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International scientific collaboration between Australia and China: A mixed-methodology for investigating the social processes and its implications for national innovation systems

Xiao Si Niu *

School of Business, University of Western Sydney, Building EDG, Corner of Victoria Road and James Ruse Drive, Rydalmere, NSW 2116, Australia

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ABSTRACT

This article is based on a study of international scientific collaboration between Australia and China. The analytical approach adopted for this research takes the concept of scientific and technical human capital (STHC) as a starting point and seeks to explain the role and the extent to which collaboration networks can be utilized as a potential source for gaining access to flows of knowledge, that contribute to both building research careers and strengthening national innovation systems (NISs). The study is based on a combination of bibliometric analysis and interviews. The bibliometric analysis indicates that international scientific collaboration between the two countries has expanded rapidly, from just four co-authored papers in 1981 to 2,040 in 2010. The interviews suggest that a framework of exchange can be used as an approach to explain the underlying dynamics of collaboration. The findings suggest that augmenting the information base with qualitative data helps toward a more comprehensive understanding of science, technology and innovation (ST&I) dynamics. This has potential implications for the formulation of future policies with respect to STHC.

1. Introduction

This paper is concerned with networks for scientific collaboration between Australia and China. The focus is on the role and the extent to which international scientific collaboration can be a source for development of national innovation systems (NISs) for both countries. According to a report prepared by the British Royal Society, international scientific collaboration has expanded on a global scale [1]. There are various forces underpinning international collaboration; mobility is an important one of these [2–5]. Scientists are mobile and as they move through their careers, they establish linkages contributing to the formation and extension of networks [6]. Through these networks scientists share resources for research, and extend their international presence [1,7]. These professional and organizational characteristics of scientific mobility, in turn, have important implications for system development and the building of scientific and technical human capital (STHC) [8]. However, little is known about how scientists' networks are formed and maintained.

Scientific and technical human capital as an analytical concept helps to explain the dynamic network capabilities of scientists. It takes into account the complicated system of professional and social interactions in the context of international collaboration. Bozeman et al. described STHC as:

> … the socially-embedded nature of knowledge creation; transformation and use; and the dynamic, capacity-generating interchange between human and social capital.
>
> [[8, p.719]]

The concept helps to explain the science, technology and innovation (ST&I) capacity for Australia and China beyond the human resource approach. This means where scientists have been and what they did at a particular point in time

* Tel.: +61 2 9685 9430; fax: +61 2 9685 9400.
E-mail address: niux.1996@gmail.com.

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should be considered in the investigation of international collaboration. The approach takes into account the sharing and learning that occurs through both formal and informal channels and in social or profession contexts (see [3,9–12]).

Many countries have adopted a NIS approach for national development (see [13–15]). The NIS approach investigates the learning capacity of institutions for national development. Lundvall et al. defined a NIS as:

> … an open, evolving and complex system that encompasses relationships within and between organizations, institutions and socio-economic structures which determine the rate and direction of innovation and competence-building emanating from processes of science-based and experience-based learning.
>
> [[16, p.6]]

However, understanding the dynamics of a NIS is a complex process. It involves a wide range of social and professional factors, formal and informal networks; and sharing and learning activities [17–19]. The NIS presumes and measures the presence of a national research system (among other components). Both Australia [20] and China [21] have emphasized the need to utilize global avenues as a source for NIS development [14,22]. This is because a sufficient STHC base needs to be in place in order for the system to develop [23,24].

The NIS depends on productive relationships between institutions as well as between countries (see [25]). Although the NIS approach does recognize social capital as an important component for national development [16], it appears insufficient in investigating the social process of relationship building between individual scientists. Interactions between scientists are important because individuals are at the front end of innovation. The present study argues that a social exchange process, built on personal relationships and trust, is central to international science collaboration. The creation and application of knowledge within and across NIS 'borders' is underpinned by an organic process through which scientists share and exchange resources to fulfill various expectations.

Scientists are not alone in the process of collaboration. They also respond to the expectations of the state, funding agencies and their organizational employers. For example, policy initiatives of governments to promote mobility are an example of how states can influence the behavior of scientists while responding to global pressure of the need to develop the NIS. The Australian and the Chinese national governments have both made significant policy efforts to stimulate the international movement of researchers [20,26,27]. A significant turning point for building international connections between China and countries in the North came with the implementation of the nation's 'Reform and Opening-up' regime in 1978 [26,28], and a series of national science reforms that followed [21,29]. The inflow and outflow mobility of students and scholars over the past three decades has helped the nation to build international connections as shown by Xiang [27]; Australia is one of China's international partners in science [30], with connections established at the individual level (see for example: [12,31]) and the institutional level (see for example: [32,33]).

The networks constructed through scientists' mobility are recognized as having a positive impact on STHC for Australia and China [14,20,24,34]. Developments in information technology have clearly contributed to increase flows of information [1,35]. Australia and China are part of this global trend. For example, the number of joint scientific publications produced between Australia and mainland China has expanded from just 4 in 1981 to 2,040 in 2010 [36]. The increase in joint research, as measured by the proxy of co-authored publications, reflects increased international collaboration.

However, relying only on bibliometric analysis to measure international collaboration misses some important information about how co-authorship evolves and what is actually shared [37]. Scientists do not live in a social vacuum [38] and the reasons behind two or more scientists publishing a paper together need to be considered beyond that of a scientific and technical in nature [39]. Bozeman et al. argued that '… in modern science being scientifically brilliant is only necessary, not sufficient' [8, p.724]. In the context of publications, that 'sufficiency' is not just about whether the work is of any academic value worth publishing but also how to locate the path for getting it published. The present study sets out a research methodology that demonstrates how bibliometrics and interview data can provide a useful mixed methodological and analytical approach for the study of international collaboration in science.

The methodology includes two parts: the first is bibliometric analysis of co-authored papers indexed in the Science Citation Index Expanded (SCIE) and of scientific publications collected from Scopus. This is used as an indicator to describe the location of dispersed/diaspora knowledge networks constructed and maintained between scientists working in Australia and China.[1] This is followed by a second phase: a qualitative analysis of selected interviews conducted with collaborating scientists in Australia and China. The latter focuses on the Beijing and Tianjin municipalities. In this part of the study, scientists identified from the bibliometric analysis were asked questions about their motivations, aspirations, and career trajectories with respect to international collaboration. The interviews help reveal the underlying dynamics of collaboration indicated by the bibliometric analysis.

2. International scientific collaboration, STHC and the NIS

Australia and China both recognize the importance of gaining access to the flow of knowledge for development of NIS. This is reflected in policy initiatives such as Australia's most recent review of the NIS [20] and China's National Medium- and Long-term S&T Development Plan (2006–2020) [42]. With an overarching aim of improving the country's innovation performance, this Chinese policy reaffirms the need to utilize international connections for the development of China's NIS [42,43]. Likewise, the Cutler Review argued that Australia needs to utilize international networks to develop NIS, while also stressing the need to expand connections with China for both social and economic gains [20]. The need to strengthen

[1] According to Stein and Stren, knowledge networks (KNs) are '… spatially diffuse structures, often aggregations of individuals and organizations, linked together by shared interest in and concern about a puzzling problem' [40, p.7]. Dispersed KNs contain the connections and nodes established and maintained between scientists for the production and diffusion of knowledge (see [41]).

relationships with China was an important national strategy set by the Australian government [22,44].

However, there are some important historical and cultural differences in the NIS that have evolved in Australia and China. First, China's rapid science, technology and economic catch-up to the developed countries since the late 1970s [28,45] reflects the recent development of institutional structures that stands in contrast to the Australian experience [20]. Second, socio-political and cultural factors mediate between Chinese scientists and those of other backgrounds. For example, Cao points out that Chinese scientists who have been living abroad for a long time can consider the relationship system in China as a cultural barrier making it difficult for them to re-adapt, thus affecting their decision of returning to China to work [46]. These differences can also serve as a motivation for scientists to develop relationships across national borders. For example, given the fact that most scientific publications are published in the English language (see [47]), in light of the language difference between Australia and China, there has been, as this paper will show, an increase in the number of co-publications between the two countries.

The social process of collaboration is a complex process. It is not simply the interactions between individual scientists and their networks, although these are very important. Governments and their institutions are also part of the process. These institutions are potentially driven by different agendas for promoting international collaboration.

As noted in the introduction, mobility is an important aspect of relationship building between scientists (see also [6,27,48,49]). According to Mahroum, 'scientific mobility is a process of networking and extending one's social space' [50, p.26]. One of the outcomes of the networking activities can be international science collaboration. Scientists are mobile and they move from country to country, from institution to institution, within their networks, in building their careers [50,51]. Networks established through this process help to fulfill expectations of individual scientists and institutions in the NIS. For example, Delicado found that the reputation of international institutions was the most important factor considered by Portuguese scientists in making decisions about where to move globally [52]. Ciumasu found that while a large number of Romanian scientists prefer to stay abroad, the networks they have with their peers in their home country remain important [53].

The networks of the Portuguese and Romanian scientists discussed above have a diaspora context (see [54]). Meyer and Wattiaux referred to this as diaspora knowledge networks (diaspora KNs) [48]. They explained that a diaspora KN is:

> … a subset of the numerous international knowledge networks that have long existed in the S&T sphere and that have multiplied and expanded in the last twenty years.
>
> [[48, p.4]]

The present study considers diaspora KNs as one aspect of dispersed knowledge networks (dispersed KNs). Welch and Zhang [12], and Hugo [31] confirmed the relevance of diaspora KNs for the study of science linkages between Australia and China. Hugo's study revealed that of the 239 China-born academics in Australia included in the survey, the majority of them continued to maintain close links with old ties in China [31]. His findings showed that physical visits and long distance phone calls to the home-country were two important avenues utilized by this group for maintaining connections. The high tendency to connect with their home country and the search for cultural and social belonging as indicated by his study, to some extent, reflect the effect of culture on the networking behaviors of Chinese people across national boundaries. There is also an outflow of scientists from Australia [55,56] and it is likely that similar home country connections are maintained when these scientists move off shore. The global flow of knowledge is thus influenced by both mobility and culture.

Ziman's study of the United Kingdom academic environment offers some interesting insights into how scientific operations are a complex 'system of markets' in which interests are fulfilled for different actors and institutions [57]. A number of other researchers have also drawn attention to the social processes embedded in science (see for example: [38,58]). Vinck has more recently argued that the social processes that underpin the way scientific work is conducted can be understood as a system of exchange:

> … free gift giving, with its attached obligations, is the central mechanism in the science exchange system from which a community is built up … along with its values ….
>
> [[59, p.121]]

Vinck goes on to explain that the way the review and publication system works in science is underpinned by a giving and receiving form of relationship that coincides with the rationale behind exchange [59]. The value of scientific work that is to be published relies on the quality of the work itself and also the acceptance of that work by peers in the evaluation process [59]. Strange has also observed that credits associated with scientific publishing such as a co-authorship opportunity are sometimes given away as gifts in rather explicit forms [60]. In a similar way, Grieger further noted that:

> [including the name of another as author] … often occurs with the aim of pleasing somebody so as to obtain some benefit, or as a means of granting some advantage to persons connected with the author (such as relatives or friends, etc.). There is almost always some reciprocity linked to this type of conduct.
>
> [[61, pp.243–4]]

These examples challenge the traditional understanding of how scientists work and how scientific credits are accumulated and distributed. In essence, the 'free' gifts are not really free. But it is worth noting that publications are only part of international collaboration; they are one of the many elements being exchanged in the science community, circulating across one or more of the different 'markets' suggested by Ziman [57].

Ensign's study on knowledge flows among research and development (R&D) firms draws on Marcel Mauss' study of traditional society to explain the contemporary collaborative process [62]. Similarly, the present research also considers Mauss' analysis as useful for understanding the social behavior of scientists and social organization in science [63]. Drawing on his work, the present study proposes that the social process of collaboration is underpinned by the compulsory nature of giving, receiving and reciprocating. Heath, however, has argued against the use of the 'gift-exchange' proposed by Marcel Mauss on the basis of its practicality in the contemporary world and also whether free gifts really do not exist, challenging the compulsory nature of return [64]. It is beyond the scope of this study to verify the validity of the perspective of 'Spirit of the Gift' (see [65]). However, for the formation of STHC and consequently the NIS, it is the rationale behind the generalized system of exchange and its use in recognizing social activities traded outside economic markets that is of relevance for this study.

3. Combining the bibliometrics and the interview data

In order to investigate the underlying dynamics of collaboration between Australia and China, the present study uses interview data to investigate the formation of personal relationships and research networks between individual scientists. Interview respondents were identified from a bibliometric analysis of Chinese/Australian based co-authors. Interview data help to identify and explain scientists' motivations, aspirations, and career trajectory strategies with respect to international collaboration.

The interview data are useful for offering in-depth insights into how a network is constructed, why it is established and how they are sustained. However, the findings generated from interviews alone can be limited in showing the comparative context of international collaboration networks. That is, the comparative density and breadth of networks in terms of geography or discipline. For the purpose of this study, bibliometric analysis was important for overcoming such limitation of the qualitative method and also to pave the way for identifying dispersed KNs for further exploration of the collaborative process involved between scientists in Australia and China. In all, the mixed method was important for building more comprehensive insights that can help in the formulation of policies with respect to STHC.

3.1. Bibliometrics as the starting point for analysis

The total number of SCIE indexed articles identified in the Web of Science (WoS) was close to 20 million between 1980 and 2010 [66]. A detailed analysis of this data revealed that the United States (US) was in number one position responsible for the maximum number of 6,215,143 articles [66]. China, in fifth position, was associated with 1,226,329 articles between 1980 and 2010 [66].[2] Australia was ranked eleventh in the list with 502,521 articles published over the same years [66]. A large proportion of publications for each of the groups were co-authored papers. The globalization of science, in which both Australia and China appear to follow, contributes to the growth in scientific output for Australia, China and the world (see [1,7]).

The networks were not a simple two-way process as indicated by the bibliometric analysis. According to the WoS, Australia had 213 international partners in science (includes China by broad territory: the mainland, Hong Kong, Macau, and the Taiwan province) between 1980 and 2010 [67]. On the other hand, mainland China had 185 partners over the respective years [67]. The US was associated with the biggest group of international partners with co-authors from 257 different countries/territories [67]. In addition, the US was the most important partner in science to Australia and mainland China, associated with 57,155 and 73,496 co-authored articles, respectively [67]. By comparison, mainland China and Australia were ranked as the 7th and 8th key partner in science to the US for the years between 1980 and 2010, respectively [67].

A comparison of co-publication network between Australia and mainland China between 1981 and 1985 and 1995 and 2010 shows an expansion in the breadth of country coverage, the number of links and publication output.[3] Over the 1981–85 period, the co-publication networks between the two locations were made up of 32 co-authored articles, 53 links, and 14 network country/territory-nodes [67].

By 1995–2010 there were 10,082 co-authored articles published between Australia and mainland China [67]. The total number of country/territory nodes in the network has increased by more than eight times to 131 since the earlier period. The collaboration networks between Australia and China in the latter period were also more global with connections to a larger number of countries [67]. Fig. 3-1 shows the co-publication network between Australia and mainland China's top 20 international partners between 1995 and 2010.

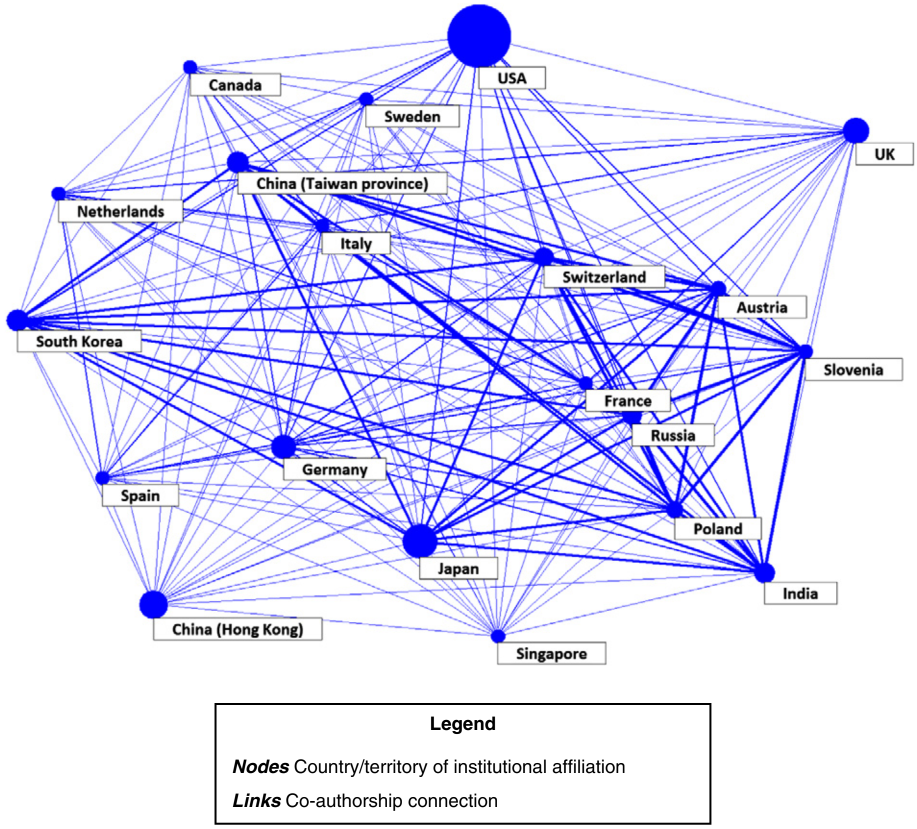
The nodes shown represent co-authors' country/territory of institutional affiliation. The different sizes of the nodes indicate the comparative differences in the number of co-authored articles associated with each location.[4] The links connecting the nodes depict a valid connection by co-authorship. The thickness of the lines indicates similarities between the co-authored articles associated with any two nodes. However, the comparative thickness of the links is less relevant for the present study. The top 20 partners shown in Fig. 3-1 are responsible for 32% of the overall network of co-publication output between Australia and mainland China from 1995 to 2010 [67]. The US remains the most preferred international partner for the two countries. The 1,397 co-authored articles associated with the US represent a network that includes 120 of the other 128 network locations of the overall network [67]. Likewise, Japan is also responsible for a large number of 108 other locations.

The complex system of nodes and links shown by the bibliometric analysis suggests sharing and learning between countries as an opportunity made possible through international collaboration. For example, a scientist (or a group of scientists) in Italy may have never met their partner(s) in Russia, but they may have undertaken collaborative work as part of a broad project through other scientists they do know in Australia and mainland China (see Fig. 3-1). These channels can be utilized as

[2] Of this group, 890,523 articles were published with at least one mainland Chinese author by institutional affiliation.

[3] Vantage Point was used to assist the bibliometric analysis and also for presenting the co-publication network maps.

[4] The comparative sizes of the nodes are presented in terms of the number of co-authored articles as a proportion to the total of the dataset. If a big difference exists between the biggest node and the other comparatively smaller nodes, then differences of the comparative sizes between the smaller nodes become visually indistinguishable.



N.B. all of the nodes shown are connected to both Australia and mainland China through multi-lateral co-authorship.

Source: compiled by the Author (Vantage Point), data from Thomson Reuters (Scientific) Inc., Web of Science (SCIE), accessed on various dates in October,2011.

Fig. 3-1. Co-publication network between Australia and China (mainland), between the top 20 partners by country/territory of institutional affiliation, 1995–2010 (total number of co-authored articles from the top 20 partners: n = 3206).

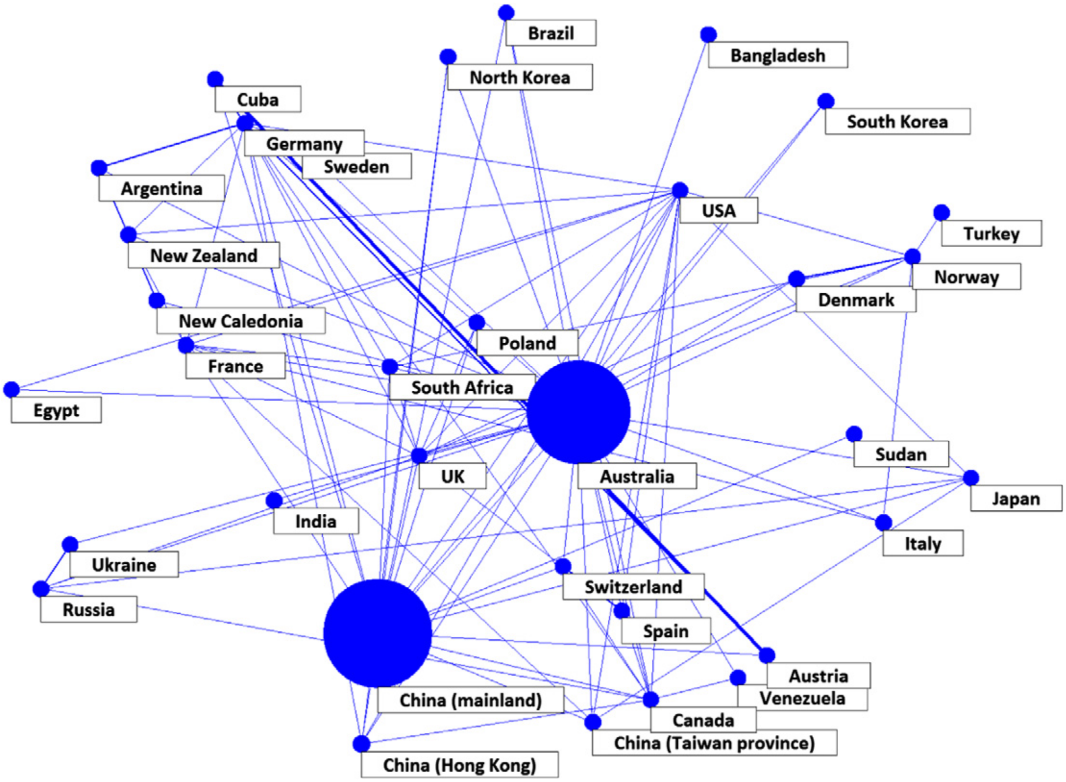
sources for countries, institutions and individual researchers to gain access to the flow of knowledge [24].

3.1.1. From national to individual level of bibliometric analysis

Research articles were identified for 64 out of the 79 interview respondents. The number of articles from the overall group increased from an annual average of 15.6 over the ten year period of 1980–89 to 186.6 over the 2001–10 period; the number of international science partners, as indicated by the respondents' publication networks, has increased from 5 in 1980 to 31 in 2010 [68]. A detailed analysis of this data showed that international collaboration between Australia and mainland China has also expanded [68]. This was reflected by the increase in co-authored articles published between the two national entities, from just one record starting in 1996 to 76 in 2010 [68]. These data also revealed that the number of countries/territories included in Australia and mainland China's collaboration network has also expanded over the period, from one bilateral collaboration only in 1996 to an expanded network of 17 international partners in 2010 [68].

An analysis of bibliometric records for all the respondents working in the earth sciences confirms the expansion of international collaboration in science, and the increasing importance Australian- and Chinese-resident scientists have to each other with respect to STHC. Four of the earth scientists were based in mainland China and the other half were based in Australia. Fig. 3-2 shows the publication networks of this group of respondents between 1980 and 2010. Publication outputs from this particular group have increased from an annual average of just 2.4 articles over the 1980–89 period to an average of 46.7 over the 2001–10 period [68]. As shown by Fig. 3-2, the two biggest national bases for generation of scientific publications were mainland China (number of articles = 373) and Australia (number of articles = 357) [68]. Of the total 585 articles published by the eight earth scientists over the 31 years from 1980, 173 were co-published between researchers in Australia and mainland China [68]. But this co-authorship activity had only started more recently in 1996.

Fig. 3-2 shows a series of interconnected micro-networks to exist for this particular group of scientists. Micro-networks can have different combinations, which can be a reflection



Legend

Nodes Country/territory of institutional affiliation

Links Co-authorship connection

N.B. although the two biggest nodes representing Australia and mainland China appear identical in size, the actual number of articles associated with each node is different. Differences also exist between the small nodes shown. These differences are not reflected above due to the way Vantage Point calculates the size of the nodes (see Footnote 4).

Source: compiled by the Author (Vantage Point), data from Scopus (physical sciences, life sciences and health sciences) of Elsevier B.V., accessed on various dates in October and November, 2011.

Fig. 3-2. Publication network of interviewed earth scientists by country/territory of institutional affiliation, 1980–2010 (total number of articles from the eight respondents: n = 585).

of the scientists' career trajectories and differences in the way connections were established at the individual level. One example of this is the triangular network that exists between Argentina, New Zealand and Germany (see Fig. 3-2). The study considers smaller networks embedded in scientists' (co-)publication network such as this one as one aspect of dispersed KNs. This suggests the complexity involved in international collaboration even at the individual level with respect to dissemination of research output. The networks shown for the earth scientists reflect potential avenues available for gaining access to STHC. However, little is known as to how the scientists shown by Fig. 3-2 gain access to, and deepen collaborations to maximize research. What underpins the construction of such network at the individual level? Building on the bibliometric analysis, the interviews conducted for the present study serve to provide a more comprehensive understanding of the social dynamics of collaboration.

3.2. Using interview data to complement bibliometrics

This section contains two sub-sections. The first presents a brief description of the methodology for the qualitative component of the work undertaken by the present study. This is followed by Section 3.2.2; it discusses the social processes that underpin co-authorship activity in the context of international scientific collaboration.

3.2.1. Methodological insights from the fieldwork

A total of 79 interviews were conducted face-to-face in either English or Chinese; some were carried out by phone, or via Skype.[5] Respondents were asked about their education background, career trajectory and international scientific collaboration activities. Some open-ended questions offered the respondents more freedom to express their views on issues otherwise not directly raised by the researcher (see [69,70]). The interviews were translated by the present author for analysis. The data were analyzed from different theoretical perspectives discussed earlier in the paper.

Debates about objectivism and subjectivism [71] meant that there is a need to think about the reliability of some of the answers from the interviews. So does the interview respondent really mean what is explicitly said? To answer this, a five-point scale comparative rating of the responses is applied to the 79 interviews. The results were drawn from the interviewing experiences of the present author, based on a comparison between the conversations on an overall basis. The purpose of this was to draw some general reflections on each respondent's openness in revealing their experiences with respect to international scientific collaboration. The analysis also drew on fieldwork observation notes.

The study also measured the openness of the respondents by the straightforwardness of responses. For example, in situations where certain respondents had tried to avoid answering certain questions and/or did not allow the conversation to be recorded would be ranked as comparatively less open. However, the way a question is put forward in a specific context and also any insinuation a respondent might saw as embedded in a question can also affect one's openness towards a particular issue. The cultural and political experiences of respondents can affect their openness in the interviews. According to Pye,

> [c]ultural sensitivity about the dangers of direct confrontations, along with their anxieties about explicit disagreements, has made the Chinese hypersensitive to conflicting bureaucratic or institutionalized interests.
>
> [[72, p.82]]

This could be a possible explanation to why some of the Chinese resident participants were more reluctant in commenting about the level of institutional support they received for international scientific collaboration. But nonetheless, the result shows that 61 out of the 79 interviews are ranked as at least relatively open.

There were a few distinguishable trends in the context of data collection and organization. Firstly, referral has helped in the data collection in both Australia and China. Secondly, differences in cultural and political norms call for a need to interpret the meaning of response according to the context in which it was said. For example, the term *guanxi* literally means relationship(s) but in some cases it was also used with a greater cultural emphasis — implying the deeper values and social obligations it carries in the Chinese cultural context (see [73]). The fieldwork experience of the present author – as a Chinese born Australian – showed that cultural similarity can potentially help to induce a sense of trust and conversation convenience in the interviews. For example, being able to communicate in the language the respondent prefers, in either English or Chinese, has helped in allowing certain cultural phrases to be more easily communicated across. This includes the use of Chinese idioms and proverbs. For example, one Chinese resident scientist described the extent to which she is familiar with international visits with the idiom of ‘pushing a light cart on a familiar road’ (*qing che shu lu*[6]).

In order to investigate these issues further, some examples were selected from the overall sample of interviews conducted with collaborating scientists in Australia and China.[7] The representative cases below illustrate why qualitative outputs are of importance in revealing the underlying social dynamics of international scientific collaboration.

3.2.2. Interview insights: fulfilling different expectations through scientists' networks

The interviews support the proposition that the social dynamics behind international collaboration deal with more than scientific and technical skills, knowledge and technologies. A wide range of professional and social expectations are at play that influences the collaborative behavior of scientists. The national research evaluation system steers scientists to undertake research towards fulfilling the expectations of their employers and the state [75]. Scientists are rewarded by their employing institution for their outputs in accordance with measures of research performance that the states recognize. One such output is publications [75–78]. Scientists are rewarded for what they offer (or repay) to their employing institution. In this sense publications are one of the items exchanged by scientists for the ‘credits’ and ‘merits’ returned through the research evaluation system. For example, a Chinese resident earth scientist explains what motivated her to collaborate:

> After all, English is not our ‘mother tongue’; we need to publish papers in international journals, because scientific research has developed to a stage where you must compete with others in the international arena and so you must use English … What [my collaborator] … has helped me with the most over the decade has been on English improvement. We had written many papers over the years and she helped us to ‘polish’ them (Chinese resident earth scientist, 2010).

This example shows that language was a motivating factor embedded in international scientific collaboration as part of a reward system in place from the evaluation of scientific abilities. The SCI (Science Citation Index) or SCIE, to some extent, acted as a common ‘accreditation place’ in which such abilities are measured, compared and competed (for example, ranking of publications by citation). This reflects a situation where the

[5] In order to preserve anonymity of the participants, some interviews were paraphrased or changed. However, the intended meaning of the interviews were not changed. In addition, the gender used in the paper does not represent the true gender of the participants. The present author has used the feminine gender in all relevant places.

[6] This means to easily get something done based on past experiences [74, p.972].

[7] Of the total 79 interviews, 12 were drawn on a convenience sampling from the WoS (SCIE) by authors' work-affiliated addresses and 67 were identified on a snowball sampling by fieldwork method in Australia and China.

China-side had a clear agenda as to what to expect from international collaboration. In a way language can be seen as acting like a 'glue' in drawing Chinese scientists closer to their Australian partners and vice versa. The interviews show that publishing co-authored articles in high-ranking journals is recognized by scientists as a visible, direct and more or less, expected benefit to gain from international collaboration.

The opportunity to publish papers exists in some networks as a way to assist the formation and maintenance of collaborative relationships. Four Australian resident scientists have taken an explicit role in assisting the Chinese with writing publications. They worked in the medical and health sciences, biological sciences and earth sciences. Both sides were aware of the likelihood of receiving something in return for the help provided (see [65]). However, some were more direct and explicit than others. For example, one of the informal but expected roles of an Australian resident biologist was to ensure collaborators get what they want. One of the key incentives helping to sustain the network appeared to be the opportunity to publish papers in the SCI or SCIE indexed journals. The Australian respondent discussed the exchange in the following terms.

> The ranking of authorship should be based on each researcher's contribution, but visitors from China sometimes have 'special demands' where they need to be the first author no matter what. … So there is some conflict in the area of intellectual property. Fortunately I have a large number of draft articles already written up from before; this means I would sometimes make some personal sacrifices to satisfy the demands of my organization and people in China. … There is a time restriction for them in China to publish papers, so I know sometimes the China-side is anxious about getting a paper published on time. This means I also need to hasten other scientists here to fulfill their need … (Australian resident biologist, 2010).

The sort of time constraint this biologist referred to was related to the pressures coming from China's research system, where publications are closely tied to a career reward system (see also [78]). For example, a Chinese resident medical scientist was faced with the urgency of fulfilling a minimum institutional requirement of publishing in the SCI in order to graduate from her PhD course and the connection with that biologist was clearly a major assistance.

> My collaborators in Australia have published many articles in the SCI, but it has been really hard for us here. One reason is that they are in an English speaking country, so it would be easier for them to write it in the language required. This is the primary reason. The other reason is that they are better at data management. They are very strict with the sample collection; all the sample details were recorded at the time of collection, to be able to build a comprehensive collection of patient records can help you write better publications. But in China, may be everyone is all too busy focused on clinical examination, people have not paid enough attention to the data collection and organization (Chinese resident medical scientist, 2010).

This shows the important role of publications as an element underpinning the collaboration between Australia and China for this particular network. The offer from the Australian side is actually made possible by a team effort where other scientists at the Australian research institute were also involved in the process.

Scientists at both ends of the Sino-Australian network seemed to understand that: firstly, publication is a credit accumulated in the process of international collaboration rather than a concluding point as the bibliometric analysis tends to imply. Secondly, writing a paper together is a way to draw scientists closer together academically and socially, and potentially a method for strengthening relationships. Thirdly, scientists are part of a broad social exchange system where favors are offered and subsequently expected to be returned. The Australian scientists who presumably took a bigger role to ensure the manuscript was published are likely to get something in return at some time in the future.

The following example shows how publication is being offered, and expected for return, in the context of international science collaboration in a medical scientific network.

> [Our collaborators in China] … want publications but they are reluctant to do the writing; they are happily to recruit patients but they want us to 'ghost-write' for them. I think you probably find that true quite a lot. … So we help them for reviewing their papers or even for some of the high professors, writing their papers. But they get first authorship because they contributed so much to the study. … They are academics and they get a lot of high quality publications in English journals. They would never get that in China because there is not that type of funding for them to generate the publications themselves (Australian resident medical scientist, 2011).

This example captures the essence of indirect and direct exchange between scientists, research institutes and hospitals in Australia and China that underpins an international project in public health. The Chinese data is a major contribution to the whole project. The nature of exchange is clear: the Australian side gives away some of their intellectual property 'credits' in order to ensure their access to certain resources through the Chinese scientists.

The examples show that the opportunity to publish in top journals is brought to light as something more than just a way for scientists to disseminate results. The Australian scientists help out their collaborators for something else in return. That something being 'exchanged' between scientists does not have to be equal by value and by form.

The idea of scientific output between scientists, their institutions and the broad science system as a form of exchange is not entirely new (see [59]). But the findings of the present study extend the analysis by documenting the social process through which the exchange takes place. Scientists are consciously engaging in the process in many different ways. The above discussions are examples of this. Scientists' choice of exchange is affected by matching and balancing expectations of individuals and institutions. They not only need to consider the likelihood of their own expectations being fulfilled for what they offer through collaboration, but also the likelihood of their collaborators and their organizational employers in accepting such offers.

4. Discussion and conclusion

This article shows how a mixed-methodological and analytical approach can be used to document and explain the social processes of international scientific collaboration. In light of forces of globalization and the advancement of information technology, the mobility of scientists is an important driver of the expansion of global scientific connections. China's increasing dominance as a key player in science in terms of the number of co-authored articles published in the SCIE needs to be recognized as a reflection of the nation's contribution to the global science arena and also strengthened linkages in science worldwide. The contributing factors to such dramatic growth are complex and are potentially resulted from the country's huge economic growth and changes in the S&T sector since its gradual 'opening-up' of its political system starting three decades ago. International scientific collaboration is an outcome of these mixed efforts. However, little is known about the underlying social dynamics of international collaboration. The study has argued that international science collaboration needs to be recognized as an organic process through which scientists, institutions and states exchange credits.

From a methodological perspective the study shows that bibliometric analysis enables an investigation of international collaborative networks by identifying the location and authorship from dispersed knowledge networks. The bibliometric analysis revealed an increasing rate of co-publication between Australia and China, and also that such collaborative networks are more complex than a simple two-way process.

Building on the bibliometric analysis, valuable insights were generated from interview data. From the interview analysis it was argued that the social process of collaboration is underpinned by a system of exchange. Through this process scientists and their institutions are able to fulfill their expectations and obligations. These expectations and obligations include motivations for building their own career as well as answering to the need of their employing institution and the NIS in which the institutions are based. Publishing research results according to the norm and rules of the domestic research performance evaluation system is an example showing scientists are not acting alone in the collaborative process. The interview findings suggest that publications were treated by scientists as an element of exchange to strengthen relationships rather than just a way to disseminate results from scientific discoveries. Research outputs such as publications are only one of, although arguably the most visible, the items exchanged through the collaborative process. The analysis reveals that it is not simply formal scientific knowledge that is being exchanged but a broad range of knowledge attributes including, contextual information, micro-organizational capabilities and social and technical skills. This paves the way for thinking about how international collaboration functions in light of scientists' mobility and globalization.

Understanding international scientific collaboration as a system of exchange carries implications for the management of policies directed toward enhancing national innovation systems. Scientists engage other scientists, institutions, and national systems of innovation as if national borders do not exist. In that sense, the dispersed knowledge networks through which the interactions occur are transnational. Policies formulated for developing scientific and technical human capital need to continue promote mobility while also addressing other social issues that can affect international collaboration. For example, one of these can be increased funding for research exchange programs with the aim of creating opportunities for personal relationship and trust building between scientists in Australia and China. While quantitative measures of research output can help to explain the context of international collaboration, increasing focus needs to be given to qualitative techniques for the establishment of a more complete information base for the formulation of future science, technology and innovation policies.

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Xiao Si Niu is a PhD candidate at the School of Business at the University of Western Sydney. Prior to the commencement of his doctoral research, he has completed a research at the Bachelor Honors level that focused on an investigation of the implications of policies for Chinese scientific diaspora.