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Scientific collaboration formation: network mechanisms, bonding social capital, and particularized trust in US-China collaboration on COVID-19-related research

John P. Haupt[1] · **Jenny J. Lee**[1]

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Abstract
Given the disruptions COVID-19 caused to normal research processes, including international collaboration, this study sought to understand scientists' experiences collaborating internationally during the pandemic on COVID-19-related research. Specifically, it explored US scientists' tie formation and reasons for international research collaboration with Chinese scientists. The study employed a sequential exploratory mixed methods design collecting interview and survey data from US scientists who co-published articles related to COVID-19 with Chinese scientists. The findings revealed the role of network mechanisms, such as transitivity, opportunity of contact, and homophily, in promoting relationship formation and maintenance. Moreover, they showed the greater role that bonding social capital played in helping scientists access valuable knowledge, skills, and resources to enhance their research potential. Lastly, they demonstrated how particularized trust based on prior interactions and experiences encouraged relationship formation and collaboration between US and Chinese scientists. Together, these results provide new insights in informing future policies and guidelines related to supporting international collaboration and, ultimately, shared pandemic challenges.

Keywords COVID-19 · International research collaboration · Social capital · Particularized trust · China · United States

Introduction

Over the last several decades, the USA and China have emerged as the top two collaborating countries in global science (Haupt & Lee, 2023). In 1996, the USA and China collaborated on 2128 articles, while in 2020, they collaborated on 62,904 (NSB, 2021). A key to this growth has been university linkages between the countries with Chinese student and scholar cross-border mobility playing a key role in developing links between the two countries (Cao et al., 2020). Moreover, the USA and China are the

✉ John P. Haupt
hauptj@arizona.edu

[1] Center for the Study of Higher Education, University of Arizona, 1430 East Second Street, Tucson, AZ 85721, USA

largest producers of science and engineering (S&E) research accounting for 38.3% of all publications in 2020, and the largest funders of S&E research accounting for 49% of global research and development expenditure in 2019 (NSB, 2021). Their enormous scientific capacities, resources, and global networks have long enabled them to both lead and attract cooperation both bilaterally and multilaterally. As such, they play central roles in global science, and collaboration between the countries contributes greatly to the global stock of knowledge, especially during times of crisis, such as the COVID-19 pandemic.

Despite such growing potential, heightening geopolitical tensions between the countries have spilled over into their science and technology cooperation, making the outlook of their scientific relationship appear uncertain. The USA has taken a strong bipartisan stance against China's interference in its science and technology enterprise while warning about potential intellectual property theft and economic espionage (US Federal Bureau of Investigation, 2022). The Chinese Communist Party has also taken their own measures to limit international collaboration, including greater governmental oversight on COVID-19-related research and the unrolling of revised researcher evaluation criteria that would prioritize domestic interests (Maher & Van Noorden, 2021). Early investigations into the impact of geopolitical tensions on collaboration between the two countries found that US-China collaboration continued to increase from 2016 to 2020 (Haupt & Lee, 2021; Lee & Haupt, 2020). However, more recent research utilizing bibliometric data and interviews with US scientists has demonstrated that these measures taken have had a chilling effect on US-China collaboration (Fuchs et al., 2021; Lee & Li, 2023; Wagner & Cai, 2022). In a survey of 1949 US scientists, Lee and Li (2023) found that US scientists, especially ethnic Chinese, have limited their collaboration and communication with scientists based in China due to concerns over the China Initiative and fears of US government racial profiling.

Geopolitical tensions between the countries were further exacerbated by the COVID-19 pandemic with the Trump administration blaming China for causing the pandemic and arguing that China was purposefully withholding information about the virus's origins (Rogers et al., 2020). Scientists raised concerns that these tensions may spill over into US-China health and medicine collaboration and limit both countries' capacities as well as the world's capacity to effectively respond to the pandemic as both countries were at the forefront of knowledge production related to COVID-19 (Aristovnik et al., 2020; Fry et al., 2020; Lee & Haupt, 2021a; Li et al., 2021). Thus, on top of the numerous challenges that disrupted scientists' abilities to work domestically and across borders, such as borders shuttering and institutions closing, making it difficult for scientists to physically congregate and access their labs (Myers et al., 2020), rising international strains had the potential to further stimy collaboration between the two countries.

There have been several studies that have examined US-China collaboration during the pandemic and specifically on COVID-19-related research. Such research demonstrated that US-China collaboration intensified at the start of the pandemic, but collaboration between the two countries waned as the pandemic continued (Lee & Haupt, 2021b; Fry et al., 2020; Cai et al., 2021; Wagner et al., 2022). Lee and Haupt (2021b) found that the two countries engaged in even higher rates of collaboration on COVID-19-related research compared to past years and on non-COVID-19 research during the early phase of the pandemic in 2020. Similarly, Fry et al. (2020) showed that the USA and China strengthened their research relationship on coronavirus research during the early phase of the COVID-19 pandemic increasing their total share of global coronavirus publications from 3.6 to 4.9%. Finally, as the pandemic progressed, Cai et al. (2021) and Wagner et al. (2022) demonstrated that US and China's collaboration rate dropped, and the USA and the UK became the top

co-publishers of coronavirus-related research. Both studies speculate that geopolitical tensions between the countries may have created obstacles that impacted scientists' capacities to collaborate.

While past research has provided valuable insight into output trends in US-China collaboration related to COVID-19 during the pandemic, most observations have been based on bibliometric data. There remains limited research beyond publication counts and that asks scientists directly about their experiences collaborating internationally during COVID-19 and directly on COVID-19-related research. Particularly, less is known about tie formation between scientists who collaborated internationally on COVID-19-related research during the pandemic as well as their reasons for choosing to collaborate internationally. Thus, this study builds on these prior studies by exploring these two facets of research collaboration, tie formation and reasons for collaboration, between US and Chinese scientists who collaborated on COVID-19-related research during the pandemic. It additionally seeks to understand the importance of ethnic ties in sustaining these collaborations based on past research findings (Cao et al., 2020; Jin et al., 2007; Sun & Bian, 2012). While the pandemic has subsided, other global challenges and geopolitical conflicts may arise in the future, and understanding why and how scientists work together across borders during times of crisis will remain a fundamental question for global science.

Scientists' social networks and the role of network mechanisms, social capital, and trust in research collaboration

This study frames international research collaboration in relation to the human and social capital scientists employ while engaging in research (Bozeman & Boardman, 2014). Scientists possess knowledge, skills, resources, and social networks that support their knowledge production capabilities (Corley et al., 2019). Regarding the latter, there are various network mechanisms that have been shown to influence tie formation between scientists. Scientists tend to form ties through opportunity of contact, or form ties with others who are in close vicinity and share the same association, such as classmates or co-workers, or participate in joint activities, such as conferences (Beaver, 2001; Melin, 2000). Moreover, scientists tend to form ties with scientists who have ties with the same other scientists following the network property of transitivity (Dahlander & McFarland, 2013; Zhang et al., 2018). Additionally, studies have shown that preferential attachment plays an important role in tie formation as scientists will establish relationships with others who are already well connected to enhance their own reputations or gain access to resources (Wagner & Leydesdorff, 2005). Lastly, scientists tend to form ties to similar others or through homophily (McPherson et al., 2001). Such ties may form between scientists who share sociodemographic characteristics (e.g., age, gender, education, ethnicity), research interests, and values and knowledge backgrounds (Dahlander & McFarland, 2013; Zhang et al., 2018). In relation to US-China collaboration, research has shown how shared ethnicity as well as shared language and culture have played important roles in establishing and maintaining research ties between overseas ethnic Chinese scientists and ethnic Chinese scientists based in China (Cao et al., 2020; Jin et al., 2007; Sun & Bian, 2012; Suttmeier, 2008).

Scientists' networks provide them with varying degrees of social capital from which they can draw. Social capital is the actual and potential resources available to scientists through their social networks that can mobilized as they engage in research processes (Nahapiet & Ghoshal, 1998). The literature differentiates between two types of social capital, bridging and bonding, that influence resource mobilization (Putnam, 2000).

Bridging social capital refers to capital embedded in inclusive, out-ward oriented networks characterized by extensive and diverse weak ties, such as those formed between scientists who may occasionally interact as part of their memberships in professional organizations (Ceci et al., 2020; Levy et al., 2013; Putnam, 2000). Bridging capital helps individuals link with external resources, access new information, identify novel opportunities, and partake in generalized reciprocity (Levy et al., 2013). On the other hand, bonding social capital refers to capital embedded in exclusive, in-ward oriented networks characterized by strong within-group ties and tightly knit, emotionally close relationships, such as those formed between co-workers or former classmates and colleagues (Ceci et al., 2020; Levy et al., 2013; Putnam, 2000). Bonding capital provides individuals with access to valuable and limited resources as well as emotional and psychological support (Levy et al., 2013). Despite the distinction, bridging and bonding social capital are considered complementary and synergistic as scientists possess various relations within their networks which give them access to different yet complementary resources that may interact to increase the potential of the other (Ceci et al., 2020; Levy et al., 2013).

Studies have demonstrated the various ways scientists mobilize resources in their networks through collaboration to enhance their capacities to engage in research. Scientists have been shown to collaborate for access to other scientists' expertise, to equipment or data that they themselves do not possess, and to competitive research funding (Beaver, 2001; Bozeman & Corley, 2004; Melin, 2000). Moreover, collaboration has been shown to provide scientists with opportunities to pool diverse knowledge, skills, and resources to research larger, more complex problems that they would not have been able to tackle alone (Beaver, 2001; Gibbons et al., 1994; Melin, 2000; Thorsteinsdottir, 2000). Scientists also collaborate to learn through the collaboration process and advance their own knowledge and skills related to their current field or a new field of study (Beaver, 2001). Furthermore, scientists are motivated to collaborate because it provides an opportunity to mentor students or colleagues (Bozeman & Corley, 2004; Beaver, 2001), who also potentially serve as key resources.

Another important feature of social networks that has been shown to play an important role in promoting and maintaining collaborative ties among scientists is trust (Bozeman et al., 2016; Melin, 2000). Studies linking trust and social capital identify two distinct types of trust, particularized and generalized (Patulny & Lind Haase Svendsen, 2007). Particularized trust is trust toward others with whom one is near and interacts with regularly (Uslaner, 2002). This trust is based on an evaluation of one's social environment and experiences interacting with others and tends to be among members of groups (Freitag & Traunmüller, 2009). Particularized trust corresponds with bonding social capital and is characterized by an emotional connection, which is believed to play an important role in the maintenance of ties (Patulny & Lind Haase Svendsen, 2007; Igarashi et al., 2008). In contrast, generalized trust is trust in other people more generally, which includes trust in strangers (Uslaner, 2002). This trust is based on a person's predisposition rather than specific experiences (Freitag & Traunmüller, 2009). It is associated with bridging social capital, and it supports linkages between members of different groups within a network (Patulny & Lind Haase Svendsen, 2007; Igarashi et al., 2008). It is considered to play a key role in the formation of ties more so than the maintenance of ties (Igarashi et al., 2008). Thus, the type of trust exhibited between researchers may influence their reasons for collaboration as well as the type of capital they are able to mobilize during research processes.

Methods

This study is part a larger project that sought to understand the nature of US-China collaboration on COVID-19-related research during the pandemic. This paper specifically focuses on network formation and scientists' social capital mobilization from the perspective of US scientists who collaborated with scientists in China. Three questions guide the examination of US scientists' collaboration experiences:

1) To what extent did US scientists previously collaborate with their Chinese co-authors?
2) In what ways did the relationships between US and Chinese scientists develop?
3) What were US scientists' primary reasons for choosing to collaborate with their Chinese co-authors on COVID-19-related research?

This study employed a sequential exploratory mixed methods design (Bazeley, 2018) and involved two phases. First, qualitative, semi-structured interview data were collected and analyzed to provide in-depth insights into US scientists' experiences collaborating with Chinese scientists on COVID-19-related research during the pandemic. Then, based on initial findings from the interviews, a survey was developed to collect quantitative data to help generalize the interview findings by providing evidence of similar patterns among a larger population of scientists. Both interview and survey findings were used to answer the research questions.

Phase I: US scientist interviews

Phase one involved interviewing 50 US scientists who served as corresponding authors on co-publications with Chinese scientists. This sample was obtained by utilizing Scopus (Elsevier, 2023) to identify US-China bilateral publications on COVID-19-related research published between January 2020 and January 2022. In Scopus, a search was conducted for all US-China bilateral publications on COVID-19-related research. COVID-19 publications were identified as those containing at least one of the following phrases, "COVID-19," "2019-ncov, "SARS-CoV-2," and "novel coronavirus," in their title, abstract, and keywords fields. Publications were further limited to include only articles, or "original research or opinion," most commonly found in peer-reviewed journals (Elsevier, 2023, p. 11), within STEM-related fields. Using this search query, article metadata were downloaded for 979 articles, and 440 US-based scientists who served as corresponding authors were identified. Due to an initial low response rate, corresponding authors were invited in order from the earliest publications to the most recent publications to participate in the study until a sample of 50 scientists was obtained. A total of 346 scientists were emailed before the sample of 50 was achieved. The 50 scientists interviewed were all employed in large, research universities. They comprised diverse STEM fields across academic ranks. Thirty-three were of Chinese descent. Almost all, except for 5, were male.

All semi-structured interviews took place via Zoom between August 2021 and March 2022. Interviews were video and audio recorded and lasted between 25 and 65 minutes. As much as possible, interviewees were matched by their shared race with the research team member who interviewed them, as determined by their last names. Interview questions were based on several themes derived from previous research on research collaboration related to tie formation and motivations for collaboration (e.g., Beaver, 2001; Melin, 2000;

Sun & Bian, 2012), the impact of COVID-19 on scientists' research productivity (Myers et al, 2020), and the impact of the China Initiative on US scientists (Lee & Li, 2023). Most questions were related to interviewees' experiences collaborating on the specific article on which they were corresponding authors; however, questions also focused on the experiences of interviewees while conducting research during the pandemic as well as collaborating with Chinese scientists in the more recent political climate.

Interview data were transcribed and coded using NVivo at two points in time. During both times, thematic analyses were conducted to identify underlying patterns in interviewee responses in relation to the research questions (Braun & Clarke, 2006). More specifically, analyses focused on how relationships formed, the length of relationships, experiences collaborating, and the implications these had regarding the social network mechanisms that promote tie formation and maintenance and the types of social capital present in the relationships. Additionally, analyses focused on why scientists chose to collaborate and its implications about resource mobilization and other factors that may promote collaboration, such as trust and shared ethnicity. Interview data were initially coded at the end of 2021 after 29 interviews had been completed. This initial coding was conducted to develop the survey instrument for the second phase of the study (see "Phase II: US scientist surveys" below). Then, after all the interviews had been conducted, all 50 interviews were analyzed together in relation to the themes that emerged during initial coding, while simultaneously being open to new themes that may have emerged with the inclusion of the new interview data.

Phase II: US scientist surveys

Phase two involved surveying 91 US scientists who co-published articles with Chinese scientists related to COVID-19. To obtain this sample, the names and emails of 980 US scientists were gathered from Scopus metadata and publicly available online information. These scientists included the 440 US scientists who served as corresponding authors from the 979 articles used to obtain the interview sample. They also included an additional 121 US scientists who served as corresponding authors on 303 US-China bilateral co-publications related to COVID-19 published between February 2022 and April 2022. Lastly, due to an initial low survey response rate, the names and emails of 419 US scientists who did not serve as corresponding authors on the articles were also gathered. The final sample reflected the interview sample with respect to a high concentration of males in leading research universities throughout the USA, and 53.8% identified as ethnic Chinese.

The survey was developed based on themes that emerged during the first 29 interviews with US scientists (see above). The survey consisted of close-ended and open-ended questions related to the specific article identified in Scopus which they co-authored. Questions were related to the following themes: (1) relationship with Chinese scientists, (2) reasons for collaborating with Chinese scientists, (3) roles and responsibilities of the US scientists, (4) benefits of collaborating with Chinese scientists, and (5) challenges to collaborating with Chinese scientists. Respondents were also asked to answer a series of demographic information questions.

For this paper, survey data on relationships with Chinese scientists and reasons for collaborating with Chinese scientists were analyzed using descriptive statistics to examine differences in ratings for the different survey items. Then, the same descriptive statistics were calculated for two groups of scientists: (1) those who self-identified as ethnic Chinese and (2) those who did not. Using these data, Mann-Whitney U tests were performed to

determine if reasons for collaborating with Chinese scientists differed based on these two groups. Mann-Whitney *U* tests were used instead of independent *t*-tests due to the lack of normality in the data (Field, 2014). Finally, after these analyses, the survey findings were examined in relation to the interview findings to confirm, reject, or modify the interview findings. This examination resulted in the confirmation of the interview findings, and thus, no further data collection was undertaken. For this article, as the survey results confirmed the interview results, the survey results serve as the primary data set, while the interview findings guide the interpretation of the survey results when appropriate.

Limitations

This study was conducted during a time of geopolitical tensions, asking about research on a politically contentious issue between the USA and China, all during the COVID-19 pandemic. Those engaged in especially sensitive topics, such as the source of the SARS-CoV-2 virus or how it was being managed by their governments, may have elected not to participate. Additionally, those whose research was too early in the process to discuss might have opted not to respond. The data for the study was collected during the China Initiative, which was heavily criticized for potential racial profiling against those of Chinese descent (Winds of Freedom, 2021). Thus, some ethnically Chinese scientists may have declined the study invitation resulting in potential response bias or amended their answers due to such fears, like past research on US-China collaborations during the same time period (Lee & Li, 2023). Although the Chinese interviewees were interviewed by a Chinese or other Asian researcher and were reminded that they could skip questions, such limitations are difficult to overcome in the current geopolitical context. Despite what remains unknown, the findings nevertheless provide new insights on an important concern about the future of US-China scientific relations.

Findings

The findings showed that most US scientists who collaborated with Chinese scientists on COVID-19-related research collaborated with Chinese scientists in their pre-existing research networks, with ethnic Chinese US scientists having longer relationships than their non-ethnic Chinese US counterparts. These relationships were mostly formed prior to the pandemic, oftentimes through a professional introduction or based on visiting scholars or students, with fewer by way of direct invitation. The top reasons for collaboration among both ethnic Chinese and non-ethnic Chinese US scientists included shared research goals/interests and personal trust.

Established versus new ties

The survey results on the length of time that US scientists knew their Chinese co-authors demonstrate that bonding social capital and particularized trust likely played greater roles in research collaborations than bridging social capital and generalized trust. Most scientists turned toward scientists in their pre-existing research networks to collaborate on COVID-19-related research as opposed to forming new relationships. The data show that 89.1% of scientists knew at least one of their Chinese co-authors prior to collaborating, while only 10.9% did not know them (see Table 1). Both ethnic Chinese and non-ethnic Chinese

Table 1 Length of time US scientists knew their Chinese co-authors

	All scientists		Ethnic Chinese		Non-ethnic Chinese	
Length of relationship time	*N*	%	*N*	%	*N*	%
Over 10 years	19	20.9%	13	26.5%	6	14.3%
5 to 10 years	20	22.0%	12	24.5%	8	19.0%
3 to 5 years	16	17.6%	6	12.2%	10	23.8%
1 to 3 years	18	19.8%	7	14.3%	11	26.2%
Less than 1 year	8	8.8%	4	8.2%	4	9.5%
I did not know them	10	10.9%	7	14.3%	3	7.1%

US scientists indicated they had long-standing relationships of 1 year or more with their Chinese co-authors, 77.5% and 83.4%, respectively. However, ethnic Chinese US scientists tended to know their Chinese co-authors for longer periods of time. Over half (51%) of ethnic Chinese US scientists knew their co-authors for at least 5 years compared to a third (33.3%) of non-ethnic Chinese US scientists for the same time period. Despite this difference, both groups of scientists had relatively strong ties with their Chinese co-authors based on prior collaborating experiences over the years. One ethnic Chinese US scientist discussed his long-term relationship with his Chinese co-author and the extent of their prior collaboration: "I have known [Chinese co-author] for about 6 years…Over the past 4 years, we have worked on 6 studies, 4 have already been published or accepted for publication, and 2 are under review."

Relationship formation between US and Chinese scientists

Data on relationship formation point to the role that network mechanisms as well as particularized trust played in relationship formation between US and Chinese scientists. Table 2 shows the most common way relationships formed was through being introduced to Chinese co-authors by a fellow researcher, or via the network mechanism of transitivity, accounting for 27.8% of the sample. In such cases, scientists likely relied on established trust based on their interactions and experiences with mutually known others in their networks as a basis for relationship formation. While this was the most frequently reported response, the proportion of non-ethnic Chinese US scientists who selected this response was greater than the proportion of ethnic Chinese US scientists, 35.7% and 20.8%, respectively. Moreover, a high proportion of US scientists formed their relationships with Chinese co-authors while in close vicinity and sharing the same association in the USA and in China, such as while classmates or colleagues. This closeness and shared affiliation likely promoted regular interactions through which close relationships developed and trust formed. A total of 20% of scientists indicated they formed relationships while Chinese co-authors were visiting scholars or graduate students in the USA, and an equal number of ethnic and non-ethnic Chinese US scientists indicated this to be true. Among the ethnic Chinese US scientists, prior relationships formed while in China were especially important. A notably higher proportion of this group's relationships with Chinese co-authors began as visiting scholars, classmates, colleagues, or students compared to their non-ethnic Chinese US scientist counterparts. Regarding the latter, one scientist explained:

> I reached out to some previous faculty members that I know at my undergrad institution to see if any of them would be interested in doing a collaboration project… They were also doing some related work. So, there was a shared interest. So, we started to talk about how we would go about the project. And then we did it. (PhD Student, Clinical Psychology)

Lastly, while there was a greater tendency for relationship formation to involve particularized trust, the data also show that relationship formation also involved generalized trust with 13.3% of scientists forming relationships with Chinese co-authors through direct invitation and 11.1% through chance meetings at conferences. In such situations, scientists' predispositions and willingness to trust others with whom they did not share an affiliation or have a relationship promoted relationship formation between them and their Chinese co-authors.

Reasons for collaborating internationally on COVID-19-related research

Scientists' reasons for collaborating also show how network mechanisms, specifically homophily, bonding social capital, and particularized trust played important roles not only in promoting but also in maintaining ties among scientists. Table 3 shows that the most highly rated reason that US scientists collaborated with their Chinese co-authors was because they had shared research goals or interests with their Chinese co-authors (mean = 4.56). Both ethnic and non-ethnic Chinese US scientists provided very similar ratings for this item, and the Mann-Whitney U test showed there was no significant difference ($U = 991.00$, $p = 0.896$; see Appendix) between the groups in their ratings for this item. Shared goals or interests formed the basis for all relationships between US and Chinese scientists, and this was true for scientists with previous collaboration experiences and those without them. In this way, homophily based on similar research interests played a key role in establishing and sustaining relationships among scientists. In most cases, interviewees explained that relationships were established due to overlapping research interests within

Table 2 How scientists' relationships formed with their Chinese co-authors and the type of trust involved

	All scientists		Ethnic Chinese		Non-ethnic Chinese	
	N	%	*N*	%	*N*	%
Particularized trust						
Introduced by another researcher	25	27.8%	10	20.8%	15	35.7%
Co-author was a visiting scholar/graduate student in the USA	18	20.0%	9	18.8%	9	21.4%
We were classmates or labmates	15	16.7%	10	20.8%	5	11.9%
I was a visiting scholar/graduate student in China	6	6.7%	4	8.3%	2	4.8%
Co-author was a colleague in China	2	2.2%	2	4.2%	0	0.0%
Co-author was my professor in China	1	1.1%	1	2.1%	0	0.0%
Introduced by a friend or relative	1	1.1%	1	2.1%	0	0.0%
Generalized trust						
Direct invitation to collaborate (no prior relationship)	12	13.3%	6	12.5%	6	14.3%
We met at a professional conference	10	11.1%	5	10.4%	5	11.9%

Table 3 Means and standard deviations for the reasons for collaborating scale items for all scientists, ethnic Chinese US scientists, and non-ethnic Chinese US scientists

	All scientists		Ethnic Chinese		Non-ethnic Chinese	
Reason for international collaboration	Mean	SD	Mean	SD	Mean	SD
Shared research goals/interests	4.56	0.69	4.57	0.68	4.55	0.71
Personal trust	3.98	1.22	4.00	1.30	3.95	1.13
Co-authors methodological skills	3.63	1.17	3.59	1.31	3.68	0.99
Access to data	3.56	1.45	3.84	1.31	3.22	1.54
Opportunity to extend generalizability of results	3.38	1.39	3.65	1.25	3.05	1.48
Opportunity to mentor colleagues	3.16	1.34	3.02	1.38	3.32	1.29
Communication in English	2.97	1.49	2.61	1.50	3.39	1.38
Ability to write in English	2.86	1.41	2.63	1.42	3.12	1.36
Knowledge about journals and publishing	2.77	1.35	2.59	1.34	2.98	1.35
Access to critical resources	2.74	1.52	3.02	1.55	2.41	1.43
Need for research labor	2.64	1.23	3.08	1.19	2.12	1.08
Opportunity to be mentored by colleagues	2.31	1.32	2.22	1.25	2.41	1.41
Communication in Chinese	2.22	1.53	2.90	1.66	1.41	0.84
Shared Chinese culture	2.20	1.38	2.78	1.49	1.50	0.82

Means are based on responses to a 5-point scale from 1 (not important) to 5 (very important)

their academic disciplines, and when COVID-19 emerged, they turned these shared interests toward investigating phenomena related to COVID-19 within their academic disciplines. A scientist explained how he and his co-authors shifted the focus of their ongoing project to COVID-19 due to lab closures on non-COVID-19-related research:

> The PI in China... his lab was interested in studying viral helicases flavivirus, not only SARS-CoV-2... So, the student originally come here to study the Zika virus helicase using our biophysical tools... and then, the pandemic started...the university shuts down, basically, you can only do things related to the COVID research, so we started a small project... related to our original idea...studying this COVID enzyme that we thought might be contributing to society because this enzyme is a potential drug target. (Associate Professor, Biology)

Beyond shared goals or interests, US scientists rated personal trust with their Chinese co-authors (mean = 3.98) as a highly important reason for why they collaborated. Again, ethnic and non-ethnic Chinese US scientists rated this item similarly, and the Mann-Whitney U test showed no significant difference ($U = 907.00$, $p = 0.500$) between the groups' ratings. Interviewees explained that trust was foundational to their willingness to collaborate and developed over time with their Chinese co-authors. This notion of trust developing over time corresponds closely with particularized trust as trust developed based on US scientists' experiences interacting with their co-authors as part of research projects. Scientists explained that trust was predicated on them being able to trust that their co-authors would produce work within expected time periods, that their co-authors would produce high-quality research, and that their co-authors were honest when reporting their data. One scientist explained:

> Trust, I mean that I don't think that [Chinese co-author] was able to cheat. For example, when she was doing something and she came to my office with the results, first of all, I will know if the results are wrong. Because of my experience, I will see that there is something wrong. But with her, mostly it was okay. You know, she is knowledgeable... and I was at ease to give her difficult problems to solve, and we were very successful in publishing in very good journals, top journals in our field. That's what I mean in that I trusted her. (Distinguished Professor, Mathematical Sciences)

Following these reasons, US scientists rated several reasons associated with an enhanced ability to engage in research as important reasons for why they collaborated with Chinese scientists. Given the length of most relationships and how most relationships formed, these findings demonstrate the importance of tie maintenance and bonding social capital in granting scientists access to valuable and limited knowledge, skills, and resources that enhance their research potential. US scientists rated their Chinese co-authors' methodological skills as the third most important reason why they chose to collaborate with them (mean = 3.65). There was no significant difference found in the ratings between ethnic and non-ethnic Chinese US scientists ($U = 972.50$, $p = 0.949$). Interviewees described their collaborations as complementary with Chinese co-authors having greater knowledge and skills or different knowledge and skills that were needed to effectively complete research projects. These knowledge and skills were associated with not only conducting experiments and analyzing data but also knowingledge the appropriate ways to collect data within the Chinese context. For example, one scientist described the importance of his Chinese co-authors for localizing data collection materials:

> There's a number of reasons why working with the Chinese added knowledge. I would say first off, there sort of is the localization of the questionnaire. Again, this was based off a questionnaire that I did in the United States. But it's not just like a simple translation, it is... are the questions relevant to a Shanghai audience. So, having somebody based in Shanghai who can speak to that is important, and I think like the localization is key. (Assistant Professor, Epidemiology)

Another important reason related to an ability to engage in research was the importance of collaborating to access data (mean = 3.57), with no significant difference ($U = 789.00$, $p = 0.102$) between the ethnic and non-ethnic Chinese US scientists. The interviews highlighted how access to data was especially important if collaboration occurred at the beginning of the pandemic when the USA had few reported cases and China had one of the highest case counts in the world. US scientists' abilities to examine phenomena related to COVID-19 required access to data from populations exposed to the virus, and thus, relationships with Chinese scientists allowed some US scientists to access data related to COVID-19 that might not have been possible otherwise. US scientists explained the importance of collaborating with their Chinese co-authors to access data:

> The Chinese team, they provide us a lot of data through some research agreements. Because at that time, there's not, maybe only China has the most of the cases. That's why they, I still remember when we do the project, the US only have maybe one or two cases, so then, all the data was coming from China. So, they are more like a data provider, and we are more like data analysis. (Assistant Professor, Radiology)

Also related to data access, US scientists also reported that the opportunity to extend the generalizability of results was an important reason for collaboration (mean = 3.38). Like with the above reasons, there was no significant difference ($U = 753.50$, $p = 0.081$) in the

ratings for ethnic and non-ethnic Chinese US scientists. During interviews, US scientists indicated that through collaboration, they were able to incorporate data from China in their analyses or extend previous studies by using Chinese data, both of which allowed them to extend their analyses beyond US samples. Additionally, scientists discussed situations in which the findings from research by their Chinese co-authors provided them with foundational evidence to further investigate a phenomenon. For instance, one scientist described how his co-authors provided anecdotal evidence of a treatment for COVID-19, and he utilized this evidence to obtain funding in the USA:

> This is a spinoff from another thread from China on approximately 100 patients that prove the concept that this could be a therapy, and now the United States is repeating with a randomized prospective trial multi-site…When the COVID pandemic erupted…I called our partners in China, and they said, "yes, we've already tested these cells, and they seem to work, but they were anecdotal cases." So, I rapidly went to FDA to ask for permission, and they said that "Yeah, we can do it, but it has to be state of the art, randomized control trial double ply fusion, so that we do it the right way." (Distinguished Professor, Medicine)

Finally, the survey data highlight the important roles that language and culture play in facilitating international collaboration. Non-ethnic Chinese US scientists rated communication in English as a significantly more important reason for collaboration ($U = 706.00$, $p = 0.020$) than did ethnic Chinese US scientists. Based on interview data, nearly all non-ethnic Chinese US scientists lacked fluency in Chinese; thus, the ability to effectively communicate in English was essential for making collaboration possible. On the other hand, the data show that ethnic Chinese US scientists rated communication in Chinese as significantly more important ($U = 494.00$, $p = 0.000$) than did non-ethnic Chinese US scientists. They also rated shared Chinese culture as a significantly more important reason for collaborating ($U = 500.50$, $p = 0.000$) than did non-ethnic Chinese US scientists. Therefore, this provides evidence of how homophily based on shared ethnicity, language, and culture promotes relationship maintenance among ethnic Chinese in the USA and China. Ethnic Chinese US scientists indicated that the ability to communicate in Chinese made it possible to smoothly coordinate between teams, and others indicated that because English was their second language, it was often easier and more effective to discuss topics in Chinese during the research process. They also discussed the importance of shared culture in relation to understanding the Chinese context and the Chinese ways of doing, such as what to expect when engaging in research in the Chinese context or with their Chinese co-authors, or how Chinese institutions operate. This knowledge of the research culture in China was especially valuable in understanding the perspectives or motivations of their Chinese co-authors. For example, in discussing the relationship between cultural knowledge and successful collaborations, one scientist explained how her knowledge of Chinese language and culture made it easier for her to collaborate with Chinese scientists compared to other country scientists:

> I will say China might be a little bit easier because I do understand the language. So, which means that when you understand the language, then you might have a little bit of background, and then you can understand a little bit more about why the culture comes through that way. (Associate Professor, Nursing)

Discussion

This study sought to provide insight into relationship formation between US and Chinese scientists who collaborated on COVID-19-related research during COVID-19. The data showed that most US scientists formed their relationships with their Chinese co-authors prior to the start of the disruptive pandemic. Scientists selected to collaborate with scientists in their existing networks with whom they had prior collaboration experience and relatively strong ties as opposed to those with whom they did not have ties. In terms of the social capital mobilized, the data demonstrate that most scientists mobilized bonding social capital to collaborate and access valuable and limited resources. For example, among the top reasons US scientists chose to collaborate were their Chinese co-authors' expertise and data, which were both needed to successfully undertake studies (Beaver, 2001; Bozeman & Corley, 2004; Melin, 2000). Furthermore, the data on relationship formation also point to a tendency for bonding capital as most relationships formed through known trusted others or through past educational and professional experiences, such as while classmates or while visiting scholars or postdocs at US universities. Therefore, US scientists were inclined to collaborate with Chinese scientists with whom they had close, trust-based relationships on COVID-19-related research.

Two explanations as to why scientists may have selected to collaborate with trusted scientists in their networks are that (a) pandemic travel restrictions inhibited scientists' abilities to travel internationally or attend conferences in-person reducing opportunities for new tie formation (Fry et al., 2020; Wagner et al., 2022) and (b) geopolitical tensions between the two countries. At the same time, the urgency to address COVID-19 and the need to efficiently produce knowledge may have also influenced those with whom scientists elected to collaborate. Personal trust was one of the most important reasons scientists provided for why they chose to collaborate (Beaver, 2001; Bozeman & Corley, 2004; Melin, 2000). Interviewees explained personal trust relates to understanding what other scientists are capable of and being confident in their abilities. This understanding and confidence develop over time and through experience, which corresponds with particularized trust and bonding capital. In situations in which there is a need to rapidly produce knowledge, there is less time for trust and knowledge of other scientists' knowledge and skills to suddenly develop. Thus, the opportunity costs to forming new ties may be too great during a time of crisis, which drives scientists to collaborate with others they know as opposed to those they do not know (Fry et al., 2020). Additionally, trust may have played an especially important role given geopolitical tensions between the two countries. As US-China relations were scrutinized, especially during the US Department of Justice's China Initiative, scientists may have been more selective about their overseas research partners based on longstanding relationships. In other words, scientists' willingness to be open and trust unknown scientists may have been reduced given the geopolitical context (Lee & Li, 2023).

Furthermore, shared ethnicity further facilitated US-China science cooperation. The findings from this study provide further evidence of the role homophily plays in tie formation between overseas ethnic Chinese scientists in the USA and ethnic Chinese scientists in China (Cao et al., 2020; Jin et al., 2007; Sun & Bian, 2012; Suttmeier, 2008). They also highlight the role that shared language and culture play in maintaining international research collaboration. While these were not among the most important reasons for collaborating for ethnic Chinese US scientists, they rated the importance of shared Chinese language and culture significantly higher than did non-ethnic Chinese US scientists. This difference demonstrates how a shared identity based on a shared language and culture help

form the foundation of these relationships and help link US and Chinese science (Jin et al., 2007; Suttmeier, 2008). In some cases, shared Chinese language and culture had functional purposes making it easier for collaboration to occur. However, it is important to recognize that homophily related to overlapping research interests as well as complementary knowledge, skills, and resources played a greater role in maintaining and promoting ties between ethnic Chinese US scientists and ethnic Chinese scientists in China than their shared ethnic identity or shared language and culture alone. The importance of overlapping interests and complementary knowledge, skills, and resources was also true for all scientists regardless of ethnicity (Dahlander & McFarland, 2013; Zhang et al., 2018).

Finally, the findings have policy implications for US-China collaboration during future times of crisis, especially given the ongoing geopolitical tensions between the countries and the evidence that this tension has likely contributed to a reduction in scientific ties between the two countries (Lee & Li, 2023; Wagner & Cai, 2022). This study does not account for ties that would have been formed if geopolitical conditions were more favorable, nor does it explain specific reasons for this reduction in ties between the USA and China. Nevertheless, the findings indicate that only a few new relationships formed between US and Chinese scientists during the pandemic. New networks primarily formed during times of relative normalcy, e.g., availability and ease of international travel. Thus, immigration and research policies that would discourage or limit tie formation between US and Chinese scientists during times of normalcy may have the potential to limit collaboration between the two countries during future times of crisis.

From a US perspective, a reduction in tie formation, such as through restrictive travel and immigration, could limit the country's future capacity to produce knowledge related to sudden crises. In the case of COVID-19, many US scientists indicated that they relied on data from China at the beginning of the pandemic because it had most of the cases. As such, without these pre-existing relationships with Chinese scientists, US scientists might not have been able to quickly engage in research on the topic. Additionally, the relationships between US and Chinese scientists were complementary in nature. Chinese scientists possessed valuable knowledge, and skills, and resources that allowed US scientists to produce knowledge more effectively. In other words, collaboration with Chinese scientists enhanced the US scientists' capabilities to engage in the research related to COVID-19. Ultimately, with the benefits that US scientists accrued through their collaborations with Chinese scientists, the extent to which ties are reduced during times of normalcy as well as crisis may have long-term implications on US scientists' capacities to effectively respond and produce knowledge, including the ability to address global concerns, such as COVID-19.

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Data Availability The participants of this study did not give written consent for their data to be shared publicly, so due to the nature of the research supporting data is not available.

Declarations

Conflict of interest The authors declare no competing interests.

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