Panel 2, Model 3)* indicates that for articles published in 2006, the latest year of this examination, papers associated with US scholars received an average of 0.21 citations *fewer* than Chinese domestic papers without international coauthors. This situation was different even one year earlier in 2005. For CKM articles published in 2005 (when *PUB-AGE* takes the value of 1), the average number of citations of the China-U.S. co-authored papers was still 0.01 greater than that of Chinese domestic papers.[18] When we focus on the interaction effect (*USCOLLAB* * *PUB-AGE*), its coefficient suggests that with each additional year, the expected increased in citations is 0.22 lower for China-US collaborative articles than for Chinese domestic articles. In other words, the citation premium of Sino-US CKM papers diminishes until the year of 2006, when CKM domestic research started to attract more citations. This finding supports Hypothesis 3, which pertains to knowledge accumulation. Similar to the regressions on JIF, Models 4 and Model 5 exhibit the results of two robustness tests using zero inflated negative binomial regressions (a ZINB and a Tobit regression, respectively). The ZINB takes into account the zero inflation of the data. The ln (alpha), which is statistically significant, shows the appropriateness of this model. The Tobit regression considers the truncated nature of the citation data. Both generate results consistent with those of the fixed-effect model.

VI. DISCUSSION

It is generally accepted that internationally collaborative papers appear in better journals and are cited more often than local research [52], yet it remains unclear whether this phenomenon is due to the self selection of researchers or the nature of collaboration types themselves. The deficiency of prior literature on this topic has different policy implications. This study has found new evidence that supports the positive impact of international collaboration on research quality, which was always in question because only the best scientists collaborate at an international level [6, 7].

Secondly, this article identified the factors influencing research quality. Language, the missing variable in the estimation equation of former studies, turns out to be the most influential factor impacting the quality of Chinese nano research. Thirdly, the regression estimates consistently report that not all types of collaboration have a positive effect. This indicates the transaction cost argument largely holds. The diminished premium of Chinese elite research institutes in China-US collaboration is particularly interesting, for it implies that encouraging non-elite universities is an effective way to reduce the inequitable allocation of education resources, a deep-rooted problem in China.

Last but not least, the discrepancy of regression results on *JIF* and *CITATIONS* seems to tell a different story on the dynamic impact of China-US collaboration on the quality of CKM research. Each indicator reflects a particular dimension of the general concept of research quality. The different message conveyed by the two indicators of research quality is intriguing. Such opposing results found in prior- and post-published peer reviews may suggest a difference between the views of gatekeepers and those of the scientific community on China's nano research quality. It introduces caveats about the validity of using a single measurement alone in research evaluation, and echoes the appeal for "combining the various types of indicators in order to offer policy makers and evaluators valid and useful assessment tools." [53]. If we believe JIF is a good indicator, the increased citations may be because Chinese researchers are parochial and they frequently cite Chinese domestic paper for whatever reason, such as no access to better paper, or cite work of domestic big shots, etc. This effect was negligible in the past, but the growing size of Chinese scientists brings this effect front now. Additional information is needed to distinguish between these alternatives [10].

This project also sheds some light on human capital management and public R&D allocation in China. In spite of its pronounced growth in R&D investment, its research policies are presenting several significant challenges, one of which is the deeply rooted problem of huge disparities in the development of science and technology from region to region. One of the most prominent regional disparities with regard to research is spatial disparity. For some time now, the Chinese national government has pursued a modeling strategy of allowing only a few regions to develop. This preferential policy favors coastal areas, which possess stronger physical and human capital resources than those in other parts of the country. The result is a "four-world" China. While the eastern seaboard region, the "first world," which harbors only 2.2% of the Chinese population, has reached a level of economic performance similar to some developed countries, the "fourth world" of China, where approximately half of the population lives, has an average per capita income below that of other developing countries. A similar profile can be found in the distribution of R&D resources. Whereas a majority of elite Chinese universities and CAS are

[18] It is calculated by (-.21+.22*1+.22*1)-(0+0+0.22*1) =0.01

located in coastal provinces and special development zones in southern and eastern China, only a few are in inland areas. This unequal distribution of research institutions contributes to the disproportionate distribution of national research projects, which reinforces investment of resources in the wealthier coastal areas. This huge disparity has been a major challenge for sustainable development in China. Empirical evidence in this study that shows a decreased premium of elite Chinese universities sheds some light on the mechanism for promoting science and technology development in underdeveloped regions: select scholars in non-elite Chinese universities for international visits.

APPENDIX 1: LIST OF CHINESE ELITE UNIVERSITIES

Rank	**Elite University of China**	**City**
1	Tsinghua University	Beijing
2	Beijing University	Beijing
3	Zhejiang University	Hangzhou
4	Fudan University	Shanghai
5	Nanjing University	Nanjing
6	Univ Sci & Technol China	Hefei
7	Shanghai Jiao Tong University	Shanghai
8	Wuhan University	Wuhan
9	Jilin University	Changchun
10	Harbin Institute of Technology	Harbin

Source: *The 21st Century Business Herald*, *China Daily*, February 21, 2005.

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