UCLA
UCLA Electronic Theses and Dissertations

Title

Global Ambitions and Local Dynamics: Organizational Coauthorship Networks of a Chinese National Flagship University

Permalink

https://escholarship.org/uc/item/5870w71r

Author

Hu, Die

Publication Date

2020

Peer reviewed|Thesis/dissertation

eScholarship.org Powered by the California Digital Library
University of California

UNIVERSITY OF CALIFORNIA

Los Angeles

Global Ambitions and Local Dynamics:

Organizational Coauthorship Networks of a Chinese National Flagship University

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Education

by

Die Hu

2020

© Copyright by

Die Hu

2020

ABSTRACT OF THE DISSERTATION

Global Ambitions and Local Dynamics:

Organizational Coauthorship Networks of a Chinese National Flagship University

by

Die Hu

Doctor of Philosophy in Education

University of California, Los Angeles, 2020

Professor Cecilia Rios-Aguilar, Chair

By adopting a case study design and a network lens, this exploratory research approached the coauthorship network in the institutional context that is internally multi-layered and externally shaped by national and global higher education. The case used is a national flagship university in China, and its network provides important details of the institutional knowledge production and helps critically assess China's rise in global science. Analyses were built upon faculty profile data obtained through university websites and the publication data scraped from the Web of science and other academic databases during a five-year window between 2014 and 2018.

The major findings are centered on the network distributions at local, national, and global levels and the variations in network cohesion and performance by sub-organizations within the university. First, the institution's global publications and ties have increased over the years, which

highlights the trend of international collaboration in global science and reflects China's internationalization strategies. The collaboration is shaped by the hierarchy of global higher education and science publication systems. Most global ties with the university were built by scholars affiliated with institutions in the global north and most national ties were connected by first-tier Chinese universities. Second, local ties built the basic structure of the organizational network. The inter-organizational network is vulnerable and is connected to only a few large schools, whereas schools in the social sciences and humanities are on the periphery of the inter-organizational network. To build a comprehensive university that matches the standards of a world-class university, the local status of the social sciences and humanities need to be elevated. A collaborative institutional climate and organizational resources would foster more collaboration among humanities and social sciences themselves. Third, in comparing intra-organizational networks within the university, network cohesion differed between natural sciences and engineering cluster and humanities and social sciences clusters. Stronger bonds between faculty within the same school are associated to higher organizational external productivity, extensity, and visibility.

The dissertation of Die Hu is approved.

Mitchell J. Chang

Ozan Jaquette

Jenny J. Lee

Cecilia Rios-Aguilar, Committee Chair

University of California, Los Angeles

2020

Table of Contents

Tables

Figures

ACKNOWLEDGEMENTS

I wish to acknowledge those who have encouraged, supported, and guided me during my doctoral studies. First, I am forever indebted to Dr. Cecilia Rios-Aguilar, who is an amazing scholar, my advisor, my dissertation chair, and my role model in academia who has gone above and beyond to support students in many ways during their PhD journeys. Thank you for guiding me at every stage of my dissertation and always giving me tremendous trust and resources. I appreciate every meeting we had during my dissertation stage, particularly as we worked from home during this very unusual period. I am so proud of being your advisee and thank you for taking me as your student.

A heartfelt thanks to late Dr. Robert Rhoads, thank you for welcoming me to this doctoral program. I remember your encouragement during our last RAC when I presented the very first idea of my dissertation. That became my motivation to work harder on this effort. I will always remember your work ethic in my academic journey ahead and will keep training myself to become a scholar like you. Rob, rest in peace. I will always miss you.

I am so grateful to my dissertation committee, Dr. Ozan Jaquette, Dr. Mitchell Chang, and Dr. Jenny Lee. Thank you all for your investment in me and my work. Ozan – I owe you a debt of gratitude. I will always be grateful for the opportunity you gave me to work on your project when I just started this doctoral program. I would not be able to do this dissertation without the experience I gained from your recruiting project. I admire your efforts on starting a transformative project to push for equity in college recruiting and admissions process and your generous guidance for students' personal growth. Mitch – it is an honor to have your guidance on research; mentorship on how to navigate academia; and invitations to collaborate with you on courses. Thank you for all the RAC time you created for us to reconnect and seek help from community during my

dissertation stage. Jenny – Thank you for serving on my committee since Rob's passing. As an expert in the field of international higher education and a former student of Rob, your support and guidance are important to me. I am deeply grateful for all the conversations we had about my topic and the field and thank you for connecting me with other scholars sharing similar research interests.

Thanks to Dr. Yang Li, Jinwen Luo, and Louise Huang for your wonderful suggestions on my network design and analysis. Thanks to the Tsinghua professors who accepted my informal interviews and generously shared their work-life at Tsinghua with me. Also, I would not be able to do this work without the support of programmers at the Sun Yat-Sen University.

Thanks to my HEOC community, as well as all the members of Rob's RAC and Mitch's RAC who not only helped me with my work, but generously extended their support in many other ways. Thanks to my lovely cohort – Ana G., Ana R., Diana, Edgar, Kaitlin, Katherine, Natacha, Patricia, Sabrina, and Sid. Thank you for always cheering for me for those even little accomplishments and standing with me when I encountered problems in school or life. You are my inspiration and I am so grateful for being one of you. Thanks to HEOC administrative, Amy and Kim, for your care and patience for students and those efficient and joyful conversations and emails. A special thanks to my writing group, Katherine, Jenny, Ana, and many friends, who helped me get through the final stage of writing in such a pressured period. Thanks to the Dissertation Year Fellowship at UCLA that allowed me to be fully devoted to my dissertation. I owe a debt of gratitude to my HEOC community and hope to give back to my community in the future.

I would also like to thank the many mentors in higher education who have generously invested their time in me. Thank you, Dr. Wen Wen, for leading me onto this academic journey and welcoming me to work with you. A special thanks to Dr. Rui Yang who welcomed me as a

visiting student at Hong Kong University and provided insights on my work. Thank you, Dr. Hong Shen, for generously giving me guidance on my career plan and job search.

I have been incredibly lucky to have the unwavering and unconditional support of my friends and family throughout my four years at UCLA. A special thanks to my roommates, Xitao and Shujin for their company.

Finally, thank you, Mom, Dad, and my little brother, Howard. You are my rocks and my haven. To my partner Yongfeng, I am lucky to have your company and support all the time since we met before I entered this PhD program. I appreciate all the sacrifices you have made for our little family when I focus on earning my PhD. Thank you for always listening when I talk about my research and providing so many great ideas. Thank you for being the "coauthor" of my life.

VITA

Education

2011	Bachelor of Arts, Journalism
	Tsinghua University, School of Journalism and Communication, Beijing, China
2012	Master of Science, Media and Communication
	London School of Economics and Political Science, London, UK
2014	Master of Arts, International Comparative Education
	Stanford University, Graduate School of Education, Palo Alto, California, USA

Publications

Wen, W. & Hu, D. (2018). The Emergence of a Regional Education Hub: Rationales of International Students' Choices of China as the Study Destination. *Journal of Studies in International Education*. 1-23. Doi: 10.1177/1028315318797154

Hu, D., & Rhoads, R. A. (2018). Fragile Elite: The Dilemmas of China's Top University Students by Susanne Bregnbæk. *Comparative Education Review*, *62*(1), 149–151. https://doi.org/10.1086/695807

Wen, W., Hu, D., & Hao, J. (2017). International students' experiences in China: Does the planned reverse mobility work? *International Journal of Educational Development*. https://doi.org/10.1016/j.ijedudev.2017.03.004

Hu, D., Wotipka, M. C., & Wen W. (2016). "International Students in Chinese Higher Education: Choices, Expectations, and Experiences." *Global Perspectives and Local Challenges Surrounding International Student Mobility*. Ed. Krishna Bista, Ed. Charlotte Foster. Pennsylvanian: IGI Global, 2016, 153-178

Wen, W., Luo, Y., & Hu, D. (2014) Bridging the Gap between Western and Chinese Evidence in the International Education Market. *China & World Economy* / 87–102, Vol. 22, No. 6, 2014

Selected Conference Presentations and Papers

Hu, Die. Understanding Transnational Academic Migration U.S. Doctorate Recipients' Choices of Returning to Chinese Academe. Paper presented at the Annual Meeting of the Association for the Study of Higher Education (ASHE) in Tampa, FL, November 2018.

Salazar, Karina*, Ozan Jaquette, Crystal Han, & Die Hu. ¿Suburbio o Barrio? Using Data

Science to Study Off-Campus Recruiting by Public Research Universities. Paper presented at the Annual Meeting of the American Educational Research Association (AERA) in New York, NY, April 2018.

Wen, Wen* & Die Hu. Motivations and Push-pull Factors of International Students Studying in China. Paper presented at the Annual Meeting of the Higher Education Research Association (HERA) in Hong Kong, May 2016.

Wen, Wen & Die Hu*. International Students' Socio-cultural Adaptation in China. Paper presented at the Annual Meeting of the Comparative and International Education Society (CIES) in Toronto, Canada, March 2014.

Awards

2016-18	UCLA Graduate Division Fellowship
2019	UCLA Dissertation Year Fellowship
2020	Chinese Scholarship Council Award

CHAPTER 1 INTRODUCTION

Since 2018, China has surpassed the United States in the sheer number of published research papers and has become the world's largest producer of scientific publications. In terms of the number of citations, the U.S. and China placed third and fifth internationally, respectively (the top two are Sweden and Switzerland) (U.S. National Science Board, 2018). The increased academic production from China, as well as the the Chinese research system has drawn much attention from around the world.

With the increase in academic production, Chinese Research University has also increased its global visibility indicated by global university rankings, as publication and citation measures are important criteria for global rankings. For example, in the Academic Ranking of World Universities (ARWU) of 2019, China earned three places in the global top 100 – Tsinghua University (43rd), Peking University (53th), and Zhejiang University (70th). All three national flagships have experienced great jumps in ranking in the last two decades. Tsinghua University, the case of this study, moved from 200th in 2003 to 43th place in 2019. Tsinghua University (hereinafter shortened as Tsinghua or THU) and its rival and neighbor, Peking University are in the top 100 global universities in four major ranking systems including the Quacquarelli Symonds system (QS), Times Higher Education (THE), ARWU by Shanghai Jiaotong University, and the U.S. News and World Report.

Nonetheless, it is unneglectable that the increased visibility of Chinese universities can be largely attributed to the elevated performance of Chinese science and engineering. The phenomenon of unbalanced disciplinary development is commonplace in the world, but it is severe in Chinese Research University (Marginson, 2011). China has increased its R&D spending

proportionally in recent years (Tollefson, 2018). With the nation's growing global ambitions in higher education (Rhoads et al., 2014), Chinese Research University also makes every effort to achieve a world-class standing shared by Chinese research-extensive universities. However, only a handful of top universities on Chinese mainland, including Peking University, Fudan University, and Nanjing University, "make a determined effort to resource the full range of globally common disciplines, including the non-science fields, at an adequate level" (Marginson, 2018).

In Tsinghua, the global disciplinary rankings reflect its unbalanced disciplinary development: Natural Sciences & Engineering (NS & ENG) is in the first-tier, and Humanities and Social Sciences (HSS) are in the lower-tier. Although Tsinghua has been trying to change its image of being seen as "a cradle for red engineers" in the post-Mao period towards being seen as a comprehensive world-class university, the gap between NS&ENG and HSS is evident. The disciplinary variations in coauthorship can be the results of the disciplinary imbalance in both the university and publication system. This study draws special attention to the disciplinary variations in the coauthorship analysis and tries to uncover the ways in which the coauthorship network may affect disciplinary development in university.

The increased global visibility of China's science and Chinese Research University has been occurred in the "glonacal" era of higher education (Marginson & Rhoades, 2002) where each dimension – local, national, global – benefits from rather than works against the others and these dimensions shape faculty coauthorship, a significant component of academic production and faculty work-life. Globally, the production of knowledge is increasingly becoming a collective process involving more individuals, groups, and organizations (Välimaa et al., 2016). Team size has grown from 1.9 authors per article in 1955 to 3.5 authors per article in 2000 (Wuchty et al., 2007). The increase in academic collaboration can be explained by several factors such as the

policy push at the federal and state level (e.g. Cummings & Kiesler, 2007); the trend of specialization and interdisciplinarity that makes collaboration become the way to address a question that is hard to be solved within one field (e.g. Moody, 2004); and the emerging Internet and Communication Technologies (ICT) development which removes the technical barriers for communication and collaboration (Castells, 2011; Välimaa et al., 2016). On a national level, China's growing global ambitions on higher education and its investment in science and engineering would change the landscape of research and faculty work-life in universities. Locally, the faculty coauthorship behaviors may be shaped by the organizational context of the university and faculty's own backgrounds. The glonacal aspects are intertwined in the coauthorship behaviors. A study on university coauthorship can help unpack the rationales behind the rise of academic production in the Chinese research system.

The remainder of this chapter will discuss why the global-local dynamics matter for academic production, the ways in which such macro-dynamics may shape the coauthorship of publications in a university in China, and how such contexts and prior studies on organizational coauthorship motivated this exploratory study. Tsinghua's university context is also an important landscape for this study which will be discussed next. The rationale of using network analysis as a lens to approach the research questions will be illustrated as well.

Global-Local Dynamics on Academic Production

The global-local dynamics are present in China's academic production and university reform. Global ambitions are shown in China's national and local strategies and efforts on promoting internationalization and elevating academic capacity. On the other hand, several concurrent issues have been debated such as the "SCI (Science Citations Index) worship", publish-or-perish academic culture; the difficulty of publishing in English; unbalanced disciplinary

contributions; and the need of knowledge indigenization and local application in Chinese research universities. The global and local dynamics can shape publications, but it is not yet clear if such dynamics affect the micro-dynamics of publications – faculty coauthorship patterns within a university. A detailed analysis on coauthorship patterns can help us understand whether, and in what ways, the organizational dynamics may interact with faculty work-life. Further, the analysis on coauthorship may provide an additional lens with which to approach China's rise in publications and its higher education institutions' increasing global visibility.

Elevating International Academic Presence

The national quest for world-class universities and internationalization marks the global ambition period of reform in Chinese higher education. China's top universities have embraced a larger international sense of themselves (Yang & Welch, 2012a). Enhancing international academic presence is one important aspect of internationalization of the professoriate. Under such circumstances, publishing in internationally recognized journals and enlarging scholarship's global impact is an important task for faculty. SCI-indexed for NS & ENG disciplines are standards recognized by Chinese academe and university officials. For HSS, more benefits were also granted for SSCI and A&HCI publications than domestic publications during this global ambition period of reform (Xu et al., 2019). SCI- and SSCI-indexed journals are dominated by North American and European countries and English is the language for the majority of these journals. Among all 9,370 SCI journals and 3,486 SSCI journals, 239 (2.6%) SCI journals and 12 (less than 1%) SSCI journals are published in China, but all SSCI journals by China are published in English (JCR, 2020). Given the English-language dominance of the journals and the pressures from the faculty evaluation and promotion policy, it is important for faculty to write in English and publish in SCI and SSCI indexed journals.

The push for English publications encourages more Chinese scholars to reach out to international scholars to foster collaboration ties. In an informal interview with a Tsinghua Engineering faculty, the professor thought the negotiation of author order could be smoother for the coauthored work with western scholars because the slightly different meaning attached on the order of coauthors. In Chinese higher education institutions (HEIs), the first author (and the corresponding/last author in some cases) takes almost all the credit of the publication. Second authorship barely adds any credit to a faculty member's performance evaluation. Such context does not encourage local collaboration among faculty, but to some extent makes international collaboration successful.

Moreover, having an international educational background or work experience might give scholars more access to international collaboration and English publications. Chinese universities' favorable recruiting programs for international scholars generates a tension between scholars with international backgrounds and those without this type of background in university settings, which hinders communication and research collaboration among university faculty. The favorable overseas recruiting programs may reflect the fact that the country is not confident about its own higher education system and is anxious to "import" talents from the Global North.

Indigenizing Knowledge Production

The organizational push for English publications in top international journals influences different fields differently. Lee & Maldonado-Maldonado (2018) asserted that prioritizing global over local interests in order to be published in English journals for some locally-oriented research is problematic for research universities in the Global South. This issue is particularly salient in the social sciences and humanities and some applied science and engineering disciplines not only in Chinese HEIs, but also in many non-English speaking countries. SSCI publications were used as

the "guiding light of social science" in South Korea, which results in the withering of indigenous social sciences (Shin, 2007).

Generally, science and engineering publications produce more facts and results than ideologies, so language often does not determine the articulation of the technical results. Science and engineering disciplines are more adaptable to the institutional emphasis on English publications, as faculty socialized in those disciplines are accustomed to reading the top journals such as *Nature* and *Science* and subsequently target them for publication. Some traditional engineering disciplines, though, have a larger group of audiences in the industry who favor reading Chinese, thus faculty aim to publish in high quality international journals while maintaining close relationships with the industries and concerning the local applications of the scientific results. Given the disciplinary culture of the social sciences, local needs and interests are important for most social science scholars too. For them, it is a practical conflict between the need to develop local research, practices, and policies and the institutional push for thinking about their presence in international/English journals (Yang et al., 2019).

Despite the organizational push for English publications and global engagement, there is a rising demand in Chinese research universities to indigenize knowledge production (Dirlik, 2012). Chinese national flagships are eager to find a way to indigenize their knowledge production while proving their global influence, but the publication languages and the types of journals can shape the type of research that faculty are encouraged to do. It is a practical concern to faculty that they might want to work on research that appeals to an international audience. The organizational push for publishing in English will likely render local research using the Chinese language unimportant.

Publishing in the journals indexed by the Chinese Sciences Citation Database (CSCD) and Chinese Social Sciences Citation Index (CSSCI) has become valued, despite institutional

variations. The importance of CSSCI journals in faculty evaluation and reward is equivalent to SSCI in a few flagship universities. In a social science school of Tsinghua, publishing two CSSCI journals is equivalent to one SSCI journal in faculty promotion evaluations. However, the paradox between the organizational push for publishing in English and the demand for indigenizing knowledge production still exists, especially in some applied disciplines such as the social sciences, and engineering.

Relatedly, Chinese academe has been reflecting on the "excessive pursuit" of SCI authorship in its academic and publishing system for years. The recent policy of the Ministry of Education and the Ministry of Science and Technology of China has explicitly discouraged institutions from rewarding individuals and departments based on the SCI articles they publish (Lau & Liu, 2020), which suggests that the Chinese research system is trying to move away from the "publish or perish" or "SCI worship" phenomenon that has existed in many Chinese universities. The assessment of academics and universities and the scientific publishing system of China would potentially change as a result. This study reviewed the publications and authorship over the past five years when the "SCI worship" culture was dominated in the research system that bolstered Chinese universities in global rankings. This research can also set an important stage for the future analysis of the policy change in Chinese research.

Why Organizational Contexts Matter

Faculty collaborations can be shaped by the organizational contexts. An institution shapes actors' perceptions of their circumstances (Meyer & Rowan, 1977). In the normative sense, an organization may enforce rules and norms that its actors feel compelled to follow (Nee & Ingram, 1998), such as a norm that publishing in English receives more credit. University coauthorship is embedded in a multi-layered organization, composed of departments/schools, faculty, students,

staff, and institutional practices such as teaching, meetings, and so forth. At the institutional level, the academic culture shapes faculty life within the university (Clark, 1987). The organizational push on publishing on A-level journals (top journals, indexed by SCI, SSCI, EI, etc.) in a timely manner can play a "discipline" role (Foucault, 1977) for faculty work-life.

This study also recognizes the disciplinary variations in coauthorship. The university as a loosely coupled entity consists of anomic subunits that may be motivated by separate objectives and beliefs (Meyer & Rowan, 1977). The highly unstandardized structures and cultures of disciplines within a university (Clark, 1989) will also likely foster different environments for collaboration. Despite the fact that coauthorship is growing in all fields, academic collaboration patterns could exhibit different features among fields. Coauthorships are generally more common in the natural sciences and engineering than in the social sciences (Laband & Tollison, 2000; Leydesdorff & Wagner, 2008; Wagner & Leydesdorff, 2005). For example in 2010, about 95% of articles in physics, nanotechnology, and biotechnology were co-authored (Freeman et al., 2014), whereas sole-authored papers are still somewhat common in the social sciences today (Leahey, 2016). The rates of collaboration in the humanities have remained flat in recent years (Leydesdorff & Wagner, 2008; Wagner & Leydesdorff, 2005; Wuchty et al., 2007).

At the intersection between the larger discipline and the local institution (Clark, 1987), the sub-units of university can intervene on faculty coauthorship. The department serves as the disciplinary representatives and the administrative leads of the institution (Lee, 2004). On one hand, departments are basic organizing subunits within a university and should be the administrative extensions of the institutional administration. On the other, departments reflect their continuing disciplinary identifications, serving as rally points for resistance to the institutional agenda that provides great pressures for change. Therefore, the varied organizational structures

and cultures across departments such as policies, standards, and values reflect the influences of the institution, the larger discipline and society. Investing in coauthorship at sub-organizational level of university will allow for an examination of both the institutional and disciplinary influences on faculty life.

Tsinghua in the Global Ambition Period

Tsinghua University was chosen as the case study for a variety of reasons that will be elaborated on in the methods chapter, but a major deciding factor was Tsinghua's unique history of the organizational changes that correspond with political and social changes taking place in the broader society (Rhoads et al., 2014). Table 1.1 outlines major events and changes at the state, higher educational, and Tsinghua levels in the four periods of reform. There are a few important features in Tsinghua in the global ambition period that affect faculty academic publishing and collaboration including rising research funds, tenure track reform, and internationalization.

Table 1.1 Four Reform Periods: Tsinghua, Chinese Higher Education, and Chinese Society[1]

Periods	Society	Higher Education	Tsinghua University
The republican period (1911-1949)	The rise of the Chinese republic	1) A debate on the idea of university about Confucianism vs. Western modernist thought	1) Tsinghua was founded in 1911 with "Boxer Rebellion Indemnity Funds," and was a "preparatory school for studying in America." 2) Tsinghua changed its designation from "School" to "University," which was a sign of the nation's progress towards higher education independence.
The socialist	A new	1) A restructuring of the	Like others, Tsinghua turned to

[1] The content of the table was mainly based on the content in Rhoads et al. (2014).

period (1950-1977)	socialist state and Mao-led communist movements	university to follow the Soviet model: specialized universities were developed to aid the economic and social goals of a new socialist state. 2) A shutdown of universities during the Cultural Revolution years.	the Soviet model. Tsinghua was restructured to a polytechnic university with most of the natural science, humanities, and social science departments leaving to join other universities. Since then, Tsinghua has been regarded as "a cradle for red engineers."
The Open Door period (1978 to the mid-1990s)	A series of "Open Door" reform policies in the aftermath of the Cultural Revolution	1) Reopening and restoration of the university. 2) Turned from Soviet model to the ideals grounded in Europe and the United States. 3) HEIs had more institutional autonomy.	1) Tsinghua re-established itself as a comprehensive university, resuming those academic disciplines that had been moved to other universities. 2) Tsinghua built a Research Institution of Tsinghua University in Shenzhen, a city that received great benefits in development due to the Open Door policies.
The global ambition period (the late 1990s to the present)	China achieves a prominent place in the world with a fast-growing economy	1) National efforts to build world-class universities. 2) Universities meet issues of marketization, decentralization, privatization, massification, and internationalization.	1) As a flagship national university, Tsinghua received preferential support from the central government in the form of extra funding and an extra degree of institutional autonomy. 2) Tsinghua increasingly took on some features of "world-class" research universities, including increasing global engagement.

Rising National Funds, Academic Production, and Global Ranks

Tsinghua is the beneficiary of every national program or project built in the national quest for world-class universities, including the Program for Education Reform and Development in China (1993); the Education Act of the People's Republic of China (1995); Project 211 (1995); Project 985 (1998); and the recent Double First-Class University Plan (2015).[2] National government funds constitute 27% of Tsinghua's annual institutional income in the year of 2014. Tsinghua obtained extra funding and extra degrees of institutional autonomy from these large-scale national programs.

Tsinghua is an example of actively expanding income besides governmental funds via its Tsinghua Technology Park (Tuspark), Tsinghua Holdings, and Tsinghua University Education Foundation. Benefiting from its engineering culture and close relationships with technology industries, Tsinghua Holdings invested 50 corporations in 2013. Tsinghua University Education Foundation was the first education foundation in China. In 2017, the number of private donation reached 1.5 billion RMB (Tsinghua University Education Foundation, 2018).

The national funds, Tsinghua investment income, and donations from Tsinghua Education Foundation, lay the foundation for Tsinghua's academic production, which also boosted the university's global rankings. Tsinghua's engineering disciplines have moved up very fast in the world ranking system in recent years. In the 2018, U.S. News Ranking, Computer Science, Engineering, and Material Sciences ranked 1st, 2nd, and 4th respectively, followed by several science disciplines including Physics (18th), Biology and Biochemistry (44th), and Mathematics

[2] Project 985 was initiated in 1998 and includes 39 universities. It aims for disciplinary development, institutional development focusing on system building. Project 211 was initiated in 1995 and includes 112 universities and over 900 disciplines. It aims for disciplinary development, institutional development focusing on fundamental construction and public support system. Double first class was conceived in 2015, which includes sponsored 42 universities and 465 disciplines. It aims for disciplinary development and a comprehensive higher education reform. The goal is that by 2020 China has a few first class discipline and by 2030 a few world-class universities.

(50th). Compared with science and engineering disciplines, social science disciplines were in the third-tier in the ranking. Economics and Business ranked 73th, the highest rank in the U.S. News that Tsinghua's humanities and social science disciplines acquired. As a "cradle for red engineers" in the Post-Mao era, Tsinghua was known for its strong engineering disciplines since it turned to the Soviet model and was restructured to a polytechnic university from 1950 to 1977. Since the Open Door policies started since 1978, Tsinghua has been reestablishing its humanities and social sciences. In the newly released 2018 National Social Science Fund of China (Key Programs), Tsinghua has funded seven social-science research projects, which outnumbers other universities that are traditionally strong in social sciences and humanities universities, which signifies great progress for Tsinghua in the social sciences. The historical features of disciplines within Tsinghua and the changing dynamics in disciplines are important factors to consider in faculty collaboration analysis.

Leading the Tenure Reform in Chinese HEIs

The personnel system reform is one of the most important organizational changes that mark the global ambition period of Chinese higher education that directly affects academic production and faculty life. Tsinghua initiated its personnel system reform in the year of its 100th birthday in 2011. After being piloted in the school of life science, and economics and management, the university-wide personnel reform officially started in 2014. The transformation of the personnel structure was centered on the design and implementation of Chinese tenure-track (with a probationary period) system, which was highlighted in Tsinghua's "Comprehensive Reform Plan of University" in 2014. Peking University, Shanghai Jiaotong University, and a few national flagships followed and implemented their own Comprehensive Reform of University in the end of 2014.

As of 2020, with a few exceptions (faculty with no more than ten years until retirement), all Tsinghua faculty have entered one of the three tracks: tenure track, teaching track, or research track. For tenure track faculty, there is a six-year trial period, at the end of which the assistant professors must either earn promotions or leave the university, which is similar to how tenure works in the United States. As the policy has just been recently implemented, Tsinghua adopted the "*xin ren xin ban fa, lao ren lao ban fa*" -- "new faculty new way, senior faculty old way." Senior faculty could opt for the teaching track or tenure track. Faculty having worked in Tsinghua for more than 12 years became tenured without evaluation. For those who opted for tenure track and have worked at Tsinghua for less than 12 years, their tenure evaluation will also consider their work before they entered tenure track, no matter when they switched to tenure track. There are slight differences in this policy between departments.

Department committees have primary power over the faculty tenure promotion evaluation, and then the University Tenure Committee is secondary. According to informal interviews with a few Tsinghua professors, research funds and publications are the most important criteria for faculty promotions and rewards, the evaluation on teaching and service is more symbolic. In the evaluative system, Tsinghua requires faculty not only publish a large number of publications in top journals, but also to produce a certain number of representative pieces. In terms of evaluation criteria, a slight institutional transition towards giving more credit to representative work other than purely being evaluated by counting numbers of publications has been noticed by Tsinghua professors.

Moreover, Tsinghua also required its schools and/or departments to implement their own reward and punishment policies for academic publishing. For example, the biology department uses the impact factors of the journals as weights of scholars' award money (Yang & Welch, 2012b). However, several departments, such as those in the school of life science and engineering

implemented the tenure system many years ago, whereas tenure systems are just being developed and tested in some of the social science schools. The unstandardized tenure track development paces across departments will likely affect the collaborative work across disciplinary or school boundaries.

Proactive Global Engagement

Tsinghua increasingly took on some features of "world-class" research universities, including the intensified global engagement. For example, Tsinghua highlights the importance of the internationalization of the professoriate; thus, there are many international collaborations at all levels at Tsinghua (Rhoads et al., 2014). There are increasingly more published articles with international coauthors and Tsinghua's international coauthors are mostly from the United States. In 2017, Tsinghua faculty co-authored 2,140 papers with U.S. scholars, four times the number of papers coauthored with the authors from the UK (the second).[3] Moreover, the organizational push for publishing in internationally recognized journals creates tensions between departments or even between scholars in the same department. Researchers in certain fields are more likely to produce English publications than others and the language barriers pose a problem for some as well. The publication language barriers the international publishing as well. Such phenomena are obvious in Tsinghua, a university with a reputation for strong science and engineering disciplines but weak humanities and social sciences.

Tsinghua's proactive global engagement goes beyond academic publishing. With the goal of becoming a regional education hub, China actively recruits international students from around the globe to study in China. In the past, learning the Chinese language was the major driving factor for international students to study in China. However, the number of degree-seekers in China has

[3] Retrieved from http://thurid.lib.tsinghua.edu.cn/rdt/charts. Note: the 2017 data for this research are papers collected on WoS platforms. The number of papers is smaller than the records of Tsinghua library.

been rising over the years (Hu et al., 2016). In 1950, Tsinghua was one of the first Chinese universities with international student enrollment. Tsinghua currently hosts around 3,500 international students from 110 countries, among whom 78% are degree seekers. The undergraduate programs are mainly delivered in Chinese, with part of the courses taught in English or bilingually (Tsinghua Website, 2020).

As mentioned above, Chinese research universities have several overseas recruiting programs that target established Chinese scholars and Chinese PhD graduates living aboard. Tsinghua also actively recruits foreign scholars as full-time or adjunct faculty. The presence of international scholars is believed to contribute to the internationalization of teaching and research at Tsinghua. In terms of institutional collaboration, the Tsinghua-UC Berkeley Shenzhen Institute was launched in 2014, which aims to promote research collaboration and graduate student education (Rhodes, 2014). In 2015, Tsinghua collaborated with Microsoft and the University of Washington to establish the Global Innovation Exchange platform that launched Dual Master Degree programs to recruit students from the globe (Wingfield, 2015).

A Network Lens

Faculty collaboration is a topic that naturally belongs to a network study as faculty collaboration entails relationships and interactions – the focus of network analysis. Coauthorship is a form of relationship among faculty members who naturally belong to multiple layers of institutions such as academic departments, universities, and subject fields.

Higher education institutions are organizations in and for "networked knowledge societies" (Castells, 2011). HEIs are connected by knowledge producers across boundaries of nations, domains, and disciplines. Networks are representations of systems in which the elements are connected by ties (Wasserman & Faust, 1994). The internal structures of HEIs are "woven fabrics,

layered and patched together in a complex arrangement" (Biancani & McFarland, 2013), which can be captured by a web of weighted network ties and several network communities.

Social network analysis (SNA) is a good approach to investigate the network within and between universities, as it has great potential to illuminate both the inner workings of higher education institutions and how they interrelate with society (Biancani & McFarland, 2013). However, compared to other applied sciences fields, higher education research is a relative latecomer to the study of social networks and has just begun to embrace SNA and the network logic these methods can bring.

SNA is the "disciplined inquiry into the patterning of relations among social actors, as well as the patterning of relationships among actors of different levels of analysis" (Breiger, 2004, p.505). SNA offers a tool set for "illuminating the on-the-ground work of the organization, and it is in that ongoing work that change is legitimated or not, ideas given meaning, relationships built, broken, or changed, and practice sustained or transformed" (Little, 2010, pp.xii). Technically, SNA is a set of methods that are used to (1) visualize networks; (2) describe specific characteristics of overall network structure as well as details about the individual nodes, ties, and subgroups within the networks; and (3) build mathematical and statistical models of network structures and dynamics (Luke, 2015).

In this study, I adopt a SNA approach to empirically illuminate the key relationships that explain how the faculty and the university are connected and to explore the underlying structure of collaborative links. The network of the present study will be a combination of socio-centric network and open system network,[4] because the faculty population of this study is bounded within

[4] There are three primary types of social networks: egocentric networks that are connected with a single node; socio-centric networks that are bounded within an organization; and open system networks, where the boundary lines are not clearly defined.

the university (socio-centric) and the faculty members in the sample will also have outside collaborators (open system). However, the focus of this study is the collaboration ties of faculty working in the university, other than all collaborators linked to the faculty in the sample.

I defined the following rules for the analysis of this study: (1) each faculty member of the university is a node (or named as vertex) in the network; (2) an edge between two scholars (one must be a faculty member in the sample) is generated, if the two people have co-authored at least one article; and (3) each edge is weighted according to the number of co-authored articles between the two nodes. The more co-authored papers found between the two nodes, the heavier the weight attached to the edge. I will provide more details on network analysis concepts that are used in this study in following chapters where relevant.

Research Questions

Guided by the social capital (Coleman, 1988; Lin, 2002) and social network theory (Burt, 2004; Granovetter, 1973, 1974; Wasserman & Faust, 1994), and organizational embeddedness (Small, 2009), the main research question that guides this research is: what are some of the organizational features of Tsinghua's coauthorship network in recent years?

This study approaches the main exploratory research question by asking four sub-questions:

1) How are the collaborative ties of Tsinghua distributed locally, nationally, and globally?

2) How do the distributions of ties differ by schools/departments?

3) What features, if any, exist in the faculty-faculty network in terms of intra- and inter-organizational networks?

4) Whether, and in what ways are the important network features of schools associated with such important facets of school performance as productivity and prestige locally and abroad?

By investigating the four sub-questions we can gain a basic understanding of the organizational features of Tsinghua's network in recent years from 2014 to 2018. To answer the first and second questions, this study utilizes coauthors' affiliation addresses to find the institutions that Tsinghua's network reached at local, national, and global levels and to examine whether the distributions of ties differ by sub-university units.

To answer the third question, the analysis focuses on faculty-faculty ties within Tsinghua. For one, it compares intra-school networks among schools and departments. Network cohesion is the major indicator used to compare intra-school networks. For another, it analyzes faculty ties that cross schools within Tsinghua. In the inter-school network, each school is regarded as a node and the aggregated ties between them are edges. The networks are displayed in graphs with radial layouts showing the core-periphery structure of the network. Centrality measures including degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality are used to measure the centrality level of each school in such inter-school network.

The last sub-question stems from the third one and explores to what extent school coauthorship network features such as network cohesion can be related to school performance, visibility, and status. School performance is measured in this study as average individual productivity and reachability meaning the number of institutions that the school connects. School visibility and status is indicated by the average ranking of subjects within the school.

Significance of the Study

This research can engage global readers by providing a detailed account of the knowledge production output of Tsinghua, which helps explain the rationales behind China's increase in academic production and the rise of Chinese universities in global ranks. By investigating the coauthorship networks of Tsinghua we can get an idea of how the publications of Tsinghua were

built by faculty with their coauthors either within or outside Tsinghua. The research can serve as a starting point for future studies predicting the knowledge flows of Chinese academic production in the new era.

Fostering collaborations requires institutions to integrate structure, rewards, resources, and hiring, and formalize the network for collaboration (Kezer & Lester, 2009). This research can help university leaders to have a holistic view of Tsinghua's coauthorship networks at different levels, reflect on their own work related to collaboration, and rethink the overall organizational structures and processes for collaboration. For example, with regard to practice, the coauthorship networks provide evidence for the university policy-makers to evaluate their initiatives for promoting collaboration such as allocating funds or building research centers for interdisciplinary research. Relatedly, this research serves as a discussion space for such broad issues that are embedded in the rise of Chinese academic production as the incentivized policy for publishing in internationally recognized journals, the disciplinary skew in publications, and the local need of indigenizing knowledge production.

In terms of research, this study is a test case to apply SNA to a higher education research on faculty work-life, which will bring new perspectives to the previous studies on faculty lives and provide additional trajectories for institutional research. This study serves as a starting point of the endeavor to build a primary database for faculty collaboration networks in universities in China. Future data collection of multiple universities could efficiently build on the data collection approach developed in this study. I will discuss more about future studies that this study would inform in the concluding chapter of the dissertation.

Organization of Paper

This study examines collaboration patterns within Tsinghua and cross national boundaries, within each school and across schools. In this chapter, I have reviewed the purpose and significance of the present work. Chapter Two provides a comprehensive overview of the extant literature on the research collaboration, and research that has been conducted with a social network analysis lens, and theories framing this study. Chapter Three discusses the research methodology that grounds this study and present a detailed description of data collection, cleaning, and validation process. The components of data utilized for analysis will be presented in the chapter. Chapter Four outlines the results of the faculty collaboration patterns found at Tsinghua. Chapter Five discusses the findings and elaborates on the implications of the study's findings for policy, practice, and research.

CHAPTER 2 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

The first part of this chapter reviews the scholarship on research collaboration with a focus on social network analysis (SNA). The second part of this chapter draws upon social capital theory, organizational embeddedness, and organizational theory to provide a conceptual framework for this study. Guided by the literature review and conceptual framework, several research expectations will be raised in the conclusion.

Literature Review

SNA has been increasingly used to study coauthorship. Coauthorship is used as a proxy for collaboration and as link between scientists within or across institutions. The boundary of coauthorship can be at nations, institutions, disciplines, journals, or conferences. This study will benefit by learning from the studies that examine the micro-dynamics of the coauthorship network and the impact of coauthorship on higher education.

Coauthorship Trends

A body of scholarship on global scientific systems and internationalization of higher education is concerned with global collaboration in research. Coauthorship trends documented in past studies can help understand the macro-structure that may shape Tsinghua's global network. First, global collaborations have increased over the last 10 years. The percentage of worldwide Science & Engineering articles produced with international collaboration rose from 17% to 23% between 2008 and 2019. Among the 15 largest producers, most have higher rates of international collaboration such as the United Kingdom (62%), Australia (60%), France (59%), and Canada (56%). European countries show higher rates of international collaboration of all publications. The European Union (EU) also shows higher internal integration, which might due to geographical

proximity and the EU policy that only research projects involving at least three EU countries can receive public funds (Wagner, 2018).

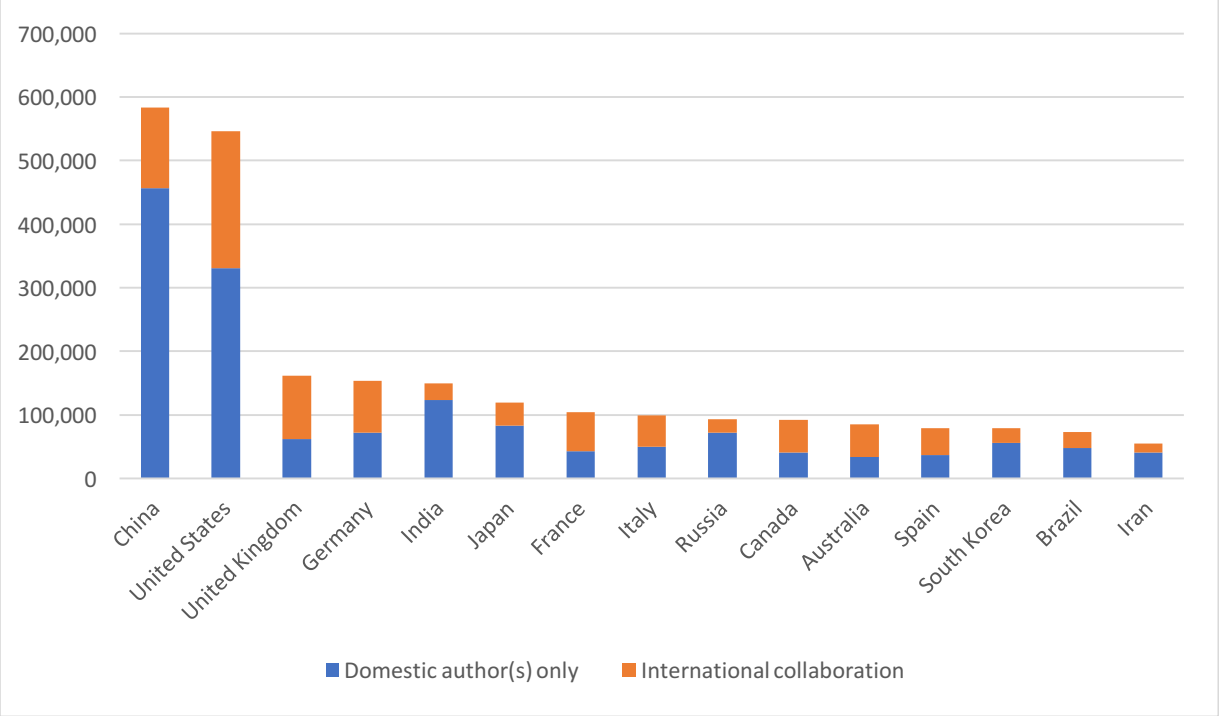


Figure 2.1 International coauthorship of S&E articles, for the 15 largest producing countries of S&E articles by country (2018)
Source: National Science Board, Science & Engineering Indicators, accessed July 2020.

Second, as countries with large S&E production, China and the United States have a collaboration rate of 22% and 39%, respectively (NSB, 2020). Given the large size of scientific systems and publications in the U.S., the large share of international collaboration shows the leading position of the U.S. in the global scientific system. The international collaboration rates for China are relatively low among largest producers. China-U.S. international collaboration has risen over the years. In 2018, about 26% of U.S. international coauthored articles were collaborated with researchers from China. Of all China's international collaboration in 2018, about 44% were collaborated with U.S. authors, which is the highest collaboration rate among collaborators of the U.S. The strength of partnership can be obtained by dividing a country's share of collaboration

with another country by its overall share of international collaborations with all countries. The strength of ties between China and the U.S. rose from 0.80 in 1996 to 1.17 in 2018.

Third, internationally coauthored papers are cited more than single-name papers. Policy makers, funders, and institutions have either directly or indirectly assigned more credit to coauthorship. Katz and Martin (1997) found a number of agencies gave preferences to multidisciplinary, multi-institutional, and multi-national teams in grant-awarding decisions in natural sciences and medicine in the U.S. (Kuzhabekova, 2011).

Besides capturing trends with international comparisons, some studies aim at comparing collaboration patterns across disciplines and fields. Friedkin (1991) found that the sub-disciplinary specialty area, rather than the disciplinary department, is the most important and consistent unit structuring collaborations. Newman found that, in general, experimental fields show higher coauthorship than theoretical fields. For example, the number of authors per paper was 1.7 in physics; 3-6 in biomedical research and computer science; and 11 in high-energy physics. Moody (2004) examined the collaboration patterns in sociology and found collaboration was more common in more scientific fields rather than humanistic or interpretive subfields when quantitative methodologies are more likely to be used. Additionally, some scholars noticed the feature of *fragmentation* in certain fields and national contexts. Gossart and Özman (2009) demonstrated that Turkish researchers in the social sciences and humanities orient towards two distinct populations by whether they publish their work in international or Turkish journals.

A few studies in the Chinese context add our knowledge to China's changing position and performance in global collaboration. Haiqi and Hong (1997) analyzed articles published in 1,218 Chinese journals in 1993 and found 25% international co-authored articles were with scholars in Japan, followed by the United States (23%) and Germany (10%). Niu and Qiu (2014) studied

international research collaboration in Chinese universities from 2002 to 2011 and mapped the countries and fields that Chinese scholars connected to by research collaboration. They found that collaborating with faculty from the United States was mainstream for international research collaboration for Chinese faculty; 30% of the international collaborated articles were with American scholars. The field with the most collaboration was physics and the fastest-growing field was molecular biology, whereas the scale and growth of international collaboration in the social sciences was limited. He (2009) examined China's collaboration with G7 countries and found the existence of different foreign partners for different fields. For example, the United States was China's major collaborator in the field of bioscience and neuroscience, whereas Japan was the major collaborator in chemistry. In an analysis on the collaboration between China and the U.S. in the field of nanotechnology between 1990 and 2009, they found the number of co-authored papers between the U.S. and China was twice that for Japan, the second-placed foreign partner for China, and three times that for Germany, the third-placed foreign partner. China-U.S. collaboration in nanotechnology exhibited a centralized pattern, with Tsinghua University and Peking University having the most China-U.S. collaborative nanotechnology articles. One-third of China-U.S. co-authored nanotechnology papers had at least one author from Beijing (Tang & Shapira, 2011). Yan, Ding, and Zhu (2010) identified the collaboration pattern and network structure of the coauthorship network of library and information science in China. They found the centrality status of coauthors were highly associated with the citation rankings of the co-authored paper.

Moreover, in the recent decade, studies of faculty life in Chinese universities have emerged. The internationalization of faculty life has been discussed by many studies such as Rhoads et al.'s (2014) on faculty lives in four rising Chinese research universities, and Xie's (2018) study on the changing face of the academic life of Chinese social scientists. Although such work did not focus

on faculty collaboration, the organizational contexts and faculty perspectives presented were closely related to the issue of research collaboration. For Tsinghua, Rhoads et al. (2014) highlighted the traits of entrepreneurialism and internationalization as part of the Tsinghua spirit and culture, so they discussed the close university-industry ties and international connections that Tsinghua holds. They found there were rising expectations and pressure on faculty, which drove faculty engagement in applied science research to entrepreneurial ventures. Moreover, as Tsinghua stressed the value of foreign talent and actively recruited professors from abroad, Tsinghua faculty members' collaboration with international scholars were great. As Rhoads et al. noted, foreign experts have collaborated with Tsinghua faculty and students in conducting research projects and publishing research papers and reports. For visiting professors, collaboration also often continues even after they leave Tsinghua. Xie (2018) stated that internationalization in Tsinghua promotes the adoption of internationalized criteria in faculty recruitment and promotion mechanisms; stimulates enthusiasm for international activities; and strengthens internationally oriented norms and practices in teaching and research. Additionally, during her interview with Tsinghua professors, Xie found a hierarchy of different discipline groups in Tsinghua with the natural and engineering sciences at the top and the social sciences at the bottom. The hierarchy of faculty groups by discipline reflects the severe discipline imbalance in research output in China, despite the hierarchy of discipline exists in the global network of research (Marginson, 2011). In 2016, the combined proportion in social sciences and psychology of all papers was 10.7% in the U.S. and 10.1% in the EU, but only 1.3% in China (NSB, 2018). China's share of NS publications accounts for 18.6% of all global publications in 2018 (NSB, 2018), whereas the share for HSS publications in Scopus database is only 3% in 2018.

The institutional context described in such work may have shaped Tsinghua faculty members' collaboration behaviors, given they had been provided the opportunities to collaborate with either industry or overseas professors, but it is not yet clear whether the institutional structures affect faculty members' choices of collaborators for publications. A study on faculty collaboration behaviors could further contribute to the understanding of the ways in which institutional structures intervene faculty working lives. It is also essential to regard faculty as actors to see if they resist being affected by institutional cultures.

Social Network Models on Coauthorship

Social network scholars have identified several fundamental characteristics of collaboration network and formed three models to approach coauthorship networks across fields – small-world model (Milgram, 1969; Watts, 1999; Watts & Strogatz, 1998); scale-free model (Barabási & Albert, 1999); and structural cohesion model (Moody & White, 2003; White & Harary, 2001). The patterns and interpretations of the three models are illustrated in Table 2.1. Newman (2001) identified the existence of small worlds of scientists in three fields: biomedicine, physics, and computer science. The "small world" networks have high clustering coefficients and short path lengths, which implies researchers share a lot of ties and that a few long-range ties connecting individuals in distinct clusters. Many empirical studies confirmed the "small-world" characteristics of research collaboration by analyzing different disciplines or fields such as digital library (Liu et al., 2005) and informational studies (Cheong & Corbitt, 2009).

Table 2.1 Three models of network

Models	Patterns	Interpretation
Small-world	High clustering coefficients, short path lengths; Distinct clusters linked by a small number of links	Scholars work in well-defined research specialties may lead to distinct clusters

Scale-free	A power-law degree distribution	The network may be generated by preferential attachment
Structural cohesion	Ties are distributed evenly in the network without a clear structure	Scholars mix freely across multiple areas

The scale free and structural cohesion models described research collaboration in alternative ways. The "scale free" model argues distribution of the number of unique collaborators will have a scale-free power-law distribution, which indicates the core-periphery structure of the network. Newman (2001, 2004) analyzed academic networks in biology, physics, and math and found a greatly skewed distribution of ties, with most individuals having only one or a few coauthors, but a few having hundreds or even thousands. Others have identified similar patterns in the fields of sociology, chemistry, mathematics, chemical engineering, biotechnology, information science, and other physics networks (Durbach et al., 2008; Kronegger et al., 2011; Moody, 2004; Tomassini et al., 2007; Xu & Chau, 2006). By mapping a biomedical research network, Brieger (1976) found that researchers at the core are most visible to the network and those at the periphery direct their attention inward to the center of the network. Researchers' awareness of their colleagues in the hierarchical structure makes the preferential attachment principle important in academic collaboration work, the mechanism of which will be elaborated upon later in this literature review.

The *structural cohesion model* (Moody & White, 2003; White & Harary, 2001) refers to the network across which ties are distributed evenly without clear fissures in the structure (Markovsky, 1998). Structural cohesion networks are opposite to the preferential attachment networks in that the connectedness of the network is not affected with certain nodes removed in structural cohesion networks (Moody & White, 2003). In Moody's (2004) analysis on sociology

by using longitudinal data from 1963 to 1999, it is found that in sociology networks, stars are not crucial for connecting the network and the ideas seem to spread over the entire network.

Tie Formation Mechanisms in Coauthorship Network

Social network studies have been focusing on exploring micro-dynamics within networks – tie formation analysis. Borgatti and Ofem (2010) labeled this type of social network analysis as *partner selection* research. This type of research focus on the mechanisms of tie or network formation to study the "who collaborates with whom" and uses ties or networks as dependent variables. These studies are concerned with the extent to which some individual and contextual factors predict the formation of ties. Individual factors can include choice of collaborators (i.e., whom to collaborate with) or positions in the network (e.g. centrality, betweenness, etc.) and contextual factors are some group and subgroup features. In this section, I will mainly review literature about the two mainstream organizing principles in this section: *homophily* and *preferential attachment*.

Homophily. Homophily argues that contact between similar people occurs at a higher rate than among dissimilar people – "birds of a feather." Lazarsfeld and Merton (1954) distinguished two types of homophily: *status homophily* and *value homophily*. Status homophily is based on sociodemographic characteristics like race, ethnicity, sex, or age and acquired characteristics such as education, occupation, and social class. Value homophily refers to values, attitudes, and beliefs (McPherson et al., 2001).

Status Homophily. Status homophily argues that people who are more structurally like one another are more likely to engage in issue-related interpersonal communication and to attend to each other's issue positions. Therefore, individuals in the same positions in one or more networks will likely to collaborate with one another (Burt, 1987; DiMaggio & Powell, 1983). Additionally,

the concept of structural equivalence is used to explain the formation of common attitudes and practices in terms of similar network environments (Borgatti & Foster, 2003). DiMaggio & Powell (1983) use measures of structural equivalence to model the notion of organizational isomorphism.

A network analysis of inter-university teams found that faculty were more likely to collaborate with colleagues from universities of similar prestige. Taramasco, Cointet, and Roth (2010) found that faculty tended to work with individuals sharing commensurate expertise in the work or having done similar prior work. Dahlander and McFarland (2013) found that homophily was a strong predictor of a first tie and a relatively weak predictor of a repeated tie, which suggests that the collaboration decisions that faculty make as they know each other better could not be based on homophonous traits between them.

Value Homophily. As value homophily refers to values, attitudes, and beliefs, the "visible colleges" phenomenon can be an example of value homophily, which shows that there is a tendency of scholars to collaborate only with other graduates of their schools (Katz & Martin, 1997). Experiencing the same academic traditions during their formal education leads these researchers to obtain similar scientific and technical human capital, defined as professional network ties, technical skills, and resources (Bozeman & Corley, 2004), which establishes an exclusive network for them (Crane, 1972).

The notion of "academic tribes and territories" (Trowler, 2001) argued that disciplinary knowledge and culture were influential in determining whether researchers operated alone or in large groups, and what the object of their research was. The impact of academic disciplines on collaboration trends is discussed in many works of research and the differences in collaboration between the natural sciences, social sciences, and humanities are significant in many cases. As a consequence of different academic cultures, faculty members' academic training – PhD degree,

involvement in research projects, post-doctoral experience – affects faculty research (Corley & Sabharwal, 2007).

Research has documented a positive side for the effects of homophily on group or individual performance outcomes. As Borgatti and Foster (2003) documented, homophily can facilitate transmission of tacit knowledge, simplify coordination, and avoid potential conflicts; however, homophily maintains inequality of status for minorities within organizations (Borgatti & Foster, 2003).

Proximity. A number of scholars extend the homophily perspective to address the geographic and cultural proximity, as homophily suggests that information that flows through networks tends to be localized. Geographical or spatial proximity is often thought to influence the conduct of informal communication (Traore & Laudry, 1997), which is the starting point of collaboration. A lot of research collaboration starts with accidental encounters that help researchers discover opportunities, then proceeds to the exploration of possibilities, and ends in collaborative consummation (Jeong et al., 2011; Katz & Martin, 1997). People tend to interact more with colleagues who are spatially proximate. Researchers prefer collaborating with partners with whom they can conduct close personal interaction (Numprasertchai & Igel, 2005) and most collaborations begin in richer communication environments, such as conferences and research sites (Wagner & Leydesdorff, 2005). Borgatti and Foster (2003) concluded that physical proximity, similarity of beliefs and attitudes, and amount of interaction are interrelated. Moreover, geographic space is more important in determining the "thickness" of a relationship (its multiplexity and the frequency of actual contact) than it does in determining the presence of a tie (McPherson et al., 2001).

Contrary to the physical proximity argument, some have conjectured that scientists prefer to work with the right people even if there is great physical distance between them (Katz & Martin,

1997). Cultural/linguistic proximity has also been discussed as a collaboration determinant. For example, Traore and Landry (1997) found that bilingual Québecois researchers who speak both English and French tended to collaborate more widely than their monolingual counterparts. Members' understanding of the possible cultural differences among them affects their collaboration significantly (Easterby-Smith & Malina, 1999). Additionally, the new technology has allowed people to create ties that may not be physically proximate.

Preferential Attachment. Crane (1977) found that the diffusion of the work of a co-author of lower status occurred more rapidly when coupled with the name of a higher-status scientist. Following Crane, Beaver, and Rosen (1979) argued that coauthorship was an acknowledgement of financial or intellectual dependency within a hierarchical social system of science, which suggests that actors tend to seek to connect to high-status academics – the essence of the principle of preferential attachment, i.e., the "rich get richer" phenomenon. Moody (2004) argued that high-status actors in the organizations brought academics more and quicker access to others that are meaningful and collaborative. High-status actors are also responsible for connecting the network, which shows the structural feature for the *preferential attachment* model.

BarabaÃsi et al. (2002) found that networks evolved through two mechanisms: the addition of new nodes, and new links between existing nodes. Their study confirmed that node selection was governed by the principle of preferential attachment. Wagner and Leydesdorff (2004) examined coauthorship patterns for six fields of science and found that the principle of preferential attachment based on reputation and rewards explained the growth in international linkages. They found that the highly visible researchers, the "continuants," within the field could choose among potential collaborators, the "newcomers." In most of the studies of collaboration networks in many fields, preferential attachment has been found to be a significant mechanism of tie formation.

On the contrary, some research has found that the mechanism of preferential attachment does not hold. In an analysis of the coauthorship network of 300,000 articles in nanoscience, Milojević (2010) found preferential attachment does not hold among authors with fewer collaborators than twenty. Biancani and McFarland (2013) suggested that future studies should consider dividing the population along these lines if an analytic network has a large team size. However, some research that failed to find the preferential attachment mechanism may be due to the small sample size that lacks the statistical significance (De Stefano et al., 2010).

Much research studied the role of seniority – being older or higher in position or having a more privileged status than someone else in the organization – in coauthorship. Factors such as faculty age, time in the profession, tenure status, academic performance, and administrative position could indicate the seniority of a faculty member in the system. The positive role of seniority in coauthorship reflects the core-periphery structure of the research collaboration, which is the underlying assumption of the tie formation mechanism of preferential attachment.

Seniority is found to be positively associated with faculty members' likelihood to collaborate and the number of collaborators one might have: the more experienced the researcher, the higher the tendency to collaborate (McDowell & Melvin, 1983; van Rijnsoever & Hessels, 2011); the more highly ranked the academic department to which the researcher belongs, the higher his or her propensity to collaborate (Piette & Ross, 1992); and the higher the author's rank, the higher his or her inclination to collaborate (Vafeas, 2010). Merton and Zuckerman (1973) explicitly addressed the role played by age and seniority in coauthorship, noting that collaboration was most likely in the middle years and that the processes involved could be reconstructed in terms of age-patterned opportunities and motivations for collaboration. Bozeman and Gaughan (2011) note that the number of research collaborators was positively associated to tenure status, having

an active grant, being affiliated with a research center, and having more collaborators. In addition, studies also suggest the opportunity cost of engaging in more commercial research collaborations is lower for older university faculty (Haeussler & Colyvas, 2011). Kollasch, Rios-Aguilar, Torres-Olave, and Rhoades (2016) studied United States' academics' collaboration networks outside their universities in the United States. They found that networks tend to be larger for senior faculty in a more secure positions at their institutions and that the collaboration networks are generally more local and national than global. Kollasch et al.'s (2016) study provides evidence based on large-scale data for the argument that stratification structure of academic labor force shapes academics' collaboration network.

Additional Mechanisms. Besides homophily and the preferential attachment principles of partner selection, the organizing principle of "follow-the-trend" (isomorphism, DiMaggio & Powell, 1987) and "multi-connectivity" were examined in a study by Powell, White, Koput, and Owen-Smith (2005). Powell et al. (2005) studied the process of partner selection in the field of life sciences using longitudinal data over a period of 12 years. Follow-the-trend mechanism suggests actors tend to choose a partner who is comparable to the choice of most other participants. On the contrary, the principle of multi-connectivity presents the inclination to the heterogeneity. Powell et al. (2005) found that a combination of preferential attachment and multi-connectivity worked for central participants, but no single mechanism dominated over all time periods. As fields are evolving themselves over the time, the differences of tie formation mechanisms between fields in terms of academic collaboration should be accounted for in research. Therefore, it is beneficial to use longitudinal data to capture the evolution of networks, rather than simply taking snapshots of the network at certain points in time.

McFarland, Biancani, Rawlings, and their colleagues collected longitudinal data on all Stanford faculty from CVs, Web of Science, and Stanford's administrative data. They examined five forms of faculty collaboration, including coauthorships, shared dissertation committees, co-investigators on grants, shared research center affiliations, and shared departments (Dahlander & McFarland, 2013; Rawlings & McFarland, 2011). Much of their research was grounded at the dyadic level, as tie formation and persistence was their major focus. Besides homophily and preferential attachment, their work tested many other mechanisms of tie formation and persistence, including organizational foci, cumulative advantage, triadic closure, tie inertia, and means-ends rationalization (Dahlander & McFarland, 2013).

Triadic closure stems from the logic that ties are more likely to form between the two individuals if they have mutual friends – the "friend of a friend" effect, which suggests a tendency for researchers with indirect ties to form a direct one – "the collaborator of a collaborator" (Friedkin, 1980; Newman, 2001). Stronger ties matter the most for the triadic closure. Dahlander and McFarland (2013) found that indirect ties were important means of discovering potential partners so that the triads tended to close, but the indirect ties had no effect on the persistence of ties. Such mechanisms as *cumulative advantage* and *tie inertia* (Seabright et al., 1992) study the persistence of ties, which are not the focus of this research on tie formation but are important organizing mechanisms for social network researchers to consider while thinking about tie formation mechanisms. *Cumulative advantage* refers to the argument that faculty who have aggregated social ties and multiple resources – grant funding being a most powerful one at universities (Small, 2009) – have greater returns in research productivity. Although cumulative advantage addresses the tie persistence part of the network evolution, the principle is important in guiding the tie formation mechanism of preferential attachment. Dahlander and McFarland (2013)

found that a well-connected individual (i.e., one with more social ties) was more likely to collaborate with other well-connected individuals than to seek more peripheral collaborators. Also, they found individuals with more grant funding were more likely to collaborate with others. However, Dahlander and McFarland found the same reasons did not contribute to the persistence of ties. As Ahuja (2000) mentioned, there was a limit to the number of ties that one could have, as time and effort were essential in maintaining ties. An unsuccessful collaboration will affect the persistence of ties, so the dissolution of ties could be explored in future studies. *Tie inertia* is concerned with the impact of tie strength and tie multiplexity on the persistence of ties. Dahlander and McFarland (2013) found as a tie changes from being uniplex to multiplex, it is more likely to repeat; in other words, strong ties are more likely to be renewed.

This section reviewed both theoretical and empirical research on mechanisms of tie formation, among which the principles of homophily and preferential attachment are the two most-used mechanisms in the studies of collaboration. Other mechanisms such as the triadic closure, isomorphism, and multi-connectivity also guide some analysis on tie formation. Besides tie formation, tie persistence and dissolution has also been the subject of many studies, so this section also reviewed principles such as the tie inertia and cumulative advantage to build an understanding of the tie persistence. Despite the fact that tie persistence and dissolution is not the focus of this research, it is a significant component of the network evolving process and should be taken into consideration in tie formation analysis as well.

Summary

Three major points that emerged from the review of literature guide the conceptualization of this research: First, it is important to note the role of multiple factors and mechanisms at play in the tie formation process. The previous research studied a variety of individual predictors of

collaboration patterns, but it is unclear how these factors collectively affect faculty collaboration. No single factor or mechanism can dominate the entire process of tie formation or maintenance; thus, relying on one or two factors or mechanisms will likely simplify the tie formation process.

Second, the prior studies, based on bibliometric information of faculty, focused on capturing coauthorship trends in country or field, but have not considered much about the organizational context where the coauthorship is built. Universities are important sites for collaboration and coauthorship is a huge component of faculty life in universities. While prior research has documented different network patterns and shapes across academic fields, not enough discussion has focused on the ways in which different fields shape faculty collaboration behaviors. There is a major gap in the literature between organizational and social network theories (Kezar, 2014). Faculty tie formation should be understood in the context of the university and its sub-organizational units, and the discipline. Focusing on the sub-organizational variations in faculty coauthorship patterns will allow for a more nuanced understanding of faculty tie formation in this study.

Third, faculty voices are rare in these empirical analyses. Qualitative field work could help explain the gaps that large-scale longitudinal analyses cannot account for. The tie formation process could either be a purposeful or non-purposeful event. The role of faculty in the evolution of network at different stages should be examined. It's unclear in such a process whether a faculty is active or passive, and it is yet to be clear by what means a faculty tries to build collaboration ties with others. Do faculty exhibit strong motivations to form a relationship with star researchers, as preferential attachment argues, and why? Do they collaborate with people at the same rank, as status homophily suggests, and why? The university context, and the sub-field structures therein, may mediate the mechanisms of tie formation and may shape the collaboration behaviors of faculty.

A detailed understanding of faculty members' meaning making of their collaboration motivations and behaviors is important to complement the social network analysis which should not be purely quantitative as it seems to be. The gaps in literature further motivate this study. This study addresses the first two points illustrated above and will focus on the third point by field work in future studies.

Theoretical Frameworks

This research is designed to explore Tsinghua's social relations as measured by research coauthorship. A major focus of social capital theory is on social relations in social structures, which makes it an appropriate grounding framework to guide the conceptualization of this study. This section first introduces the concept of social capital and its connections with several theoretical perspectives in the social network studies. As Tsinghua has its departments and schools as sub-units, it is imperative to incorporate the university structures and contexts into the conceptualization. The "organizational embeddedness" theory is complemented to the social capital and social network theory in guiding this study.

Introducing Social Capital Theory

Social capital theory is a widely-used theory and framework in sociology and has many definitions and interpretations across fields and time, but the intellectual roots of the theory lie more firmly in the works of Bourdieu and Coleman (Small, 2009). Bourdieu defined social capital as "the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition" (Bourdieu, 1986, p.246). Bourdieu sees social capital as a form of capital that can be acquired by members of a social network or group. For Coleman (1988), social capital is a function of social structure producing advantage. He also studied the role of social capital in the creation of human

capital.

Lin (2002) synthesized Bourdieu's and Coleman's work and defined social capital as "the resources embedded in a social structure that are accessed and/or mobilized in purposive actions." He claimed that social structure matters for accessing and using social capital and the structure includes: 1) *positions* showing social embeddedness; 2) *authority* acting as power to control access; 3) *rules and procedures* that lead to uniform actions; and 4) *agents* who occupy positions and are empowered to act out the rules and procedures. Lin saw social capital as constrained by the position in the organizational structure, accessibility through the network, and the hierarchical structures of the network. Besides emphasizing the importance of structure, he added that opportunity and action are major components of social capital.

There are several assumptions or principles that help theoretically explain who is more likely to gain better access to social capital: 1) the structural position of the ego (node); 2) the strength of the tie; 3) the location of the tie in the networks. In next section, I will illustrate several theoretical trajectories that conceptualize how social capital is accessed.

Network Cohesion as Social Capital

Social capital contains resources that are embedded in the ties of one's networks, which include materials goods and symbolic goods such as education, degree, reputation, and fame. Individuals may or may not be aware of the social capital they possess. Coleman thought collective social capital could be maintained or reproduced in dense or closed networks. Similar to Coleman's view, Robert Putnam defines a group's social capital in terms of broad cross-cutting interconnections among all group members (Borgatti & Foster, 2003).

Coleman's *network closure* argument is prominent with respect to social capital. Coleman (1990) described "any social structure with a higher than average density of obligations as a group

with *closure*" (Meyer & Rowan, 1977). Closure means the existence of sufficient ties between a certain number of people (Portes, 1998). The network closure argument is supported by the highly influential theory regarding tie strength first documented in Granovetter's 1973 paper. Granovetter defined strong ties as those having a higher degree of intensity, frequency of intimacy or trustworthiness, reciprocity, and acknowledged obligations among the relationships. The stronger the tie, the more likely the sharing and exchange of resources (Granovetter, 1977). The norms and trust observed by all the members of the community further facilitates the formation of stronger ties while lowering the risk of cooperation and stronger ties are conduits for getting access to social capital. Related to the principle of value homophily (e.g. Lazarsfeld and Merton, 1954), stronger ties reflect the similar or contiguous characteristics of resources shared within the community. Strong ties allow access to social capital that is similar, thus the strength-of-strong-tie also reflects a structural advantage (Lin, 2002).

Structural Hole as Social Capital

Contradictory to the network closure proposition that conceptualizes social capital as acquired in dense networks, the structural hole theory posits that social capital is produced through a loosely coupled network in which actors can broker connections between otherwise disconnected segments (Oh, Chol & Kim, 2005). Burt (1992) defined *structure hole* as "the separation between nonredundant contacts" and a "relationship of nonredundancy between two contacts." A structural hole is a "buffer" and a "bridge" that connects two contacts in distinct cluster. The "bridge" or "structural hole" serves as an important role in accessing to resources in both social circles. Thus, "the closer individuals are to a bridge in a network, the better the social capital to which they will have access" (Lin, 2002).

The spanning of structural holes provides actual mechanism relating weak ties to positive outcomes in Granovette's (1973) strength of weak ties theory (Borgatti & Foster, 2003). The weak tie is additive rather than overlapping. Weak ties contribute to individual's access to better information in other social circles than one's own, which allows access to wider resource heterogeneity (Lin, 2000). In a coauthorship network, strength-of-weak-ties theory suggests that members within a weakly-tied social network may be more different than similar (Sawyer & Crowston, 1999). Coauthors with a higher number of weak ties will have more social capital. The diversity of contacts measured as the number of coauthors can be an indicator of the power and influence of a scholar's ability to control communication and information (Abbasi et al., 2011). Additionally, the weakest ties are not useful as they provide no incentive for exchanges (Bian, 1997). The effect of bridge or structural holes and effect of weak tie share similarities, but are not the same. The argument of structural hole or bridge highlights the important of tie location and provides a more structural account of social capital advantage (Lin, 2002).

Scholars have referred these two forms of social capital as the "bonding" and "bridging" social capital. The bonding mechanism emphasizes the important of ties that were reproduced and connecting members whereas the bridging mechanism highlights the heterogeneity of resources that cross boundaries. Burt (2000) argued that whether social capital functions to bond or to bridge depends on the context.

Social Capital and Organizational Embeddedness

Social capital theories such as "strengths of weak tie" and "closure" explain how social capital can be assessed from the micro-level, but the successful mobilization of social capital also relies on the resources embedded in social networks that are affected by the organizational context. People's agency in mobilizing connections matters, but the mobilization is also mediated and

sometimes perpetrated by organizations. Organizational opportunities and constraints may affect the relative utility of stronger or weaker ties (Lin, 2002). As Small noted (2009, pp.15), "In sum, independent of their own intentions, people are more likely to form ties when they have opportunities to interact, when they do so frequently, when they are focused on some activity, when they are not competitors, and when they have reason to cooperate." According to social capital theorists, resource gaining and maintaining is a rational investment (Lin, 2002), but if mediated by the organizational context, tie formation process may exhibit different patterns.

Small (2009) summarized three means by which organizational contexts may affect social capital: 1) Organizational contexts affect most aspects of social capital, including whether a person makes ties; what kind of ties s/he makes, whether the goods in those ties are available to the person; and how those goods are acquired; 2) Organizations may affect social capital either purposely or non-purposely, and through the influence of either actors or institutional practices; and 3) Organizations, or their members, may be motivated to affect social capital by either internal or external pressures. In sum, the context of social interaction is shaped by both the actors and the institutional practices that constitute an organization, which may be motivated by internal and external factors (Small, 2009).

The theoretical perspective of organizational embeddedness is an essential lens that guides this research. It adds a layer to the social capital theory by highlighting the role of organizational context in social relations. Coauthorship is conceptualized as an individual faculty behavior in the context of both university and sub-organizational units.

The Organizational Contexts: University, Sub-unit, and Field

Powell & DiMaggio (1998) defined an organizational field as a result of the activities of a diverse set of organizations that constitute a recognized area of institutional life. Powerful forces

and norms of the organizational field shape the accessing of social capital. An institution shapes actors' perceptions of their circumstances (Meyer & Rowan, 1977). In the normative sense, an organization may enforce rules and norms that its actors feel compelled to follow (Nee & Ingram, 1998), such as a policy that new faculty members should teach more classes in their first years or a norm that publishing in English receives more credit. Universities are composed of departments/schools, faculty, students, staff, and institutional practices such as teaching, meetings, and so forth.

A university is a loosely coupled entity (Meyer & Rowan, 1977), the units that compose it may be motivated by separate objectives and beliefs. Academic departments as universities' basic subunits should reflect the overall institution's priorities and values, but departments also reflect the influence of the larger academic fields (Lee, 2004). Departments are the intersections of the institutions and disciplines, thus departmental level duties are highly unstandardized within universities (Clark, 1987). Disciplines and their objects of study (e.g., particles vs. people) are in part socially constructed through shared paradigms (goals, methods, interpretive schema) for performing research (Kuhn, 1970), so that disciplines are distinct ways of working and knowing – i.e. they have their own languages, cohering around totems and rituals (e.g. academic journals and conferences), and seeking to reproduce their social structures and statuses through the control of professional rewards (Bloor, 1991; Collins, 1994; Knorr-Cetina, 2009).

Moreover, prior research found that some knowledge domains indicate a high paradigm as they have an overarching agreement on the goals and methods of research (Kuhn, 1970). For example, the social sciences are not high-consensus disciplines (Collins, 1994). A high paradigm has a stronger and more centralized social organization. Higher-paradigm fields have greater mechanical solidarity, while lower-paradigm fields rely more on interpersonal contact to generate

mechanical solidarity (Rawlings & McFarland, 2010). The collaboration patterns across departments may reflect the nature of low or high paradigms.

Additionally, the lens of academic culture is appropriate in this study, which regards faculty life as a cultural process where faculty become enmeshed and change within (Clark, 1987). Tierney and Rhoads (1993) elaborated on five aspects of academic culture that affect the socialization process of faculty life, including the culture of the nation; the culture of the profession; the culture of the discipline; and the culture of the institution; and the individual cultural differences. These aspects are interconnected and have weighted impact on faculty experience. Faculty coauthorship motivations and behaviors can also be affected by their identifications with their institutions and their disciplines.

The Present Study

In this study, coauthorship is conceptualized as a social relationship that is also a form of social capital. Research questions explore how the coauthored ties are distributed at local, national, and global levels by sub-organizational levels at the university. Guided by the theories, a major argument that this research proposes is that the structural position and status of sub-organizational units in the coauthorship network of the university reflect the group social capital they possess, though they may have different forms of social capital obtained through structural hole or network closure. The organizational contexts at institutional levels may further shape accessing and mobilizing social capital for sub-organizational units and individuals.

Social networks play a central mediating role between micro and macro levels. Granovetter (1985, 2017) asserted that the "meso" level of social networks helps avoid the theoretical extremes of under-socialization and over-socialization – "actors do not behave as atoms outside a social context, nor do they adhere slavishly to a script written for them by the particular

intersection of sociocultural categories they happen to occupy" (Granovetter, 2017, pp.14). The conceptualization of this study is grounded in the framework of social networks, which constitutes a meso level of research lying between individual action and social institutions and cultures. With a focus on the influence of organizational factors on the coauthorship network, this study also tries to incorporate individual factors into the study.

In light of the theoretical framework, the analysis and interpretation will be conducted in the following manner. To answer the first question, the network size and number of nodes and edges within different boundaries of data is the major indicator utilized. In answering the second question, the dimension of sub-units of the university – departments or schools – is added. The third question focuses on the within-university network in terms of intra-organizational and inter-organizational network. With respect to inter-organizational networks, the centrality of each sub-unit in the graph is calculated in four major forms including degree centrality, betweenness centrality, closeness centrality, and eigenvalue centrality. Each way of calculating centrality reflects different focus of coauthorship patterns in the network. With respect to intra-organizational network, the network features – size and connectivity – of each sub unit are examined and compared. The connectivity or cohesion within the network is measured by number of components, size of giant component, transitivity scores, and average tie strength. The fourth question explores how the varied network features identified in the above questions may be related to the varied social capitals among sub-organizations of the university. How the faculty-faculty connectivity within a school/department will be associated with the school/department external productivity and reachability is a focus in answering the last sub-question.

Table 2.2 Four centrality measures, definitions, and interpretations

Centrality	Definitions	Interpretation by social capital theories

Degree centrality	The number of direct ties a faculty member has	Central nodes acquire most direct relationships within the network, thus possessing good social capital
Betweenness centrality	The probability that a path from any two actors takes a particular path	Central nodes act as "gatekeepers" or "bridge", thus having more social capital
Closeness centrality	A vertex is central if it connects to many other vertices.	Central nodes can reach more nodes in the network
Eigenvalue centrality	A vertex is central if its neighbors are central	Central nodes connect more well-connected nodes

Based on theory and past studies, several expectations for the answers are listed. First, implied by the principle of homophily, information that flows through networks tends to be localized, so the ties will be more local and national than international. However, with the worldwide trends of global collaboration increasing and China's rise in global science, there should be greater recent international ties in faculty coauthorship networks over the years. Second, the features of network patterns will vary by school culture and norms affected by the institution and disciplines. Network shapes – small-world model, a scale-free model, or a structural cohesion model (Moody & Paxton, 2009) – may vary by school networks of different schools. With the prior research findings in mind and the characteristics of different types of network, this study therefore posits: The academic patterns in the departments with high-consensus disciplines will be likely to share the features of the scale-free model, whereas the academic patterns in the departments with low-consensus disciplines will likely fit the small world model or structural cohesion model. Third, schools with higher status and prestige locally and globally should have denser networks. Dense networks possessing more social capital tend to have higher productivity (coauthored papers) and extensity (diversity of ties). Lastly, as individuals tend to seek to build social ties with those having better chances in mobilizing resources, coauthorship patterns will

reflect instrumental actions. Faculty central in the network will likely be (1) high-status faculty; (2) senior faculty; (3) faculty with diverse institutional experiences.

CHAPTER 3 METHODS AND DATA

This chapter first elaborates on the research design of this study and then explains the data collection, cleaning, and validation procedures in details. A brief overview of sample faculty information and primary publication data is included. This chapter ends with a section on the limitations of the methods and data for which the analysis and interpretation should account.

Research Design

This research focuses on one Chinese research university as a case study of network patterns of faculty within that university. A social network analysis logic and network measures are applied in this research. This study utilizes social network analysis (SNA) to examine faculty collaboration patterns within and cross the sub-organizations of a university and the ways in which individual and organizational factors shape coauthorship networks. Primary data relied on faculty profile information on school websites and publication data (2014-18) on Web of Science (the previous ISI Web of Knowledge, shortened to WoS in this paper). An exploratory research question frames this study: what features does the current faculty coauthorship network of Tsinghua exhibit? Four sub-questions focus on 1) tie distributions at local, national, and global levels; 2) sub-organizational variations in geographical distributions; 3) intra-organizational and inter-organizational patterns; and 4) relationships between network features and group social capital by schools/departments.

A Case Study

A case study investigates a phenomenon within its real-life context (Yin, 2017). This research adopts the case study methodology since the organizational contexts matter for the forming and transforming of collaboration network patterns. Chapter One outlined major events and changes in Tsinghua which corresponds with political and social changes taking place in

higher education and the state. Tsinghua University (shortened as Tsinghua or THU in this paper) is chosen as the case of this study for the following reasons.

First, Tsinghua is a prestigious national flagship university of China with a traditionally good local reputation as well as rising visibility in global rankings. Tsinghua has achieved top status among Asian universities and has been ambitiously enhancing its global visibility. The following table displays Tsinghua's ranking performance in the four widely used ranking systems. The large increase in rank goes hand-in-hand with Tsinghua's increasing publications in global science. Capturing Tsinghua's coauthorship patterns can contribute to understanding the rise of status of Tsinghua in global science and global higher education. Tsinghua is a comprehensive research university with 20 schools and 58 departments.[5] The faculty group of Tsinghua is one of the largest in China. The basic breakdown of students and academics in Tsinghua is presented in Table 3.2.

Table 3.1 Tsinghua's ranking performance change in the decade

	2011 Global Rank	2019 Global Rank	2019 Regional (Asia)
ARWU	151-200	43	3
US NEWS	NA	36	2
TIMES	58	22	1
QS	54	17	3

Table 3.2 The number of students, faculty, and researchers at Tsinghua (12/2017)

Students, faculty, researchers	Number
Faculty	3,416
Postdoctoral researchers	1,817

[5] http://www.tsinghua.edu.cn/publish/newthu/newthu_cnt/faculties/index.html

Enrolled students	47,762
Undergraduates	15,619
Incl.: international students	1,227 (8%)
Post-graduates	19,062
Incl.: international students	1,249 (7%)
Doctorate candidates	13,081
Incl.: international students	389 (3%)

*http://www.tsinghua.edu.cn/publish/thu2018en/newthuen_cnt/01-about-6.html

Second, Tsinghua has been a pioneer in China's higher education reform in many ways. With global ambitions in mind, Tsinghua led the personnel system reform and the comprehensive reform plan, among others. Internationalization, as an embedded pursuit of the world-class university quest, has been promoted in Tsinghua for years. Many forms of international collaborations occurred in Tsinghua, partly due to Tsinghua's promotion of the internationalization of its faculty (Rhoads et al., 2014). As elaborated in the introduction, before the comprehensive tenure reform started in 2014 and includes all faculty in Tsinghua, the school of life science and engineering have implemented their individual tenure system earlier as plot studies. Thus, acknowledging the unstandardized tenure reform stages among departments of Tsinghua is important for a structural understanding of the variations in coauthorship patterns across sub-units.

Third, Tsinghua has a reputation for strength in science and engineering disciplines, which partly explains a great number of university-industry collaborations in Tsinghua. Its engineering disciplines have moved up very fast in the world rankings in recent years. It is ranked the top university for engineering in the U.S. News and World Report. The ranking performance of Tsinghua's natural science cluster follows the lead of its engineering departments: physics (18th), biology and biochemistry (44th), and mathematics (50th). Compared with NS & ENG disciplines,

social sciences and humanities' visibility is minimal in global rankings. In U.S. News subject ranking and ARWU subject ranking, only the economics and business disciplines were ranked. The other disciplines in the HSS are not listed within the top 500 universities. Factors such as the orientation of the academic publishing system, differences in research paradigms, and the evaluative criteria of the ranking systems can provide additional explanations for the fact that Tsinghua's social sciences fall behind in the disciplinary rank. Receiving much institutional support and attention, Tsinghua's HSS have made great progress in the past two decades, trying to catch up with its rivals who have traditionally strong HSS departments such as Peking University and Fudan University. Therefore, the local dynamics in the disciplines and the associated sub-organizations within Tsinghua will add a layer to this study for examining departmental collaboration patterns.

Lastly, thanks to the internationalization efforts in recent years, the websites of Tsinghua are good and have both Chinese and English versions, which is particularly convenient when trying to collect data such as that used in this research. Although there is not a uniform layout or formatting style for every school or department in Tsinghua, most faculty members have their own profile pages on the university website and the information is mostly up-to-date. Moreover, Tsinghua library has been developing the Tsinghua University Research ID (ThuRID) database and has collected 2,554 faculty members' publication records and links to the articles. Data retrieved from ThuRID are important for ensuring the data quality of publication records collected.

To investigate this case, I will adopt the tool of network analysis. A thorough network descriptive analysis on faculty members' publication records and individual information across departments will provide a basic understanding of faculty collaboration patterns in Tsinghua, and further motivate the framework of fieldwork and predictive analysis in the next phases.

A Network Analysis

SNA has great potential to illuminate both the inner workings of higher education institutions and how they interrelate with society (Biancani & McFarland, 2013); but it is underused in research on higher education. The focus of this research on faculty networks, and specifically coauthorship patterns, makes SNA a perfect approach for this research. Given that faculty members often have many collaborators, network analysis allows researchers to study the structure of a complex web of aggregated relationships.

First, I collected faculty members' profile characteristics and publication data. The large amount of quantitative data collected allows for an extensive description of faculty coauthorship networks. Next, I examined the features identified from the networks and investigated how network features may be shaped in organizational contexts.

Data Collection

In this section, I explain the rationales for selecting the population of this study and describe the sources contributing to the dataset, followed by a detailed data collection, cleaning, and validation plan. A few network measures are introduced by discussing how I would use them to analyze the data.

Sampling

According to Tsinghua official website, Tsinghua has 20 schools and 58 departments, with some departments associated with the 20 schools. In certain cases, departments are also regarded as school units in the sample. Not every department or school is included in the sample. The sub-units that were excluded from the sample include: 1) schools where adjunct guest, visiting faculty, or practitioners are the majority; 2) schools or institutes that are training or professional oriented; 3) schools/institutes that are branches or joint campus that are located outside Tsinghua.

In summary, this study sampled a population of faculty members belonging to the 22 units (or interchangeably referred to as "schools"). The faculty network includes those who are full-time faculty members, so visiting professors, adjunct/guest professors, and post-doctoral fellows are not included in the sample. A basic breakdown of the population by school-level units (n=22) is shown in Table 3.3. A more detailed descriptive analysis of the population will be presented in the next chapter.

Table 3.3 Population by Schools (N=2,430)

School	Frequency	Percentage
Department of Chemical Engineering (no associated school)	75	3.09
Department of Electrical Engineering (no associated school)	36	1.48
Department of Engineering Physics (no associated school)	100	4.12
Institute of Education	27	1.11
School of Aerospace Engineering	123	5.06
School of Architecture	125	5.14
School of Civil Engineering	157	6.46
School of Economics and Management	164	6.75
School of Environment	92	3.79
School of Humanities	171	7.04
School of Information Science and Technology	462	19.01
School of Journalism and Communication	28	1.15
School of Law	69	2.84
School of Life Sciences	93	3.83
School of Marxism	29	1.19
School of Materials Science and Engineering	86	3.54
School of Mechanical Engineering	33	1.36
School of Medicine	90	3.70
School of Pharmaceutical Sciences	30	1.23
School of Public Policy & Management	58	2.39
School of Sciences	298	12.26
School of Social Sciences	84	3.46
Total	2,430	100

Data Sources

This research collected two categories of data: 1) faculty profile data, and 2) faculty publication data. Table 3.4 shows the components of data collection.

Table 3.4 Data collection components

Categories	Components
Faculty profile	
Basic demographics	Gender; ethnicity
Educational backgrounds	PhD institutions and graduation year; Master's and Bachelor's institutions
Prior work institutions	As a postdoc in HEIs; as a faculty member in HEIs; as a visiting scholar in HEIs; as an employee in industries, etc.
Current work situation	Rank/tenure status; administrative positions, if any; the start year in the university; the start year in this position
Other	Email addresses; CV or personal website links
Faculty publication data	
Basic information	Article title, publication type and year
Coauthorship data	Coauthor names, co-authors' affiliated institutions

Faculty profile data. Since it is difficult to obtain an official list of all full-time faculty in Tsinghua, I collected each faculty member's profile information through (1) faculty profile webpages on university websites; (2) faculty members' CVs or personal websites, if any; and (3) Google/Baidu/Wikipedia searches. As summarized in Table 3.4, I collected faculty members' basic demographics, occupational statuses, and prior educational and working experiences. The accuracy and comprehensiveness of the data depends on the information put on the departmental websites. Although I did multiple searches via different sources to cross-check faculty profile

information and filled in the missing information, there are missing data points for a few faculty for which the data analysis plan accounts.

This study captures a snapshot of faculty lists from 2018, since it is almost impossible to track personnel changes in every department over the years. This study is not able to track the information of faculty who retired, transferred to other institutions, or left Tsinghua at some point before 2018. Therefore, the size of the faculty group in previous years is likely to be larger than the group captured in this study. This study is designed to (1) capture the changes of collaboration patterns within and across universities within the recent five-year window (from 2014-2018), and (2) examine the factors that affect collaboration patterns by using five years' data. It is important to consider that the lack of data for former faculty members may impact the network patterns and bias the results to some extent.

Faculty publication data. I mainly retrieved faculty publication data from two interdisciplinary academic databases: Web of Science Database and Tsinghua Researcher's ID Database. Web of Science, a widely used comprehensive academic database collecting English publications. The Web of Science Core Collections include Science Citation Index Expanded (SCIE), Conference Proceedings Citation Index (SPCI, former ISTP), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), which collect important subsets of journals that Chinese universities value and use to evaluate faculty members. WoS also included the Chinese Science Citation Database (CSCD), which makes it a comprehensive database that includes almost all publications that will be valued by Chinese flagship universities.

ThuRID is a database collecting Tsinghua researchers' publications from multiple academic databases. It is still under development. The publications listed on ThuRID database were mostly verified by schools or faculty authors, which assures the quality of the data scraped

from the database. However, publications of faculty from a few schools such as the School of Social Sciences have yet been added to the database. Given the evaluation of the two databases and the research design, using a combination of the two databases would fit the research. The strengths, weaknesses, and the solutions to deal with the problems of the two databases are listed in Table 3.5.

Table 3.5 Data management of ThuRID and WoS databases

Databases	ThuRID	WoS
Strengths	Univ library official data Structured includes WoS data	Structured and clean complete information for each publication
Problems	Social sciences and humanities departments missing collaborators' addresses missing	Difficult to retrieve all the publications for scholars due to name spelling [One scholar may have 2-3 name formats] Large amount of data cleaning work
Solutions	Use this database as the main data for paper collection	Use this database to fill in address information missed in ThuRID. Use this database to collect publications that had not been collected by ThuRID.

Data Collection

This research used Python, a programming language/tool, to web-scrape the publication information of every faculty in the sample. Two parts of data were scraped from each publication front page: 1) basic information of the publication including the article title, keywords, publication type, year, and journal name or publisher; and 2) a list of co-authors and their institutions. Data were specifically collected by a few steps on ThuRID and WoS. The steps of actions are listed in Table 3.6.

Table 3.6 Data collection procedures

Step	Action	Outcome Data
1	Obtained a list of faculty name list on Tsinghua Webpages	List 1
2	Scraped ThuRID and get all information on ThuRID	Dataset 1

3	Filtered faculty in the list and have publications collected on ThuRID	Dataset 2
4	Used WoS paper names in D2 to scrape authors' address information and added to D2	Dataset 3
5	Obtained a list of faculty who do not have records on ThuRID	List 2
6	Based on L2, scrape publication information on Web of Science	Dataset 3
7	Merge D3 and D4	Dataset 4 – WoS Collection

Data Validation

Given the data collection results, there were three main data quality challenges: 1) Name-publication matching: the first challenge was to match faculty names to the authors of the publications. Because of the same or similar name spellings, scraping algorithms may scrape somebody else's articles; 2) Incomplete or missing address problems: about 20% papers collected do not have clearly matched addresses for each author and a portion of papers omitted address details, which makes it impossible to use algorithm checks to ensure the author is the sampled faculty; 3) The third problem is that there might be some articles that the algorithms missed due to the varied spellings of names that faculty may have used.

Three major solutions were utilized to tackle the problems identified in the data. 1) A major effort was undertaken to check if the paper matched the people. Identifiers including faculty names, abbreviations of names, school names, and university names, were used to check if the name in the author list belongs to the faculty in the sample. As a result, papers that were mistakenly collected and matched to faculty members were removed; 2) missing addresses for several papers were filled in by matching information in the existing database; 3) manual checks were done in places where algorithms could not work efficiently: several pieces of missing information were

added in the database. For faculty who do not have Web of Science publications identified, searches on Web of Science were done to check whether they have any publications.

With algorithmic and manual checks done, a randomly selected sample of the cleaned dataset was taken to evaluate the overall data quality of the dataset. One thousand out of the 25,849 papers were randomly selected to test whether the publication was correctly matched the faculty member and address of the faculty. A very low level of error (<1%, at 95% confidence level) was found, with no signs of systematic errors by school.

Data Analysis

Network data were created by the two datasets: 1) Faculty profile dataset and 2) Web of Science publications dataset. The network data consists of two parts, one is an edge list of coauthorship, and the other is a table displaying vertex attributes. The edge list has two columns with as many rows as there are the number of ties in the dataset. Edges between the two nodes are weighted in analysis according to the frequency of coauthorship between them. The vertex attributes table displays the information of every node in the edge list. For faculty members, information includes school, gender, rank, appointment year, PhD awarded university, and graduation year. For coauthors who are not Tsinghua faculty, the information used is their address information, specifically university and country information. A network graph was created based on the edge list and vertex attributes data.

The analysis has two stages. The first phase aims to understand the distributions of ties of Tsinghua and explore the features of the different types of ties. Local ties, national ties, and global ties, defined by coauthors' affiliations, were the major categories of analysis. The second phase analyzed Tsinghua's inter- and intra-organizational networks and explored how network variations across schools may explain the sub-organizational productivity and status.

Network descriptive analyses were conducted in R. Other software specialized for data visualization, such as Tableau, assisted in visualizing patterns. The definitions and usages of several important network analysis measures employed in this study are listed below.

Component: shows the number of subgroups in a network. The giant component is the largest subgroup containing the vast majority of the vertices. In practice, analyzing the giant component allows for understanding the overall feature of the network.

Clustering: is the tendency to form closed triangles that are triads where all three ties are observed. Clustering is measured by transitivity, defined as the proportion of closed triangles to the total number of open and closed triangles.

Network density: describes the portion of the potential connections in a network that are actual connections.

Network centralization: a measure of how central its most central nodes is in relation to how central all the other nodes are.

Degree centrality: measures the number of direct ties a faculty member has, which is a direct way to capture the scale of coauthorship for individuals and to identify which actors are central in a network.

Betweenness centrality: measures the probability that any two actors takes a particular path. Nodes with high betweenness centrality will act as "gatekeepers" or "bridges" in a network, which demonstrates great prominence in a network.

Closeness centrality: measures the node's average farness (inverse distance) to all other nodes.

Eigenvalue centrality: measures the level of influence of a node within a network. This score is relative to the number of connections a node will have to other nodes.

Data Overview

The sample of faculty members and the data collection of publications are described in this section.

Faculty Sample

There are 2,745 full-time faculty members included in the sample, 72% of whom (1,964 faculty) were found having publications in Web of Science databases during 2014 to 2018. Table 3.7 displays the breakdown of the sample by gender and rank. Female faculty are less represented as they constitute 16 percent of the sample, whereas males constitute 80 percent of the sample (4% gender data missing). Senior professors are the majority, with 46% being full professors and 43% associate professors, assistant professors constitute a very small portion of the sample.

Table 3.7 A summary of faculty rank and gender

	Assistant Professors	Associate Professors	Professors	NA	Grand total
Female	25 (1.27%)	171 (8.71%)	110 (5.60%)	3 (0.15%)	309 (15.73%)
Male	124 (6.31%)	637 (32.43%)	785 (39.97)	17 (0.87%)	1,563 (79.58%)
NA	8 (0.41%)	36 (1.83%)	13 (0.66%)	35 (1.78%)	92 (4.68%)
Total	157 (7.99%)	844 (42.97%)	1,908 (46.23%)	55 (2.80%)	1,964

In the sample, 3% faculty do not have PhD degrees and 8% faculty members' PhD information is missing from their profiles. Faculty who do not hold a PhD tend to be senior faculty, as the average appointment year is 1987 for those faculty who do not hold a PhD whereas the average appointment year of the sample is 2003 (Figure 3.1).

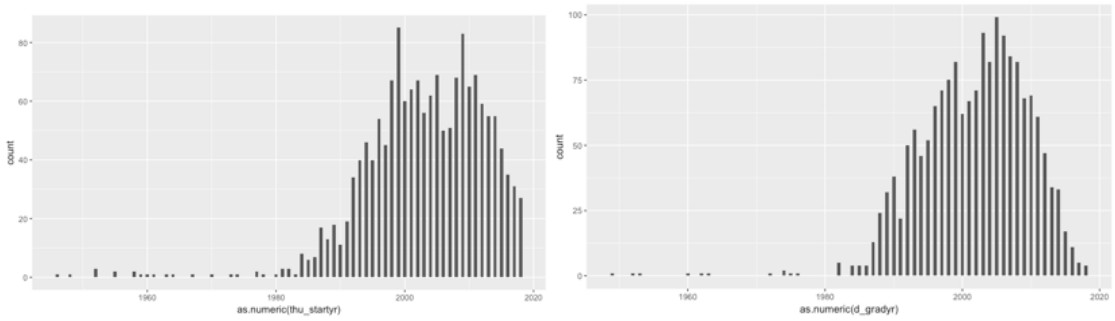


Figure 3.1 Frequency of the PhD graduation years of Tsinghua faculty in the sample

Figure 3.2 Frequency of the Tsinghua appointment years of Tsinghua faculty in the sample

The average year of PhD graduation among faculty is 2001 (Figure 3.2). In the sample, 62% (1213/1964) of faculty members obtained their PhD degrees from Chinese universities, the 65% of which are Tsinghua PhD holders. Other Chinese universities where most Tsinghua faculty earned their PhD degrees are all first-tier research universities. Chinese PhD degree holders constitute more than half of the sample in most schools, whereas most are returnee faculty members in the schools of economics, social sciences, pharmaceutical, education, and humanities.

The top three overseas countries where Tsinghua faculty got their PhDs are the United States (12%), Japan (4%), and the United Kingdom (2%), which suggests that the reputation of the higher education or the doctoral education or training systems in those countries are recognized and valued by top Chinese top universities. Additionally, these overseas countries are the traditional host countries for international students from all over the world for a variety of reasons that are not limited to higher education quality and reputation. Most overseas PhDs graduated from top global universities such as the University of California at Berkeley (21), University of Tokyo (20), University of Cambridge (14), MIT (11), and Kyoto University (10) (Table 3.9, Table 3.10).

There is a declining trend in the number of faculty members being hired after 2010 (Figure 3.3). Among new faculty members who joined Tsinghua after 2010, the difference in number between domestic PhD degree holders and returnee PhD degree holders is reducing.

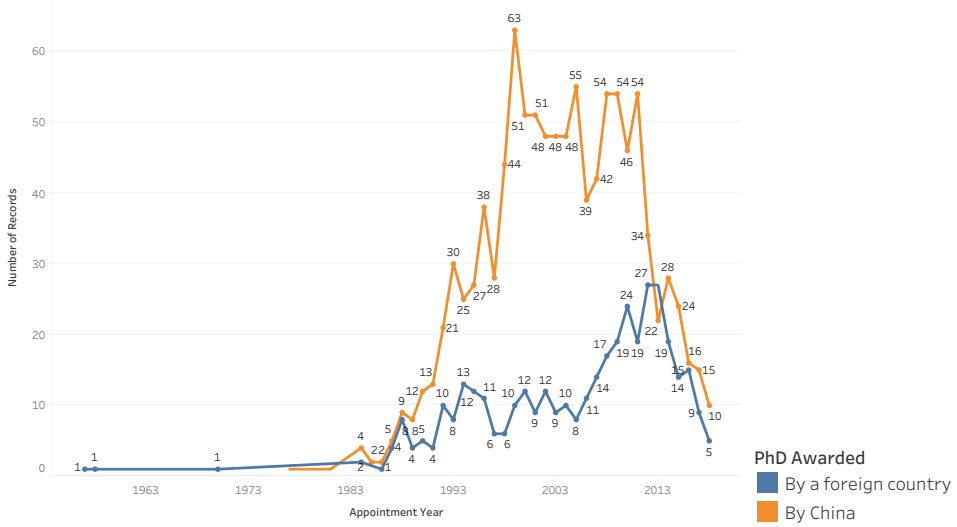


Figure 3.3 Faculty members' appointment year by their PhD awarded regions

Table 3.8 Countries or regions where THU faculty obtained their PhD degrees

China (1,213)	France (13)	Australia (5)	Austria (2)
USA (226)	Russia (12)	Ukraine (4)	Denmark (2)
Japan (81)	Netherlands (10)	Ireland (4)	Serbia (1)
UK (49)	Singapore (10)	Switzerland (3)	South Korea (1)
HK, China (38)	Canada (9)	Sweden (2)	Yugoslavia (1)
Germany (27)	Belgium (8)	Italy (2)	

Table 3.9 Top 10 institutions where most THU faculty obtained their PhD degrees (n>=10)

PhD institution	Country	Number
Tsinghua University	China	789
Chinese Academy of Sciences	China	84
Peking University	China	44
Harbin Institute of Technology	China	28
Xi'an Jiaotong University	China	26

University of California Berkeley	USA	21
The University of Tokyo	Japan	20
University of Science and Technology	China	16
Zhejiang University	China	15
University of Cambridge	UK	14
Hong Kong University of Science and Technology	HK, China	13
Chinese University of Hong Kong	HK, China	13
Massachusetts Institute of Technology	USA	11
Kyoto University	Japan	10

Table 3.10 Top 10 overseas institutions where most THU faculty obtained their PhD degrees

US - University of California, Berkeley (24)	US - MIT (13)
JP - The University of Tokyo (18)	US - Cornell University (13)
UK - The University of Cambridge (18)	US - Columbia University (12)
US - Harvard University (14)	JP - Tokyo Institute of Technology (12)
JP - Kyoto University (14)	UK - University of Oxford (12)

Publications

The analysis uses data on WoS between 2014 and 2018. As the dataset considers the publications for the more recent years, it may better represent the real picture of Tsinghua publications on the WoS.

Papers. In total, this study's dataset has 25,042 papers from 2014-18, which captured 1,964 Tsinghua faculty members' publications. The number of publishing papers collected varied by school. Table 3.11 illustrates the discipline imbalance in terms of published papers by using a broad disciplinary category. Schools in the physical sciences and STEM cluster have a dominant role in knowledge creation at Tsinghua, as large as 91.8% WoS journal articles at Tsinghua were published by faculty in these disciplinary categories. The contribution of HSS faculty on Tsinghua's number of publications is limited.

Table 3.11 Number and percentage of papers and ties by broad fields

Broad fields	Paper	Percentage	Tie	Percentage
Physical sciences and STEM cluster	24183	91.80%	227355	92.7%
Biological, medical and life sciences	1638	6.22%	16061	6.5%
Social sciences and Humanities	523	1.99%	1799	0.7%

On average, each faculty member had 12.75 published papers during the 2014-2018 period across schools. The paper/faculty ratio ranges from 1.57 (School of Journalism) to 35.79 (School of Materials Sciences - MAT). Faculty of MAT published 35.79 articles during 2014-2018 per person. Schools in the social sciences and humanities have lower paper/faculty ratio. The highest among the social sciences is the school of social science. A social science faculty published 3.4 articles in the 5-year window. The productivity ratio difference between returnee faculty and domestic faculty is large in MAT and ENV. On average, MAT faculty who hold foreign PhD degrees had published 9 papers more than those who hold domestic PhD degrees.

Not all faculty in the original sample were found in either publication database. Schools in the humanities and social sciences have higher percentages of faculty members not being captured in WoS database. Only 7% School of Law faculty and 4% faculty of School of Marxism were found in the WoS databases. Other profile information for the missing faculty portion does not suggest any significant faculty characteristics which may lead this type of data missing.

There is a steady upward trend in the number of publications from 4,871 (2014) to 5,736 (2017). However, the number of publications decreased 27% to 4,200 in 2018. Publications from the school of informational sciences and engineering faculty constitute a large portion of the entire publication dataset, and the drop in 2017-18 is associated to the drop of the publications from the school of informational science and technology (INFO) during 2017-18. The average number of

papers captured for INFO faculty members decreased from 2017 to 2018, the rationales behind the drop should be explored in an extensive case study.

Among the papers collected for each year, the proportion of sole-authored papers was around 1%. There is not any significant increasing or decreasing trend in terms of the percentage of sole-authored papers over the years.

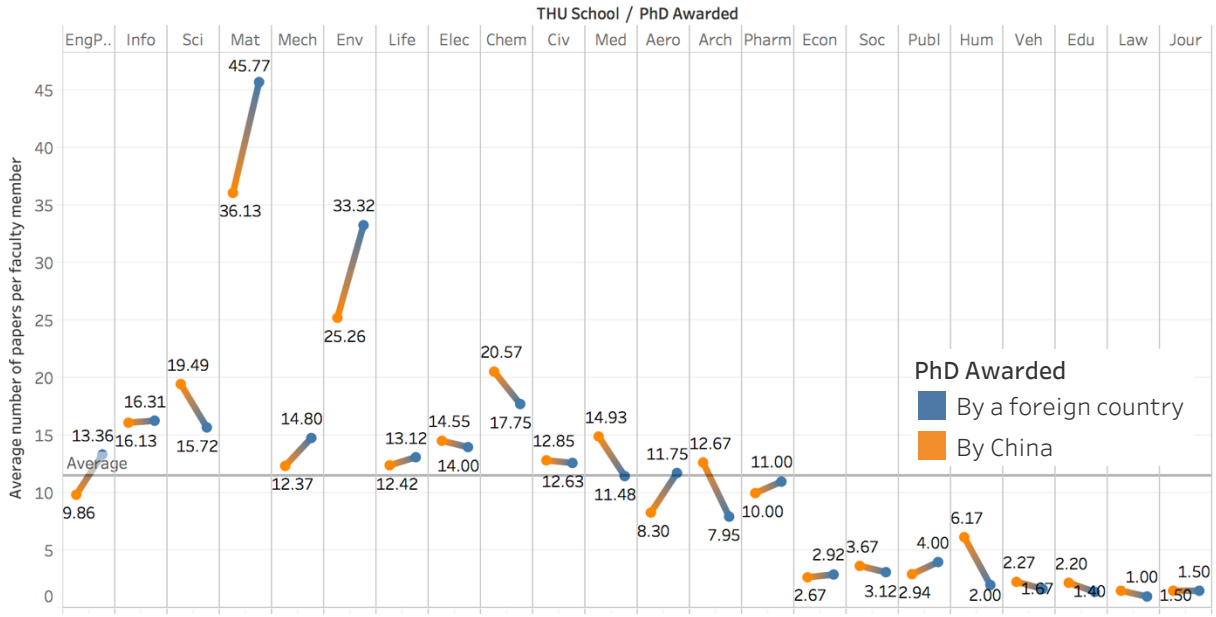


Figure 3.4 Average number of papers per faculty by schools

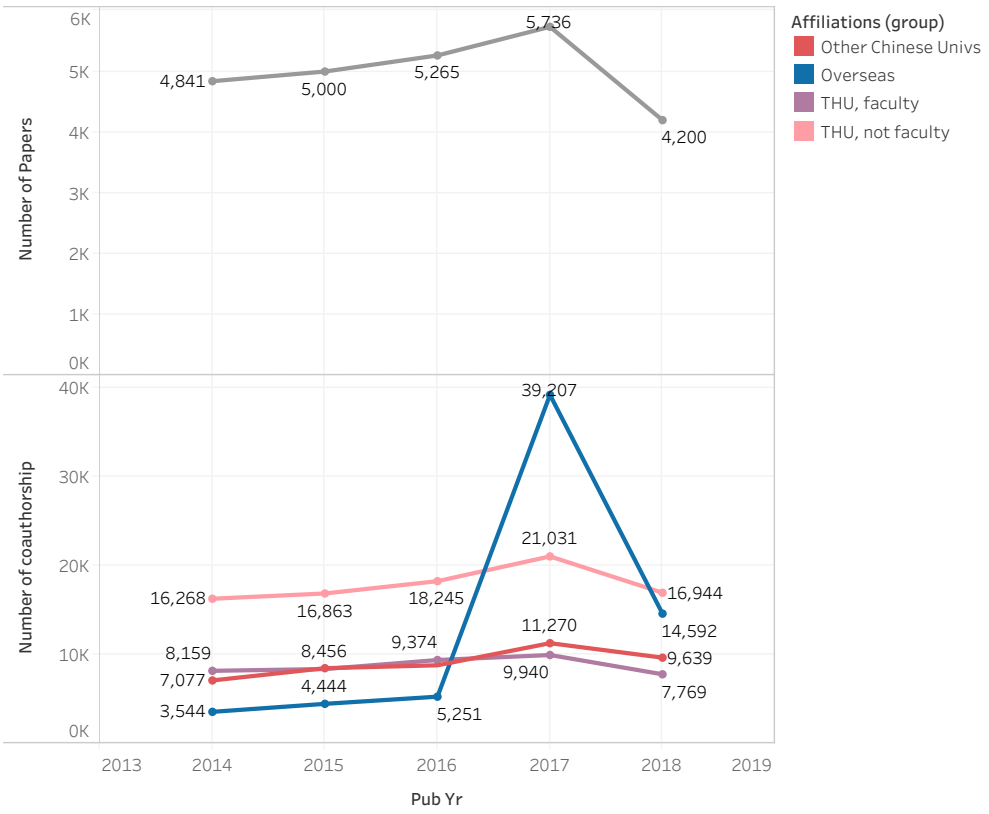


Figure 3.5 Trends of papers and coauthorship of THU between 2014 and 2018

Coauthorship. In total, there are 245,215 pairs of coauthorship obtained in the data. The number of coauthorships had a huge jump from 2016 to 2017 due to an increase in overseas coauthors during that year (Figure 3.5). A few faculty participated in large group collaborative projects which boosted the overseas coauthorship. For example, a faculty in the Engineering Physics participated in several papers funded by the LhCd global group projects, which generated thousands of coauthorships. The outlier case should be warranted when making comparisons between schools.

The descriptive summaries intend to firstly show a basic picture of the data in as many perspectives as possible and to explore problems that could be further analyzed. The affiliations of coauthors display the spectrum of Tsinghua University's academic collaboration as an organization during a time window. Data have revealed different faculty group profiles and

collaborative styles across schools. Such factors as faculty group features, school features like ranking, reputation, and requirement, and disciplinary cultures would likely affect the forming of local, national, or global ties. More analysis on the affiliations of coauthors is in the next chapter of findings.

Limitations of Methods and Data

The present research is a case study that adopts a social network lens. Research questions are exploratory and examined by using primary data collected from publication databases and university websites. As discussed in this chapter, several methodological and data limitations should be recognized while conducting and interpreting the analysis.

First, Tsinghua's case should be meaningful for other Chinese university to reflect on their own, though the results may not be directly applicable to other Chinese universities. The influence of institutional culture and status on coauthorship patterns can be assessed by incorporating more cases into the study in this regard. Thus, while case study design allows for an examination of Tsinghua's coauthorship patterns in its layered organizational contexts, it should be warranted to attribute network features to comparative institutional factors or extend the results to other institutions.

Second, the sample of faculty members was based on information on schools' websites of Tsinghua by end of 2019, but some schools may not update the list as frequently as the other. Thus, some changes of appointments may not be promptly captured. Also, it should be recognized that WoS does not cover all publications, though it has the official recognition of the Chinese institution. For Humanities and Social Sciences, WoS can only cover a very small portion of faculty members and their publications. As such, this study can only describe the coauthorship patterns generated by WoS collected articles. Patterns could change with other sources of data added, especially for

HSS. To address this limitation, future study can try to be more inclusive by adding a Chinese publication database. It would be interesting to compare the coauthorship networks categorized by languages and examine if the fragmentation exists in coauthorship network of Chinese higher education.

Third, this study used five years of publication data from 2014 to 2018. Due to the relatively short period of time, the results may not reflect the longitudinal trend of coauthorship patterns within Tsinghua. The trends of an organizational coauthorship network can be monitored by keep updating new publications in future. To study the intra-organizational and inter-organizational coauthorships patterns, the five years of data were used without considering the yearly variations, thus the changes in intra- or inter-school networks will not be discussed in this study.

Fourth, the sample size is unbalanced by sub-organization. The school of information science and technology (INFO) constitutes about 20% of all faculty and has a large share in publications at Tsinghua, so that the school's patterns will largely affect the coauthorship patterns at the university level. The School's heavy contribution to Tsinghua's publication is also an important finding of this study. There's a steady upward trend in the number of publications from 4,871 (2014) to 5,736 (2017), but the number of publications decreased 27% to 4,200 in 2018. The drop in 2017-18 is attributed to the drop of INFO publications during 2017-18. The average number of papers captured for INFO faculty members decreased from 2017 to 2018, the rationales behind the drop and the trends in INFO publications in the following years should be monitored and examined.

Lastly, ensuring the quality of the primary data is a challenge. Data cleaning and validation has been done to address with data challenges, but several issues might also affect the data quality. The data collection relies purely on publicly available data and some restricted-access publication

data (from university library access). The errors on original databases cannot be accounted for. There might also be some articles in which the algorithms failed to scrape or match due to multiple spellings of the same names or the potential name changes. Due to the less than 1% error rate of the large-scale dataset, such problems would affect the current dataset to a limited extent. I address these methodological concerns in data analysis and interpretation.

CHAPTER 4 FINDINGS

This research aims to explore the organizational collaboration networks of Tsinghua University by using faculty members' publication records in Web of Science databases. One aspect of the research question is to explore the local, national, and global dimensions of the Tsinghua network. The other aspect of the question examines the sub-organizational variations in network features that may affect the school performance and status. The analysis answers the four sub-questions of this study: 1) How are the collaborative ties of Tsinghua distributed locally, nationally, and globally? 2) How do the distributions of ties differ by schools/departments? 3) What features, if any, exist in the faculty-faculty network in terms of intra- and inter-organizational networks? 4) Whether, and in what ways are the important network features of schools associated with such important facets of school performance as productivity and prestige?

Tsinghua Network at a Glance

In this study, the university's academic collaboration network is the aggregated individual networks of faculty members. Cross-school ties and common outside coauthors connect schools together. Tsinghua's network consists of 1,964 faculty members and 47,118 coauthors – they are all called nodes or vertices in the following sections. The edges of the network were built among faculty nodes or between faculty nodes and coauthors nodes – one end of the edge was a Tsinghua faculty member, and the other end was either a Tsinghua faculty member in the sample or scholars not in the sample. Authors from the other end of the tie, no matter if they are in faculty sample or not, are named as coauthors in the interpretation of findings.

Network Size by Sub-Organizations of University

Sub-organization is an important dimension of the analysis. The number of coauthorship of school (network size) can be closely related to the school size (the number of faculty members),

as more nodes (faculty) will likely lead to more edges (coauthorship). Generally, the school size of NS & ENG schools are larger than those of HSS, which partly reflects the traditional institutional culture of Tsinghua – "red cradle for engineers and scientists." For historical reasons, Tsinghua is known for its strong engineering and sciences disciplines. Tsinghua's humanities and social sciences were rebuilt so they are relatively new. For some social sciences departments such as the Institute of Education, the institutional goal of it is to build a "small and exquisite" research institute rather than expand its size.

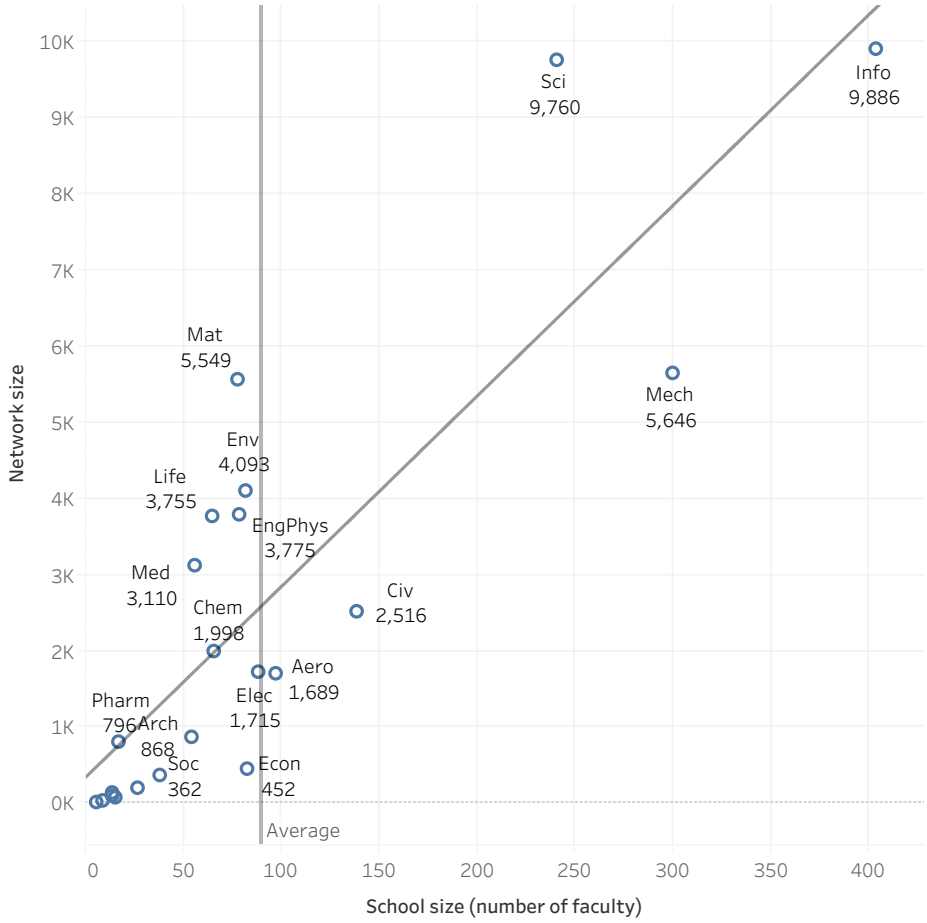


Figure 4.1 Network size (number of nodes) by school size (number of faculty members)

Figure 4.1 displays school's network size by its faculty size. For most Tsinghua schools in the sample, the larger the school size, the larger the network size. However, several schools of the

same sizes have vastly different network sizes, the schools/departments of materials science, environment, engineering physics, electrical engineering, and the school of economics and management are about the same size (around 80 faculty members), but their network sizes are 5,549 (Mat), 4,093 (Env), 3,775 (EngPhys), 1,715 (Elec), 452 (Econ), respectively. School size is related to the network size, but not a determining factor.

Coauthorship by Affiliations of Coauthors

The affiliations of coauthors display the spectrum of Tsinghua's academic network from local to global. Coauthors' affiliations are categorized in this study as: 1) Tsinghua (faculty); 2) Tsinghua (non-faculty); 3) other Chinese institutions; and 4) overseas institutions. Accordingly, local ties refer to the ties connecting Tsinghua faculty with either another Tsinghua faculty or Tsinghua researchers who are not faculty. National ties refer to the ties that connect Tsinghua faculty and another scholar affiliated to any other Chinese institution. Global ties connect Tsinghua faculty with scholars affiliated to any overseas institutions.

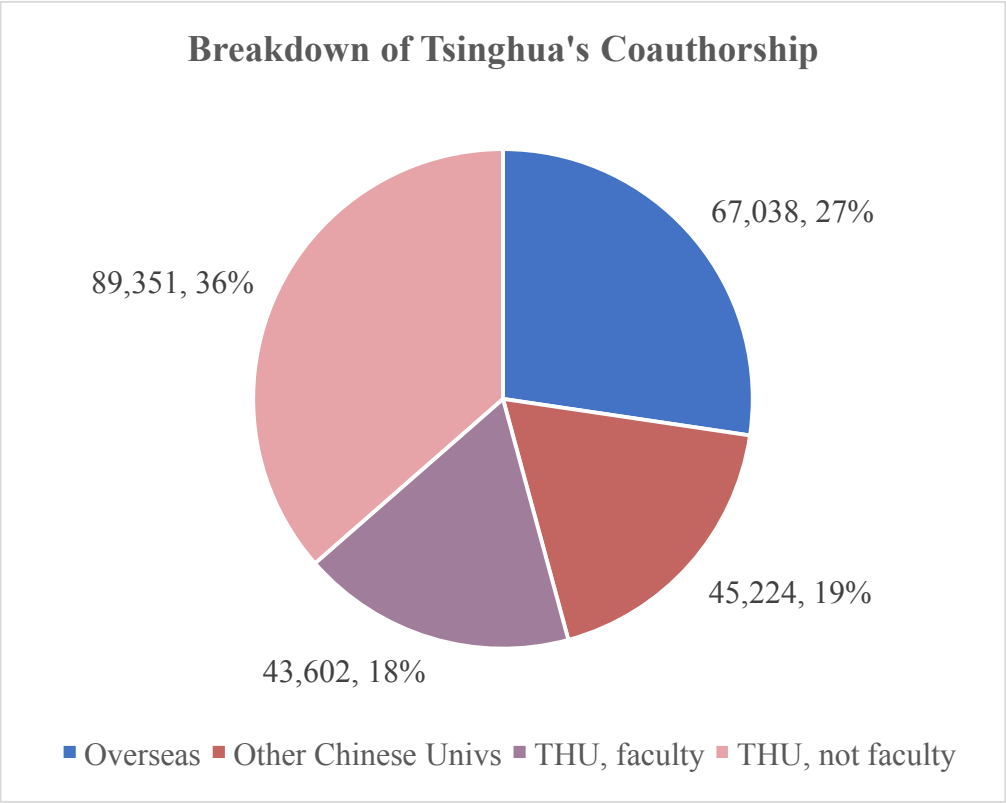


Figure 4.2 Pie chart of Tsinghua faculty members' coauthorship

Coauthorship with Tsinghua researchers takes the largest share of all coauthorship (36.44%). This group of coauthors are not faculty but affiliated to Tsinghua university may include post-docs, students, or other researchers. Most of them should be involved in the research projects of the faculty. The second largest portion of ties are global ties: 27.34% of all ties are from scholars affiliated to overseas institutions. The share of coauthorship with other Chinese university's scholars and with Tsinghua faculty is 18.44% and 17.18%, respectively.

Several features emerge in the overall breakdown of coauthorship of Tsinghua. First, the Tsinghua network is heavily reliant on its local ties, with 54% ties are bounded at Tsinghua. Among local ties, a small portion (23%) are built between faculty members whereas a larger proportion (77%) are built between faculty members and other Tsinghua researchers. Local ties build the basic structure of the Tsinghua coauthorship network. Second, national ties are fewer than global ones,

which suggests that the geographical or cultural proximity argument may not hold for the case of Tsinghua coauthorship. Third, compared to coauthoring with faculty members from Tsinghua, faculty are more likely to seek to collaborate with scholars outside Tsinghua.

In the following sections, I will describe Tsinghua's global, national, and local ties. In local ties, faculty-faculty ties including intra- and inter-organizational faculty ties are the focus of the study.

Global Coauthorship Network

This section examines Tsinghua's ties generated by global collaborated publications. The two focuses are the affiliations of global coauthors and the global tie distributions by schools.

Global Ties by Country and Institution

There was a rising trend of global collaboration in Tsinghua between 2014 and 2018. The number of ties and coauthors also increased accordingly (Table 4.1). The surge of global ties in 2017 was mainly boosted by a few giant papers with hundreds of international coauthors. Although the number of global coauthorships dropped in 2018, it surpassed that of national ties and Tsinghua faculty-faculty ties. With more longitudinal data, future studies can examine whether the rising trend will continue and whether the global network of Tsinghua will have greater weights in the Tsinghua collaboration network.

Table 4.1 Yearly trends of global collaboration papers, ties, and coauthors

Year	Global Collaboration Papers (%)	Global ties (%)	Global Coauthors (%)
2014	0.22	0.10	0.17
2015	0.24	0.12	0.19
2016	0.26	0.13	0.22
2017	0.26	0.48	0.24
2018	0.27	0.30	0.22

Among 6,282 global publications that have at least one foreign address, 86% of them are bilateral collaboration and 14% of them are multilateral coauthored papers. One outstanding feature of Tsinghua's global collaboration papers is the broad presence of scholars affiliated to institutions in the United States. Collaborating with U.S. scholars has been commonplace in the global collaboration of the Tsinghua. Among all global collaboration, 53% are associated with at least one scholar from a U.S. institution. Tsinghua-U.S. joint authorship is usually a bilateral institution-institution type of collaboration. Half of the bilateral collaboration of Tsinghua are U.S.-China collaboration, 18% of which involves more than one U.S. institution. Coauthors from the U.S. also contribute to the multilateral coauthored papers. Among the total of 898 multilateral coauthored papers, as many as 72% papers have a U.S. address.

From 2014 to 2018, the global ties of Tsinghua mostly came from the United States and European countries – the "Global North" which has a decisive role in the academic publication system that can affect faculty publication behaviors. With respect to ties, 20% of global ties were built with United States (20%), followed by the United Kingdom (16%), Switzerland (11%), Italy (10%), Germany (7%), France (6%), and Russia (6%). In terms of institutions, Tsinghua was connected to 2,006 international institutions outside of China. The top 10 international institutions having the most ties with Tsinghua are European Organization of Nuclear Research (Switzerland), *Ecole* Polytech Fed Lausanne (Switzerland), Heidelberg University (Germany), Dortmund University (Germany), University of Manchester (UK), Syracuse University (USA), University of Oxford (UK), University of Zurich (Switzerland), University of Cambridge (UK), and University of Bristol (UK).

Moreover, about 32% of all the international institutions in Tsinghua's global network are U.S. institutions. Germany is second to the U.S., having 7% of institutions in the global network

of Tsinghua. With respect to both number of institutions and coauthors, the United States is the largest partner of Tsinghua. The top 10 U.S. institutions having most ties with Tsinghua faculty in the network are Syracuse University, University of Cincinnati, University of California at Berkeley, University of Maryland, Massachusetts Institute of Technology, University of Illinois, Pennsylvania State University, Argonne National Lab, Georgia Institute of Technology, and University of California at Los Angeles. It seems Tsinghua's collaboration with the U.S. occurred most with large public universities.

Syracuse University and University of Cincinnati are the top two universities in the Tsinghua-U.S. network as Tsinghua faculty collaborated with faculty from the two universities on a few giant papers that generated hundreds of authors. Taking out such ties, Tsinghua's largest partner on academic coauthorship in the United States is University of California Berkeley, a national flagship university having organizational connections with Tsinghua. For example, the Tsinghua-Berkeley Shenzhen Institute (TBSI) was established in 2015 under the support of the Shenzhen Municipal Government. It is a "university-government-industry" model of cooperation which promotes "interdisciplinary research," "international education," and "industrial partnership."[6]

Global Ties by Sub-Organizations

National versus Global Ties. Tsinghua's global ties constitute one-thirds of all ties, but the proportion of global ties differ by sub-units. Table 4.2 displays the number of percentage of global and national ties by sub-organizations of Tsinghua. All schools but the department of engineering physics have more national ties than global ties. The percentage of global ties ranges

[6] https://tbsi.berkeley.edu/. TBSI offers a dual-degree program, a master's program in engineering at Berkeley and a master's science degree at Tsinghua. The TBSI was funded by Shenzhen municipal government and the Tsinghua Education Foundation

from 0.81 (Department of Engineering Physics - EngPhys) to 0.46 (School of Law). Across all schools or departments but EngPhys, they collaborate with U.S. scholars the most (Table 4.3).

Table 4.2 Number and percentage of global ties and national ties in schools

School	*Global ties*		*National ties*		
	Number	Percentage	Number	Percentage	Total
EngPhys	46,886	0.81	10,726	0.19	57,612
Info	4,189	0.1	37,814	0.9	42,003
Sci	3,732	0.11	31,221	0.89	34,953
Mat	1,878	0.08	20,672	0.92	22,550
Mech	1,756	0.08	20,201	0.92	21,957
Env	2,297	0.13	14,834	0.87	17,131
Elec	888	0.11	7,533	0.89	8,421
Chem	505	0.06	7,597	0.94	8,102
Life	948	0.12	6,962	0.88	7,910
Civ	1,172	0.16	6,233	0.84	7,405
Med	1,193	0.17	5,702	0.83	6,895
Aero	662	0.18	3,035	0.82	3,697
Arch	279	0.1	2,471	0.9	2,750
Pharm	196	0.16	1,042	0.84	1,238
Econ	147	0.25	440	0.75	587
Publ	111	0.24	343	0.76	454
Soc	114	0.25	338	0.75	452
Veh	43	0.17	204	0.83	247
Hum	14	0.08	156	0.92	170
Edu	15	0.19	65	0.81	80
Law	12	0.46	14	0.54	26
Jour	1	0.07	14	0.93	15

Table 4.3 Top 10 countries where Tsinghua's global ties came from

School/ Country	USA	UK	Switzerland	Italy	Germany	France	Russia	Spain	Brazil
EngPhys	2975	9238	7615	6540	4152	4007	3735	2435	1768
Info	2242	481	25	28	83	76	4	46	2
Sci	1847	507	44	28	259	82	16	18	12
Env	1261	147	13	26	48	53	1	10	4
Med	865	13	2	13	30	13	1	3	0

Mech	802	140	0	1	43	44	4	18	1
Mat	786	99	3	8	129	44	1	7	0
Life	606	87	8	11	44	9	4	15	1
Civ	540	81	3	2	26	42	0	0	0
Elec	513	107	4	2	4	9	0	2	0
Aero	461	13	1	2	15	8	7	0	0
Chem	252	19	0	1	40	7	3	1	0
Arch	150	44	0	3	1	0	0	0	0
Pharm	109	15	1	1	8	0	0	2	0
Econ	83	12	0	0	4	1	0	2	0
Publ	60	7	0	0	1	0	0	0	0
Soc	29	25	4	0	5	1	0	0	0
Veh	22	14	0	0	2	0	0	0	0
Edu	9	2	0	0	0	1	0	0	0
Law	8	0	0	0	0	0	0	0	0
Hum	7	0	1	0	2	0	0	0	0
Jour	1	0	0	0	0	0	0	0	0
Total	13628	11051	7724	6666	4896	4397	3776	2559	1788

The Department of Engineering Physics is an outlier as it has a lot more global ties than national ties. An EngPhys faculty participated in a large international group collaboration (i.e. LhCd) and published a few papers with hundreds of coauthors from the project, which largely boosts the global collaboration records of EngPhys and the entire university's global collaboration. After removing the outlier, the number of European ties was largely reduced.

In this study, such collaboration on big teams are evaluated in the way that the collaboration contributes to the flows of information and the network expansion. Collaboration on big or small team should be different and the contribution of each coauthor on different sized teams should vary. Participating on a large team would generate hundreds of ties that enlarge the network, which benefits academic exchanges and information flows. Using author order may help get a rough understanding of the individual contribution, but it would be hard to estimate the actual connections and ties built through working on the same publication. Moreover, the strength of ties

can differ by team sizes and the strong or weak ties function in different ways in the network. The strength of ties in different sized teams can be analyzed in future studies.

Smaller sized schools in the social sciences such as the school of economics and the school of public policy have higher percentages of global ties, although the number of ties is not much given their sizes. These schools are also relatively new schools with a shorter organizational history, compared to other traditional schools in Tsinghua.

In terms of national ties, most of them are local ties bounded at Tsinghua. Except local ties, ties with other Chinese institutions make up 18% of all ties. Faculty collaborated with a diverse range of Chinese universities, most of which were built with scholars from such Chinese universities as Chinese Academy of Sciences (13%), followed by Peking University (4%), University of Science and Technology (2%), Beihang University (1.5%) – all are first-tier universities located in Beijing.

Global Ties and Faculty Education Background. Tsinghua's global ties were built mostly with the United States and European countries. In Tsinghua, most faculty graduated from overseas institutions and obtained their PhD degrees from United States and European countries – those countries are also traditional hosts for international students. Figure 4.3 displays the number and percentage of returnee faculty by school, total coauthorship generated by domestic and returnee PhDs, and individual coauthorship of group of domestic PhDs and group of returnee PhDs in each school.

First, larger schools have more global ties, with a few exceptions including the schools of mechanical engineering, environment, and economics and management. In these schools, the number of global ties is not proportional to the size of the school. Second, it is found that the proportion of returnee faculty in a school is not significantly associated with the proportion of

global ties a school has. Contrary to the expectation, the school context with more returnee faculty is not significantly related to the percentage of global ties within schools. This study does not consider other educational backgrounds of faculty than doctoral university, so the results cannot reflect all the "transnational social capital" (Zweig et al, 2005) that the faculty group has. The results imply that other international education or working experiences may contribute to the number of global ties of schools, which can be investigated in future studies.

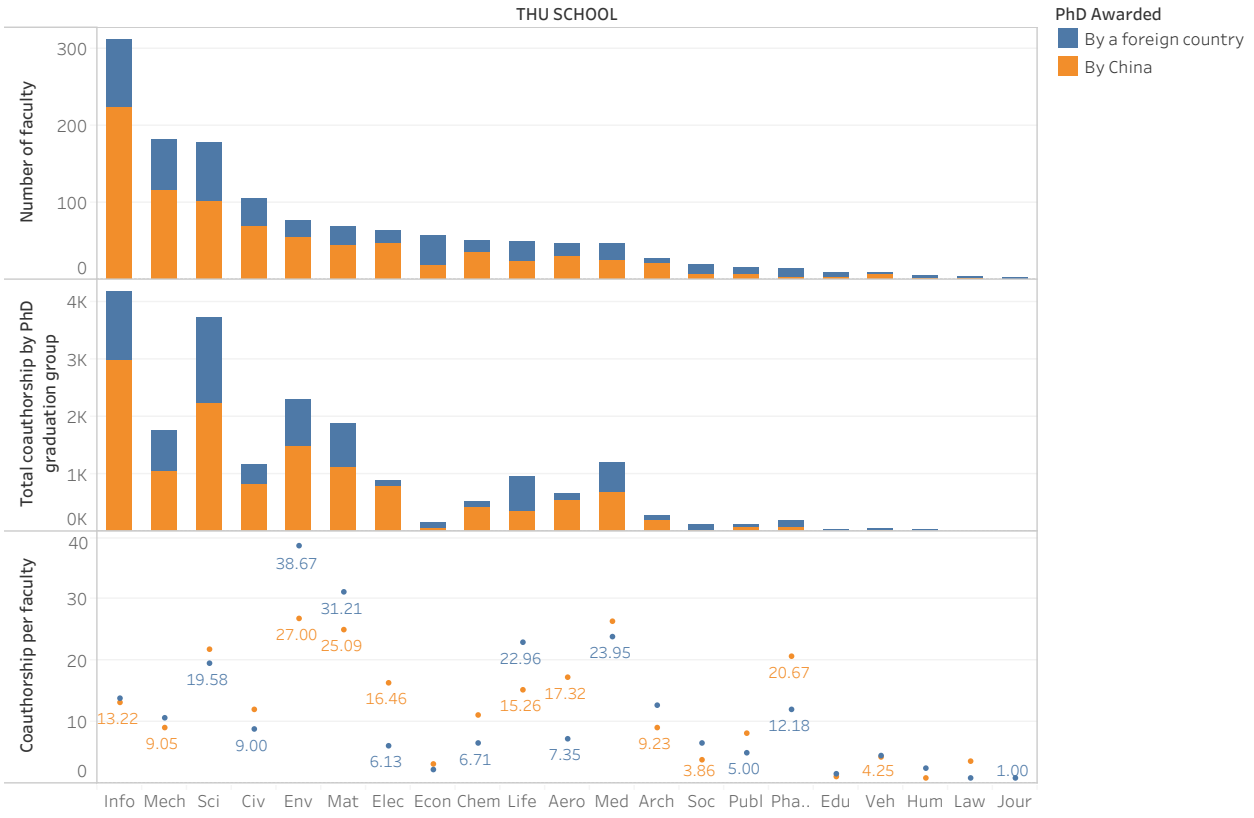


Figure 4.3 Comparing the number of global ties between domestic and returnee faculty by school

According to Figure 4.3, returnee faculty generated more global ties than their peers in the HSS cluster and life and medical sciences. On the individual level, returnee faculty generated more global ties in the schools of environment, materials sciences, and life sciences. An environment faculty who holds a foreign PhD degree has about 12 ties on average more than an environmental

faculty who holds a domestic PhD degree. For some schools, their returnee faculty members have fewer global ties than their domestic PhD holders. For example, on average an electrical engineering faculty member who obtained a domestic PhD degree has 10 more global ties than an electrical engineering foreign PhD degree holder. There are school variations in the impact of returnee faculty on generating global ties.

According to the description of the sample, Tsinghua has implemented a very strict hiring policy within the past decade. The number of newly hired domestic PhD holders has largely decreased, whereas the number of newly hired foreign PhD holders has remained flat. In Tsinghua's hiring posts, and other Chinese universities' as well, overseas learning or research experience is becoming a requirement of new faculty. Given the preferable hiring policy towards overseas scholars, an evaluation of returnee faculty's productivity and comparison with domestically trained faculty has been the focus of many studies. This research finds that the comparisons of productivity between scholars should not only be captured in university, but also put into sub-organizational contexts. Such factors as the faculty group profile, institutional culture and agenda, and local and global status of the sub-organizations would influence the evaluation of productivity of scholars. For example, although returnee faculty have educational proximity to scholars from their study destination and their "transnational social capital" will likely help them build more global ties, other organizational dimensions may also shape global collaboration. The internationalization level of the schools or fields may relate to the connectedness of global scholars. A future research should study the formation of global ties in fields or sub-organizations.

Faculty Network Bounded at Tsinghua

Most Tsinghua ties are local ties – coauthors are affiliated with Tsinghua. The largest proportion of local ties were between Tsinghua faculty and another Tsinghua researcher,

assumedly student, post-doc, or research associate on the faculty member's team. Such collaborations can be faculty-led and project/lab/class based, which can be very different from the other collaborations captured in the data. From the network perspective, faculty-led collaborations form many network circles with the faculty as the central nodes. By such collaboration styles, the network circles are hard to connect to one another without faculty-faculty collaboration. It is essential to study the local faculty-faculty ties to see how the local collaboration network is structured.

The first graph of Figure 4.4 show the vertex degrees of faculty-faculty network. The distribution of degrees associated with the 3,906 edges among 1,964 vertices. There is a substantial fraction of vertices of quite low degree. There's a linear decay in the log-frequency as a function of log-degree. Beyond the degree distribution itself, the notion of the average degree of the *neighbors* of a given vertex help understand the way vertices of different degrees are linked with each other (Kolaczyk & Csárdi, 2014). A plot of average neighbor degree versus vertex degree in the data suggests that there is a tendency for vertices of higher degrees to link with vertices of lower degrees. However, vertices of lower degree tend to link with vertices of both lower and higher degrees. It is rare that vertices of higher degree are connected in the Tsinghua faculty network.

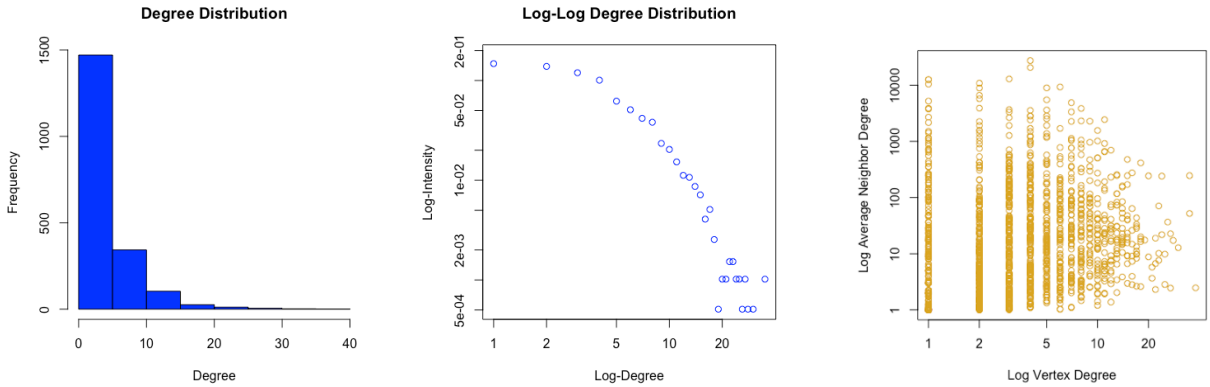


Figure 4.4 Degree distribution for a network of faculty-faculty ties. *Left*: original scale; *Middle*: log-log scale; *Right*: Average neighbor degree versus vertex degree (log-log scale) for the faculty-faculty ties

Faculty-faculty ties have two parts: intra-organizational (intra-school) ties and inter-organizational (inter-school) ties. Intra-school ties refer to the ties connecting faculty from the same schools in the sample. Inter-school ties refer to the ties connecting faculty from different schools. In the following sections, intra-school network and inter-school network will be discussed separately.

Intra-organizational Network

For each school, intra-school edges constitute a very small proportion of all edges. The percentage of intra-school edges across schools range from 2% to 7%, but intra-school edges are important for school's egocentric network by connecting individual faculty member's networks. Network cohesion as a significant feature of the school network is the focus of analysis. Definitions of network cohesion differ depending on the context of the question being asked (Kolaczyk & Csárdi, 2014). According to the conceptualization of this study, the network cohesion of school can be understood collectively by two parts: 1) Components: the number of components within the *Graph* can indicate how many distinct subgraphs make up the network. The giant component is the maximally connected component of the network and the size of the giant component can indicate the percentage of nodes that are reachable from every other node. 2) Transitivity (global clustering coefficient): this measure captures the clustering in the giant component. With the aid of visualization, these measures can tell a basic structure of the network. Figure 4.5 displays the visualizations of several schools' intra-school networks.

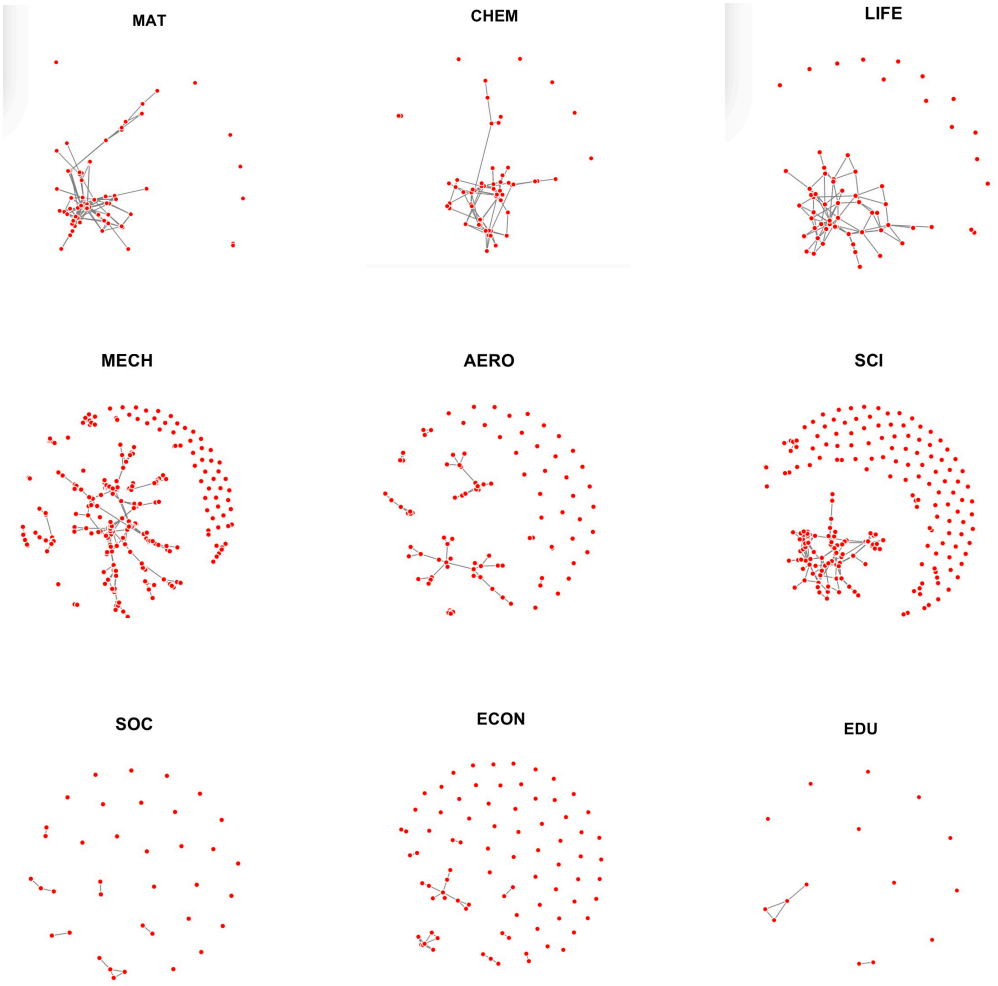


Figure 4.5 Representative intra-school graphs

Giant Component. The size of the giant component is calculated by the percentage of faculty nodes in the giant component of the intra-school network (Table 4.4). In each school's intra-school network, there's a *giant component* showing the largest group collaboration of the school. The number of components within a network and the percentage of nodes that the giant component contains can help us understand the basic structure of the network. In practice, often attention would be restricted to the giant component alone in carrying out further analysis and modeling (Kolaczyk & Csárdi, 2014).

A larger "giant component" containing more faculty nodes indicates a higher connectedness among faculty. The giant component of several intra-school networks contains a

small number of vertices (e.g. school of social sciences: 11% nodes). There are several small "circles" in which some faculty collaborated with one another. The sparse network indicates there is not a single "core" of the school in terms of publishing. For such schools with a sparse network shape as the school of social sciences (SOC), most faculty vertices are not reachable from every other. The limited direct ties show the weak connectivity of such a network. On the contrary, some schools have a large giant component, which suggests faculty members of the school are mostly connected with each other. Schools such as chemical engineering, engineering physics, information science and engineering, environment, and materials sciences have large giant components, each of which contains 80% of all vertices. Faculty in these schools collaborated much with one another, which increases the connectedness of the intra-school subgraph of these schools.

I used two examples – the school of social sciences and the school of environment – to elaborate on how network cohesion is reflected by the size of giant component. The giant component of social science network has 22% of all nodes. Though it is the largest component compared to others, it cannot represent the entire network. Figure 4.6[7] shows the communities within the intra-school subgraph of SOC. Direct faculty-faculty ties only occur within the boundary of the department. The number of direct faculty ties within the department is also limited. There is no direct faculty-faculty in the department of international relations in SOC. Psychology faculty are much connected compared to their peers in other departments of the school of social sciences.

The intra-school network of school of environment is a very different one from that of SOC. From the subgraphs of ENV, only a very few of the faculty members who have no direct intra-

[7] The institute of science, technology, and society was moved to School of Humanities in May of 2017 and renamed as Department of the history of science.

school ties. The intra-school network laid the foundation of the entire network and coauthors connected the faculty who were not collaborating, which makes the ENV network a compact one. After removing the edges that have small weights and nodes that have smaller degrees, it is found that not many intra-school ties were broken due to the removal of "unimportant" nodes and edges. It indicates that the faculty members of ENV tend to work with one another on a regular basis. During the five-year period window, most of them collaborated with one another quite frequently.

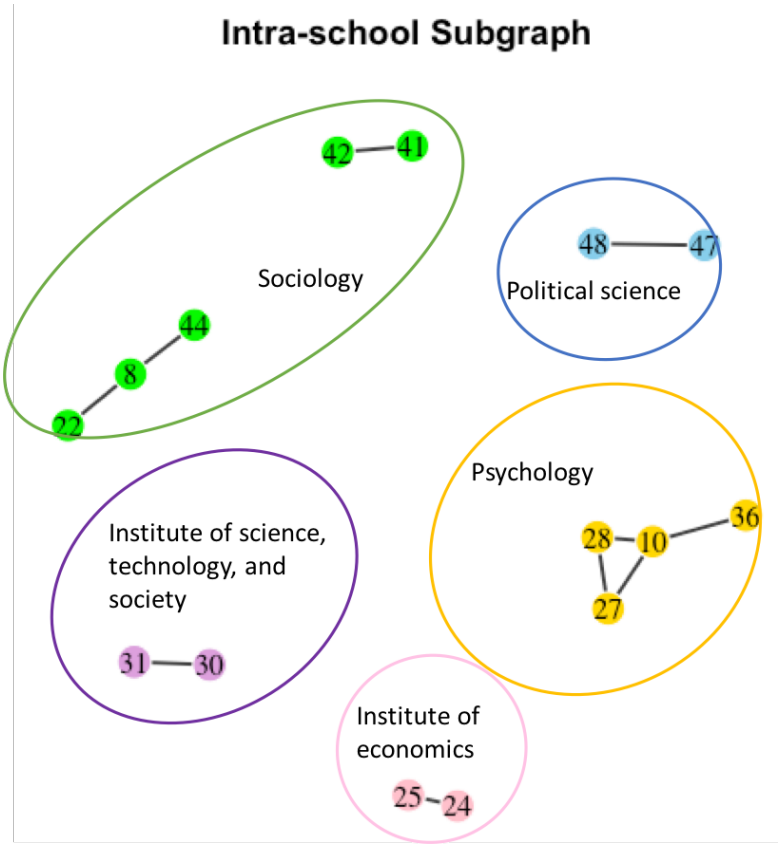
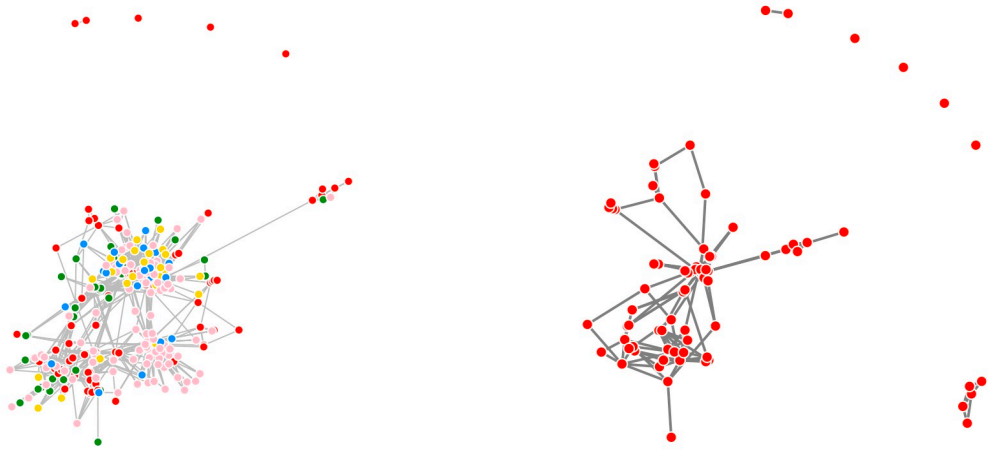


Figure 4.6 Intra-school subgraph of SOC

ENV Network ENV Intra-school Subgraph



*removed edges (weight < 5); removed nodes (degree < 5)

Figure 4.7 ENV Network with some edges and nodes removed. Left: the big network; Right: the intra-school subgraph.

Transitivity. The clustering coefficient (transitivity) of the network is another measure of network cohesion. Due to the vastly different proportions of the nodes in giant component by schools, it is less meaningful to solely compare clustering coefficients for all schools. For example, although 60% of triples tend to close inside the giant component, which is a high clustering coefficient, the giant intra-school component of SOC only contains 10% of all faculty (4 vertices) and cannot represent the entire intra-school network of SOC.

Schools were divided into three categories based on the proportion of nodes in giant component. The clustering coefficient ranged from 0.28-0.6 for schools with higher to medium level of connectedness. Higher clustering means higher possibilities for connected triples to close to form triangles. For schools of smaller giant components, the clustering coefficient spread from 0 to 1. An extreme case is school of pharmaceutical sciences with the clustering coefficient being 1, for the giant component of it is already a closed network where each node is connected. Considering the giant component of school of pharmaceutical sciences only contains 26% nodes

of all faculty within the school, the high clustering of the giant component may not apply to the entire intra-school network of the school. Among the five schools that have a giant component containing about 80% of all nodes, the department of engineering physics has the largest clustering coefficient – about two-thirds triples are about to close to form triangles. The clustering coefficient of the other four schools/departments is around 0.40, which is a moderate transitivity score.

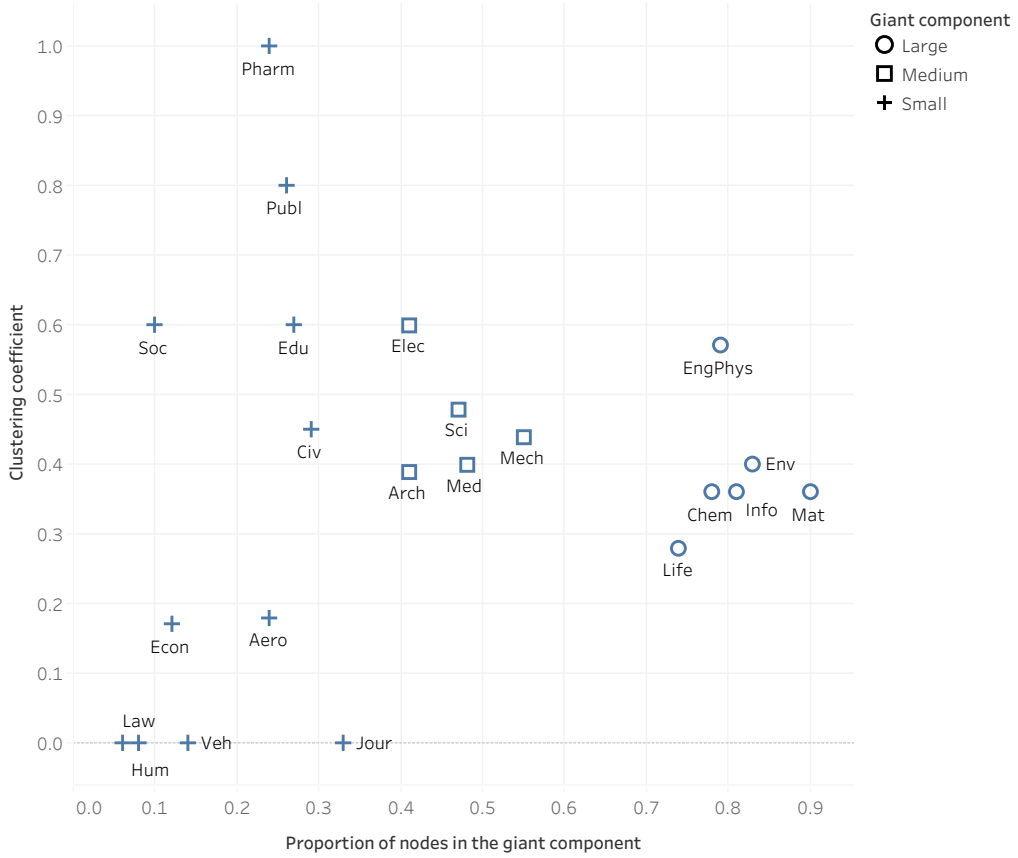


Figure 4.8 Proportion of nodes in the giant component and clustering coefficient

Tie strength. Additionally, as the frequency of interactions is an important index of the time and effort that the partners have invested in one another (McFadyen & Cannella Jr, 2004), the average tie strength of the school is used as a proxy for network cohesion as social capital. Average ties strength is simply the average of the weights of the network. That means dividing

the sum of tie strength (i.e., the number of collaborations) by the network size of the author (i.e., the number of different co-authors).

Productivity, Reachability and Visibility. Organizational performance has been broken down into three components. Average productivity is measured by the paper-faculty ratio by school. External productivity only considers papers coauthored with outside scholars. Reachability or extensity of the school is measured by the average number of external institutions connected by faculty ties. Visibility is indicated by the global subject ranking of the disciplines within the school.

Table 4.4 Intra-school networks: network cohesion measures and school performance measures

School	Giant component size	Tie strength	Transitivity	Productivity	Reachability	Rank	Tier
Aero	0.24	158.54	0.17	4.93	2.85	14	Tier 1
Arch	0.41	696.6	0.39	5.86	4.07	0	Tier 4
Chem	0.78	545.94	0.35	8.06	4.1	4	Tier 1
Civ	0.29	194.67	0.44	8.12	4.3	3	Tier 1
Econ	0.12	36.28	0.18	2.34	2.11	63	Tier 2
Edu	0.27	8.8	0.6	1.08	1.83	>500	Tier 4
Elec	0.41	1,068.35	0.6	8.23	4.28	8	Tier 1
EngPhys	0.79	205.72	0.56	6.58	6.92	3	Tier 1
Env	0.83	1,746.92	0.42	15.23	8.9	12	Tier 1
Hum	0.08	4		3.9	2.9	0	Tier 4
Info	0.81	930.27	0.38	8.58	3.25	9	Tier 1
Jour	0.33	4		1.4	1.2	>500	Tier 4
Law	0.06	0	1	1.12	2.13	0	Tier 4
Life	0.74	137.19	0.28	7.57	5.49	75-100	Tier 3
Mat	0.9	1,222.87	0.36	22.33	8.55	11	Tier 1
Mech	0.55	390.95	0.46	5.94	2.66	3	Tier 1
Med	0.48	81.29	0.39	9.46	7.52	23	Tier 1
Pharm	0.24	49.33	1	6.18	8.47	201-300	Tier 3
Publ	0.26	24.8	0.8	2.74	3.39	75-100	Tier 3
Sci	0.47	893.89	0.5	11.45	4.9	43	Tier 2
Soc	0.1	6.1	0.6	3.34	3.41	201-300	Tier 3
Veh	0.14	27.33	0.6	2.93	2.43	2	Tier 1

Figures 4.4 and 4.5 suggests a linear relationship between network cohesion measures and the average external productivity and between network cohesion and extensity. Network cohesion within the school boundary is positively associated with the external productivity and extensity. More and stronger bonds between faculty members within schools are associated with higher individual productivity and wider reach to institutions outside Tsinghua. Additionally, the external productivity is highly correlated with the extensity.

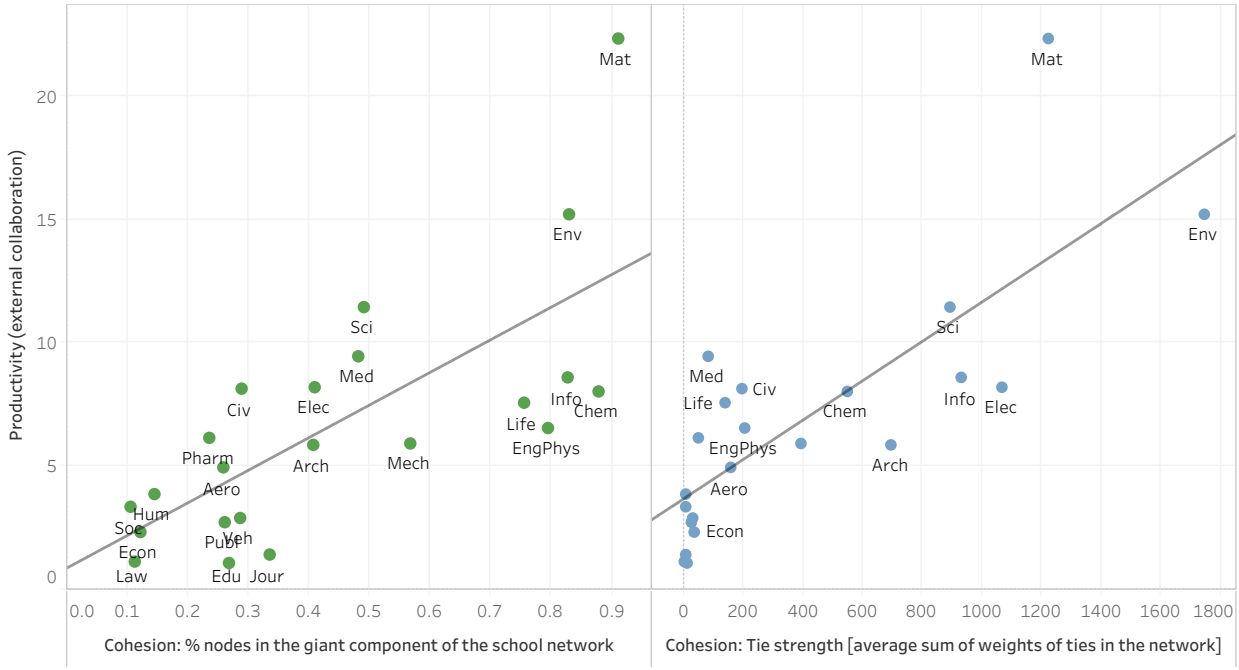


Figure 4.9 Network cohesion and productivity (collaboration involving scholars outside Tsinghua)

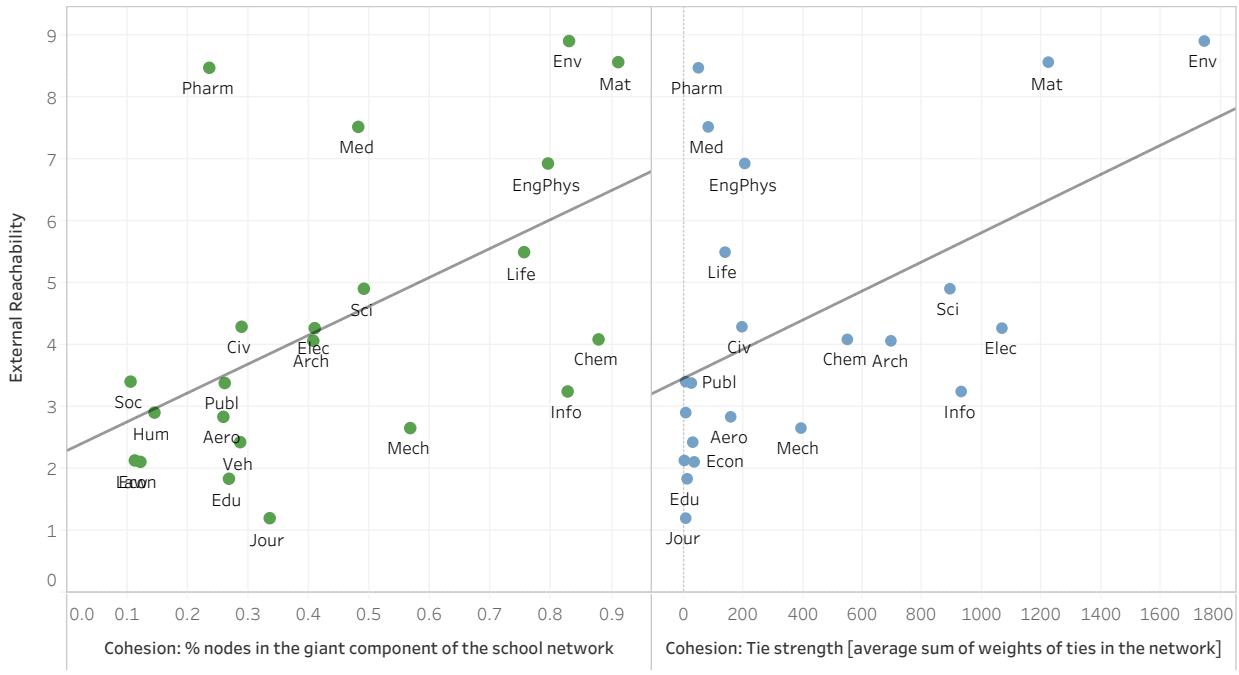


Figure 4.10 Network cohesion and extensity (external reachability)

Table 4.5 Predicting school's external productivity by its internal giant component size

	Productivity				*Extensity*			
Variable	*B*	*Std. error*	*R squared*	*p-value*	*B*	*Std. error*	*R squared*	*p-value*
Constant	0.845	1.456		0.568	2.280	0.826		**
Giant component size	13.206	2.813	0.524	***	4.664	1.595	0.299	**

Table 4.6 Predicting school's external productivity by its internal tie strength

	Productivity				*Extensity*			
Variable	*B*	*Std. error*	*R squared*	*p-value*	*B*	*Std. error*	*R squared*	*p-value*
Constant	3.646	0.842		***	3.4473	0.561		**
Tie strength	0.008	0.001	0.632	***	0.0023	0.001	0.251	***

Moreover, using ARWU 2019 subject ranking results, this study plotted the relationship between network cohesion of schools and their disciplines' ranking and found there is a positive relationship between school network cohesion and ranking performance.

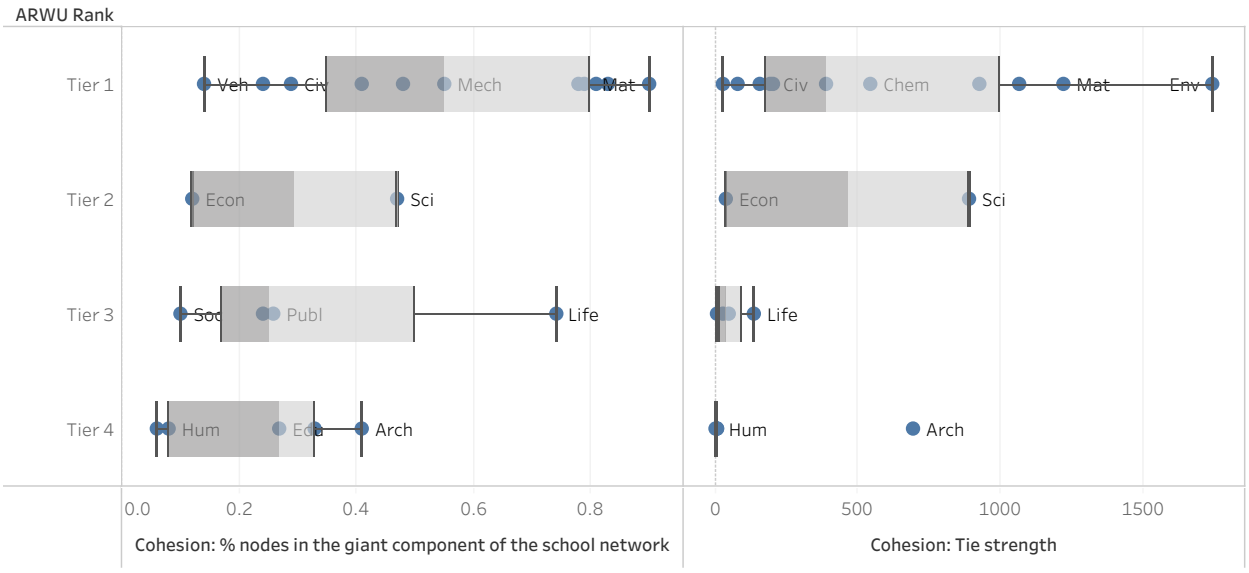


Figure 4.11 School's network cohesion and ranking performance

School productivity and reachability measured in this study contributes to ranking, as ranking considers a variety of weighted factors such as publications, citations, research impact, international collaboration, etc. In this study, the ranking of disciplines can also indicate the network cohesion of the school associated.

All the five schools with giant component containing more than 80% of nodes are in Tier 1. Subjects including law, journalism and communication, and education were absent from the top 500 list of ARWU rankings and they have a less cohesive intra-school network. A cohesive faculty network is important for the performance shown in the ranking. Although faculty ties only constitute a small portion of ties that Tsinghua has, they are important in building up the grounding structure of the entire network. The network cohesion of the intra-school network is highly correlated with the schools' overall performance indicated by ranking. Additionally, neither

ARWU nor US News includes architecture and humanities into the ranking, so the relationship between their network cohesion and overall academic performance is still ambiguous.

Additionally, there could be several reasons why some subjects of Tsinghua are not currently ranked. Such factors as small school sizes, young organizational ages, ranking system's preferences may make the rankings of those subjects currently unavailable. However, this phenomenon reflects the relatively weak global visibility of those subjects of Tsinghua. The connectedness of faculty by means of academic collaboration for these schools is also quite weak. However, it should be warranted that the status of a school in a university may not only be related to its global visibility and performance, but also affected by local dynamics and the organizational goal of the university. Whether the global ranking of subjects may affect the local status of schools is yet to be assessed and faculty collaboration must also be understood in relation to the local status of schools.

Faculty-Faculty Ties: The Inter-organizational Network

Intra-school ties connect faculty from the same school, whereas inter-school ties connect faculty from different schools. All schools but the school of journalism have inter-school ties, so the school of journalism is not in the inter-school network of Tsinghua. Table 4.7 displays the number of ties that any two schools have. The number of ties between schools ranges from 1 to 351 (CHEM-SCI). The school of sciences has collaborated a lot with other Tsinghua schools such as the department of chemical engineering (351), the school of informational sciences and engineering (214), materials sciences (184), environment (134), mechanical engineering (128). There are plenty of pairs of schools that only have one coauthorship, which suggests that the connectivity of the inter-school network is quite vulnerable.

Table 4.7 Frequency of inter-school edges

Edges	Weight	Edges	Weight	Edges	Weight	Edges	Weight
Mech-Info	91	Info-Med	28	Chem-Pharm	1	Life-Soc	1
Mech-Civ	5	Info-Aero	11	Sci-Mat	184	Life-Env	13
Mech-Chem	40	Info-Arch	16	Sci-Life	18	Life-EngPhys	3
Mech-Sci	128	Info-Soc	1	Sci-Med	13	Life-Pharm	8
Mech-Elec	3	Info-Env	6	Sci-Aero	19	Veh-Aero	2
Mech-Mat	84	Info-Econ	4	Sci-Arch	3	Med-Aero	6
Mech-Life	12	Info-EngPhys	14	Sci-Soc	5	Med-Soc	7
Mech-Veh	27	Info-Pharm	7	Sci-Env	134	Med-Env	1
Mech-Med	12	Civ-Chem	10	Sci-Econ	1	Med-Pharm	18
Mech-Aero	33	Civ-Sci	19	Sci-EngPhys	36	Med-Hum	2
Mech-Arch	4	Civ-Elec	1	Sci-Pharm	20	Aero-Arch	3
Mech-Soc	4	Civ-Aero	1	Sci-Hum	3	Aero-EngPhys	10
Mech-Env	4	Civ-Arch	18	Sci-Law	1	Arch-Env	5
Mech-Econ	5	Civ-Soc	1	Elec-Mat	9	Arch-EngPhys	2
Mech-EngPhys	2	Civ-Env	1	Elec-Aero	4	Soc-Econ	1
Mech-Hum	1	Civ-Econ	1	Elec-Env	2	Soc-Publ	2
Mech-Publ	1	Civ-EngPhys	2	Mat-Life	12	Soc-Edu	1
Info-Civ	5	Chem-Sci	351	Mat-Med	1	Env-Econ	2
Info-Chem	46	Chem-Elec	2	Mat-Aero	22	Env-EngPhys	3
Info-Sci	214	Chem-Mat	28	Mat-Arch	2	Env-Publ	1
Info-Elec	98	Chem-Aero	4	Mat-Env	6	Econ-Publ	8
Info-Mat	107	Chem-Arch	4	Mat-EngPhys	13		
Info-Life	24	Chem-Env	4	Life-Med	98		
Info-Veh	1	Chem-EngPhys	4	Life-Aero	2		

Figure 4.8 presents a circle layout of the inter-school network of Tsinghua. To have a clear visualization, this graph does not show edges that have weights smaller than 10, the network was broken into several components because of this omission. Schools including the schools of law, education, public policy, humanities, and social sciences, were disconnected from the main component.

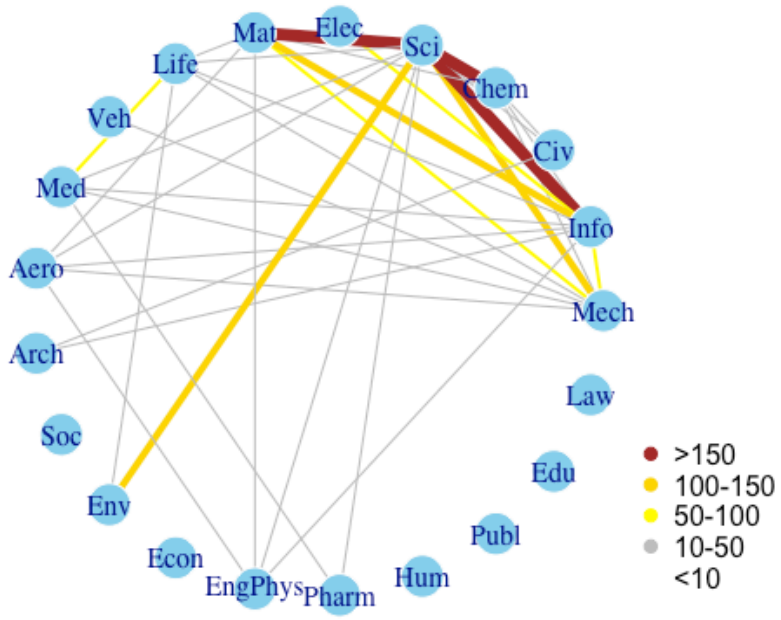
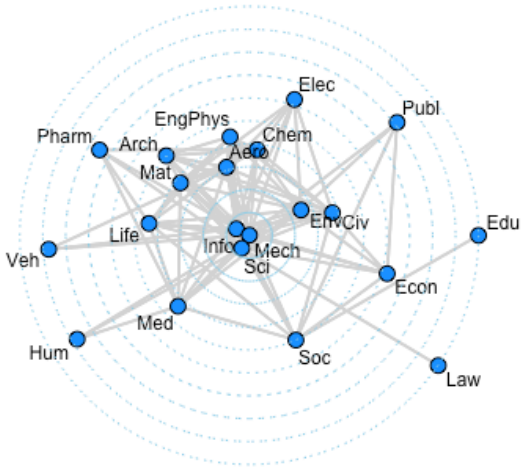


Figure 4.12 Inter-school network graph of Tsinghua

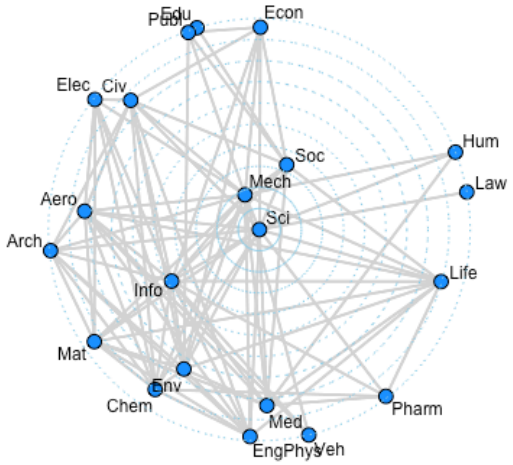
To explore the structure of inter-school network of Tsinghua, I employed a radial layout to present the centrality of each school in the inter-school network (Figure 4.9). Four measures of centrality, including degree, eigenvalue, closeness, and betweenness, were been used to capture the different representations of "central."

Degree centrality

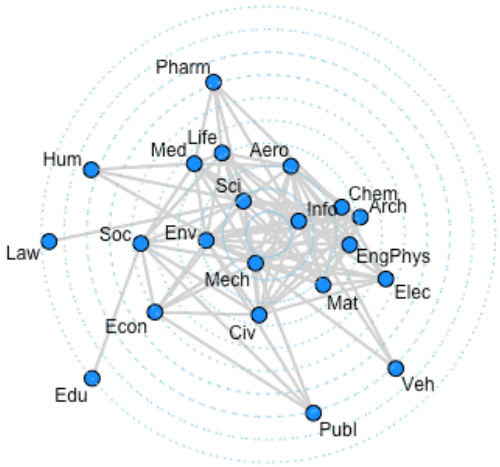
Betweenness centrality



Eigenvector centrality



Closeness centrality



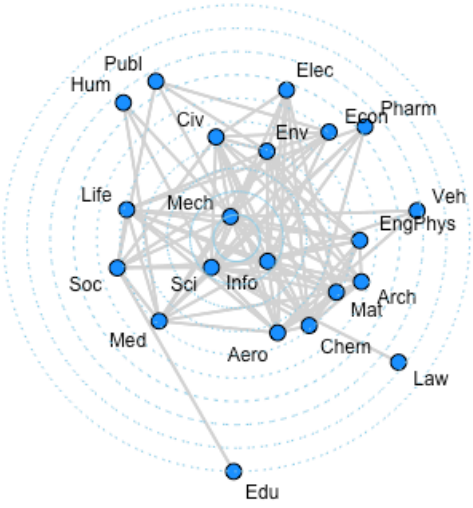


Figure 4.13 Target plots showing various vertex centralities for the inter-school network

Degree centrality shows the nodes in the central are the ones with the highest degrees. According to the degree centrality graph, the three arguably most important units in Tsinghua are the schools of mechanical engineering, information science and technology, and sciences.

Betweenness centrality measures are aimed at summarizing the extent to which a vertex is located “between” other pairs of vertices. A degree-based concentralization figure seems to be particularly sensitive to the local dominance of points, while a betweenness-based measure is

rather more sensitive to the "chaining" of points. In the graph showing the betweenness centrality, there are only four nodes in the core, whereas the other vertices in the network appear to be maximally distinct from the center. Although the school of social sciences has a lower degree centrality, it is central in the betweenness centrality graph. The school of social sciences seems to have played a "bridging" role in connecting other schools in the inter-school network, connecting the schools in the sciences and engineering and schools in the social sciences and humanities.

Closeness centrality measures attempt to capture the notion that a vertex is "central" if it is "close" to many other vertices. If a school has a higher closeness centrality score, it has collaborated with more schools. MECH, INFO, and SCI have collaborated with most schools, so they are in the core. The Institute of Education has only one collaborative tie with another school, so it is on the periphery of the closeness centrality graph.

The eigenvector centrality measures the idea that the more central the neighbors of a vertex are, the more central that vertex itself. The eigenvector centrality is positively related to degree centrality. Measures of centralization can tell us whether a graph is organized around its most central points, but they do not tell us whether these central vertices comprise a distinct set of points which cluster together in a part of the graph.

Although each centrality measure can indicate the structure of the network in a unique way, some centrality measures are correlated with one another. In this study, degree centrality is highly correlated with closeness centrality and eigenvalue centrality. Betweenness centrality is correlated with degree centrality in a logarithmic shape. A few nodes with larger degrees also exhibit strong betweeness, whereas most the nodes do not differ much in betweenness centrality. The four scatterplots on centrality correlations also demonstrate the central roles of the three schools – MECH, SCI, INFO – in the inter-school networks, regardless the centrality measures being used.

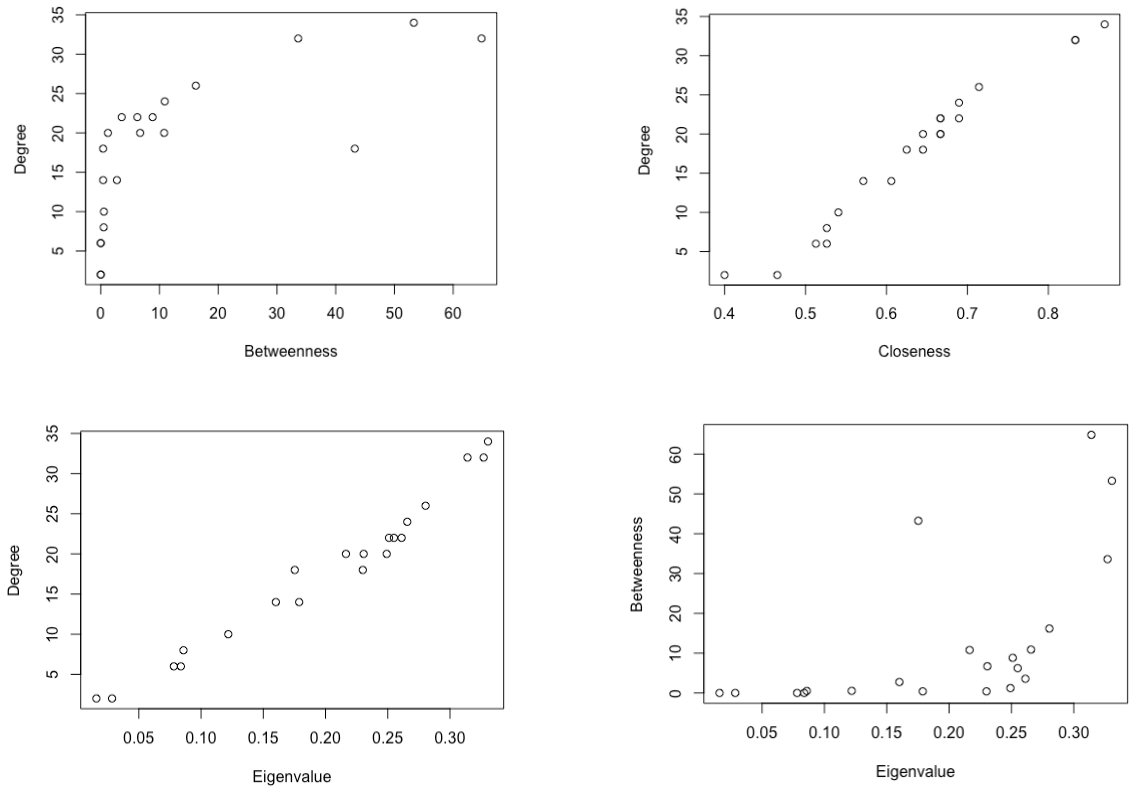


Figure 4.14 Correlations between centrality measures

The "Bridging" Role of School of Social Sciences. There are very few inter-school ties of social sciences. Only six faculty of SOC have collaborated with faculty from other Tsinghua schools. However, the SOC has connections with seven other Tsinghua schools including not only schools in the social sciences such as public policy and education, but also in the hard sciences (e.g. life sciences) and engineering (e.g. civil engineering). As discussed in the last section, social science faculty connect schools that do not collaborate or collaborate much, so the school of social sciences is central in the betweenness centrality graph.

Although inter-school ties are few, the school of social sciences does play a role in bridging schools that were "far" from one another in the inter-school network, but the actual "bridging" effect needs to be furthered measured by examining the actual collaborative behaviors. The school

of social science, compared with other schools, seems to show potential to become a "hub" for interdisciplinary collaborations that connect disciplines that were distinct in culture.

	MED	PUBL	ECON	INFO	CIV	MECH	EDU
SOC	7	2	1	1	1	1	1

Several forms of inter-school collaboration of SOC faculty were investigated. First, many inter-school papers of SOC were worked on by one person. A total of 14 papers from the school of social sciences were cross-school papers, half of which linked to the school of medicine of Tsinghua. Six papers that collaborated with the medicine school were coauthored between a medical school professor and a social sciences professor who is affiliated with Institute for Hospital Management of Tsinghua University – a multidisciplinary research center that aims to promote hospital management. The center was built in 2012 and provides a collaborative platform for schools of economics, public policy, law, medicine, social sciences, and informational science. As the links indicated, the SOC-MED collaboration has remained at the individual level other than school level with the platform to promote interdisciplinary research. The SOC professor connecting to medicine school is also in the center of SOC networks at all levels.

Second, a few papers were led by faculty from other schools according to the order of the author list and the sources of funding. In such work, SOC faculty could have participated in but not led the collaborative work. The collaborations with the schools of informational science, civil engineering, and education are in this category of collaboration forms.

Third, two papers were joint works of three schools: the schools of social sciences, economics and management, and public policy. Authors contributed to the papers equally and were ranked alphabetically. It seems that a group of faculty members from the three schools already laid the foundation for future collaborative research that should be interdisciplinary in nature.

Individual Factors on Network Centrality

While this research focuses on organizational factors of the Tsinghua coauthorship network, a few analyses have been conducted to predict the individual effects on individual network centrality for a better understanding of the Tsinghua network and as a pilot study for future micro-level investigations. As findings show, individual network features varied by school and can be largely dragged by large schools. In this pilot study, I tested a few individual factors on in two schools – the school of information science and technology and the school of environment.

Seniority

Faculty rank and appointment year can capture the seniority of faculty members. For the environment school, seniority of faculty was positively associated to faculty centrality in collaboration. First, in terms faculty rank, professors were significantly more central in network than assistant and associate professors in both the school of environment and the school of information science and technology. Second, appointment year was positively related to degree centrality in the environment network and was positively associated to betweenness centrality in the intra-school network. Faculty who entered the school of environment earlier tended to be more central in the network. One more year in the environment school is associated with 6.37 more ties in the network. Senior environment faculty tended to be in a bridging position connecting chains of points. Unlike ENV, the correlation between appointment year and degree centrality was not significant for faculty in school of information science and technology.

Educational Backgrounds

For the environment network, factors related to educational backgrounds are not significantly related to centrality in the network. For example, faculty who graduated from overseas institutions may have advantages in expanding global network to have a higher global

centrality, but the collaboration data of ENV does not support the assumptions. Also, faculty that graduated from Tsinghua did not significantly contribute to local centrality degree.

For information science and technology, there is a significant difference in local degree centrality between those who obtained Tsinghua PhD degrees and those who did not. Tsinghua PhD holders have an advantage in building their collaborative network at the local level. On average, SIST faculty as Tsinghua graduates got six more direct ties than faculty who did not graduate from Tsinghua. There is not any significant difference in global degree centrality between those who obtained foreign PhD degrees and those who did not.

Summary of Findings

This chapter analyzed the overall patterns of the Tsinghua network at global, national, and local levels and identified some of the network features of intra- and inter-school networks. First, this study provides an institutional case for the analysis of international production and coauthorship. The Tsinghua network shows the increasing trend of global collaboration papers and ties during the five-year period, which responds to the overall trend in global science. Compared with American research universities like Harvard, MIT, and UCLA where over 50% of publications use international collaboration, Tsinghua's international collaboration is 27% of all publications and is expected to continue to increase in the years to come when it keeps promoting higher education internationalization. Additionally, schools have varied proportions of global ties. Smaller schools in the social sciences such as the school of economics and the school of public policy have higher percentages of global ties, although the number of ties is not much given their sizes.

Second, Tsinghua faculty collaborated most with scholars affiliated to institutions in the United States in its global network. The proportion of national ties in the Tsinghua network is

smaller than that of global ties. Tsinghua collaborated with first-tier national universities in China. Organizational status equivalence seems importance in the formation of national ties.

Third, the Tsinghua network heavily relied on local ties – intra-organizational and inter-organizational ties within Tsinghua. Most local ties are bounded at the sub-organizational level, whereas inter-organizational ties are very few. In terms of intra-organizational network of Tsinghua, the analysis was focused on examining the school's network cohesion by measuring the number of components, size of giant component, and clustering coefficient. Closely-knit networks with stronger bonds between faculty members have more trust and consensus within the sub-organizations. Network closure acts as social capital that contributes to better outside performance. It is found that structurally cohesive schools have higher external productivity, extensity, and global visibility.

Fourth, the inter-organizational network of Tsinghua is vulnerable as it can be easily broken down into several distinct clusters with a few links removed. A core-periphery structure is clear in the inter-organizational network of Tsinghua, with the schools of sciences, mechanical engineering, and information science and technology in the center, and social sciences and humanities in the periphery. Additionally, the school of social sciences plays a bridging role in connecting NS & ENG and HSS.

CHAPTER 5 DISCUSSION AND IMPLICATIONS

This study explores research collaboration patterns of Tsinghua University during a 5-year period from 2014 to 2018. Two major foci of the exploratory investigation were on 1) tie distributions at local, national, and global levels; and 2) school/department level differences in network features. The findings portray Tsinghua's current global network across schools by showing the places where Tsinghua can reach by collaboration and the ways in which Tsinghua's ties are currently spread out in schools. First, while Tsinghua's network is reliant on its local ties, this study finds the overall rising global collaboration in Tsinghua and a high collaboration rate with U.S. researchers. Second, the school variations in distributions of ties are evident. Third, there is a hierarchical structure in the inter-school collaboration of Tsinghua with certain units in the sciences and engineering in the center. Fourth, the internal network cohesion of the intra-school network indicated by giant component, tie strength, and clustering is positively related to the sub-organization's external productivity, reachability, and visibility.

In this section, I will discuss two themes that emerged from the findings: the geopolitical influence on Tsinghua's global ties and the extreme discipline hierarchy represented in the local networks. The discussion would be elaborated on by using theoretical perspectives on social capital, organizational embeddedness, and globalization. This chapter will conclude with implications for policy, practice, and future research of this study and a conclusion section.

A Geopolitical View of Global Networks

At present, global academic collaboration grows as the globalization trends compress time and space, which largely increases the efficiency of global collaboration. In the past decade, the percentage of worldwide publications from international collaboration rose from 16.7% to 21.7% (NSF, 2020). Like the global trends, this study finds that the trend of global collaboration of Tsinghua has increased in recent years and that the percentage of global collaboration increased

from 22% in 2014 to 27% in 2018. Accordingly, the share of global ties in Tsinghua network increased from 10% in 2014 to 30% in 2018.

The increase in global collaboration of Tsinghua is the result of the university's elevated research capability in science and its strategy of promoting institutional internationalization. It's national and local joint effort. In the larger context of China's "global ambitions" towards creating a few "world-class" universities, internationalization and global and regional research impact are important for Chinese universities to gain institutional prestige in the world, as internationalization and research capacity measures such as publications and citations are critical measures for global rankings. Global ranking can play a "discipline role" (Foucault, 1977) in shaping national higher education systems and actors' performance towards the norms. Rankings have become a key driver for institutional prestige (Pusser & Marginson, 2013) and demonstration of the influence of national higher education systems. Tsinghua's active global collaboration is a component of its internationalization campaign. While the meaning and interpretation of internationalization differs by nations, the internationalization has been regarded as critical to cultivate student talent and advance innovative research in prestigious Chinese universities such as Tsinghua (Rhoads et al. 2014). Marginson and Wen (2019) thought the global coauthorship could indicate the internationalization of the HEIs and that global prestigious universities are the ones with a high share of global coauthored research. For example, prestigious universities such as Harvard and UCLA have more than 50% coauthored papers of all are global coauthored papers during 2014-17 (Marginson & Wen, 2019). This study found the share of global coauthored papers on Web of Science in Tsinghua is 27% in 2017.

The increase of global coauthored papers and the expansion of the global Tsinghua network interacts with the increasing global visibility (i.e. rank) of Tsinghua. As a leading research

university in a rising economy, Tsinghua's success in terms of global rankings brings pride and confidence to both the institution and the nation. Although they may not be able to fully represent the performance of subjects and the schools, the rankings reflect the power, resources, and status of the university and attract more national and global resources and talents to the university, which will continue to increase knowledge circulation and network expansion of the university. Tsinghua's global collaboration network is expected to increase to connect more clusters that were far away in the past.

Additionally, besides the "discipline" effect of rankings on the rise of global publication and collaboration, the institutional culture of Tsinghua also contributes to the rise of global coauthorship in Tsinghua. Tsinghua's international culture is rooted in its history and reflected by its faculty group portraits; share of international students and scholars; and global programs. Faculty pride themselves on paying attention to connecting foreign experts to the campus academic community throughout the institution (Rhoads et al. 2014). The culture of openness to international scholars contributes to the internationalization of the curriculum, research, and the institutional culture.

Nonetheless, the geopolitics in higher education, in terms of national or regional publishing power and knowledge production, is evident in Tsinghua's case by the geography of international scientific collaboration. Tsinghua collaborated most with countries or regions in the "Global North" that have established scientific powers (Gui & Liu, 2019) and editorial controls in the publishing industry (Braun, 2005). Among all the global partners, Tsinghua collaborated with the U.S. the most. Half of the global articles of Tsinghua were coauthored with at least one scholar from an institution in the U.S. Among all the multilateral collaborations which are associated to at least

three countries including China, as many as 72% papers have an author's address in the U.S. (i.e. China-U.S.-Other). Coauthorship with U.S. scholars is common for Tsinghua scholars.

Tsinghua-Global North or Tsinghua-U.S. coauthorship can be explained by the preferential attachment mechanism at the organizational levels. Preferential attachment suggests actors tend to seek to connect to high-status academics, which acknowledges the intellectual or financial dependency within a hierarchical social system of science (Crane, 1969; Beaver & Rosen, 1979). The United States has ties with almost every country in the global academic network. In 2008, 43% global coauthored articles were linked to U.S. scholars (Tang & Shapira, 2011). As the high-status actor in global higher education legitimated by global rankings, the United States is the most central player in the global science collaboration network and can structurally connect the network and bringing academics quicker access to others (Moody, 2004). Chinese national flagship universities used to compare themselves with their prominent Western peers and are chasing after their peers in the "centers" mainly in North America and Europe. They focus their strategic collaboration overwhelmingly on prestigious global partners (Yang, 2015). Connecting to U.S. institutions can extend Chinese institutions' research impact (Lee & Haupt, 2019) and expand its collaborative network.

The Tsinghua-U.S. collaboration is beyond the realm of research collaboration. Most Tsinghua international organizations were built with the U.S., such as the Tsinghua-Berkeley Shenzhen Institute (TBSI) and Global Innovation Exchange Institute in Seattle. Based on these organizational partnerships, Tsinghua has established a few joint degree education programs and student exchange programs. For example, the TBSI offers a dual-degree program, a master's program in engineering at UC Berkeley and a master's science degree at Tsinghua. Many faculty have either studied or worked in American higher education institutions. However, in case studies

on several schools in this study, faculty members' PhD background is not significantly related to the likelihood of having international coauthors. The multiple layered international linkages at both the individual and organizational levels should not only bring convenience for the formation and persistence of research ties, but normalize the research collaboration with U.S. institutions or scholars, but more detailed information should be gathered on the ways in which the multiple layered international linkages at both individual and organizational levels affect faculty coauthorship. Such studies in the future can help understand the formation of global collaboration and organizations' role in fostering ties.

The increasing research capacity of Chinese universities will likely increase their status in the network, as the network is an "open space" which shall respond to the evolving global science and research system. Lee and Haupt (2019) found that China led the U.S.-China research collaboration in the 2014-18 data, given the first authorship and governmental funding patterns. Due to its national prestige and international culture, Tsinghua should play an important role in the China-U.S. research collaboration. Tsinghua-Berkeley Shenzhen Institute is an example of a successful research alliance between China and the U.S. The venture was entirely funded by the Shenzhen municipal government ($52 million) and the Tsinghua Education Foundation ($22 million). The funding was used on the building of labs and sponsoring student scholarships and faculty research in the areas of information technology and pharmaceuticals (Antony & Nicola, 2020).

China and the U.S. have become each other's largest partner in academic coauthorship (Wagner et al., 2015) and they mutually benefit from the research collaboration. The U.S. extends the global reach of China's research with its established scientific heft, and China brings financial investments to scientific research (Lee & Haupt, 2019). However, the trend of future U.S.-China

collaboration or the global scientific collaboration is yet to be predicted, with the rise of "scientific nationalism" that the U.S. and China may embrace in the years to come. The U.S. would benefit from promoting "scientific globalism" and keeping collaborative connections with China (Haupt & Lee, 2020). From China's side, to what extent Chinese HEIs promote scientific nationalism over scientific globalism would also likely affect U.S.-China collaboration. Chinese universities have started to reflect on its "SCI/SSCI worship." The issue that the academe in China may have excessively relied on using SCI and SSCI as the "gold standards" for research publications has been discussed as of late in China. Per President Xi Jinping's recent talk, China should have its own standards, rather than just follow the West. Huang (2020) thought that if Chinese institutions would lessen the reliance on SCI and SSCI, the publishing requirements for faculty would likely to change and the international collaboration would inevitably drop for China.

Reform of the publication system has been more relevant in social sciences in the current context, as more and more Chinese flagship universities have started to value CSSCI journals and consider them equivalent to SSCI in faculty requirements and tenure evaluations, though higher prestige is still afforded by most Chinese universities to SSCI and A&HCI journal publications by means of higher weighting in monetary and career-related incentive schemes (Xu et al., 2019). In a social science school of Tsinghua, publishing two CSSCI journals is equivalent to one SSCI journal in faculty promotion evaluations. The international collaboration in HSS may be dropped as the increasing recognition of CSSCI in China and the local-oriented disciplinary nature of HSS would lessen the institutional pressure on publishing in SSCI indexed journals. However, international HSS publications only take a very small share of China's international publications. Past studies about global scientific collaboration of China are often about sciences other than humanities and social sciences, which shows the central status of sciences in the global knowledge

flows and the limited global visibility of HSS of Chinese HEIs. The drop in international collaboration in the fields of HSS in Chinese universities may not happen or happen quickly for the NS part in China. In Tsinghua's case, the scale of global collaboration has risen over the years. Taking the school of social sciences as an example, the number of papers published in international journals is rising, but the percentage of papers that were collaborated with international authors has dropped a little. With the rise of research capability and global visibility, science and engineering of Tsinghua would likely attract more international coauthors to engage in deeper collaboration with the central players in the scientific network. The change in faculty collaborative behaviors should be followed in the next few years to see if the scientific nationalism perspective is activated in Chinese HEIs and affects faculty members' research. However, the geopolitical stratifications of higher education and power dynamics in the scientific system and publishing industry may be hard to change quickly in the short-term.

Table 5.1 Number and percentage of international collaboration papers in Tsinghua

School	2014	2015	2016	2017	2018	% Trend
Environment	78 27%	108 29%	115 29%	155 36%	160 39%	Increasing
Information Science and Technology	325 23%	322 27%	381 31%	350 29%	209 30%	Increasing → stable
Social Sciences	9 69%	6 35%	13 45%	12 40%	18 45%	Decreasing → stable

Moreover, compared to global ties, Tsinghua's national ties connecting other Chinese HEIs than Tsinghua University are fewer. First, international coauthored papers yield more citations on average which increase the prestige and visibility of scientists involved (Haupt & Lee, 2020). The benefits of being involved in international research projects attract scholars to seek for global

collaboration and ties. Second, the internationalization culture of the institution drives publications towards global orientations, rather than national. The invisible "award" obtained or "prestige" attached to publishing international collaborative work may encourage faculty to collaborate globally. Third, most of the national ties of Tsinghua were built with other Chinese first-tier HEIs that share similar status with Tsinghua. Given the unbalanced development of Chinese research universities, Tsinghua has risen quickly in the world rankings, which make it much more visible than its domestic peers in the world and increases its global engagement. Lastly, the globalization that compressed time and space and the emerging norms of using ICTs for collaboration largely increase the efficiency in the global exchanges. The geographical proximity may no longer be an important factor for academic collaborative behaviors, as past studies documented. With technical barriers removed, the "network proximity" is becoming a contributing factor on collaboration. Collaborations are more likely to occur among institutions with similar status and prestige.

Representations of the Discipline Hierarchy in Tsinghua

Schools/departments are important categories of inquiry of this research. This research found the difference in network structure and in faculty collaboration patterns among schools. First, Tsinghua's publication network exhibits an extreme discipline imbalance overall – there is a huge discrepancy in the total number of ties between schools in the nature sciences & engineering and humanities and social sciences. Second, the inter-school network suggests a hierarchical structure of ties across school boundaries – nature science and engineering in the center and humanities and social sciences schools on the periphery. The three arguably most important units in Tsinghua are the schools of mechanical engineering, informational science and technology, and sciences. The schools of law, education, public policy, humanities, and social sciences, were on the periphery in the inter-school network. Third, the shape of the intra-school network for the schools in distinct

cluster varied: most schools in the NS&ENG have quite dense networks while schools in the HSS exhibit sparse networks. Faculty in the NS&ENG collaborated with one another much more frequent than their colleagues from schools in the HSS. The internal cohesion of the network is positively correlated with the school's external productivity and reachability. Schools with cohesive networks rank better. These findings are representations of the discipline hierarchy in Tsinghua University. In this section, I will elaborate on these findings by using social capital and organizational theory, and academic culture theory.

This study found that the level of network cohesion in school's intra-school network is associated with external productivity, reachability, and global rankings, respectively. For schools where faculty collaborated with each other more and frequently, they also have more collaboration with scholars outside Tsinghua and reach more external institutions. The positive correlations between network cohesion and productivity, reachability, and global visibility (rank) can be explained by Coleman's (1988) network closure theory which argues that the closely-knit networks and cohesive ties foster a normative environment that facilitate cooperation. Dense networks with many direct or indirect ties contribute to an extensive amount of knowledge sharing among members (Berg et al., 1982). The trust and norms being established and reproduced in the collaboration within organizations will aid the future research collaboration. The stronger bonds between faculty in schools such as school of materials sciences and environment, on one hand, contribute to the schools' overall performance in many forms and further benefit the researchers and the organizations in achieving status and prestige, on the other. A cohesive core of networks may be the best form of social capital for schools in need of legitimacy and identity locally and globally. In Tsinghua's case, cohesive networks have better status and resources in developing themselves. However, the closely-knit networks allow faculty sharing networks and thus reproduce

the networks and knowledge. Network cohesion may not only lead to knowledge creation, but also lead to the homogeneity and redundancy of information or the maintaining of the status quo, which restricts new contacts and novel research. In this sense, Burt's (1992) structural hole theory is contradictory to Coleman's social capital theory in that Burt sees cohesive ties as a source of rigidity that hinders flexibility and heterogeneity (Gargiulo & Benassi, 2000). Future studies might benefit from examining the presence of structural holes within ego networks as a basis for the flow of certain types of knowledge (Burt, 2004). The trade-off between the networks that guarantee the safety of the cooperation and the networks that assist the flexibility and heterogeneity can be examined by analyzing the structural holes and closures within the network.

All humanities and social sciences schools have no cohesive cores within their intra-school networks. There is no "core" in these networks and the average strength of ties is limited. The global visibility of Tsinghua's HSS is limited, too. Unlike NS&ENG schools that exhibit cohesive networks, HSS networks are sparse. In other words, HSS may have more flexibility to build effective cooperative ties across a variety of intra- and inter-organizational boundaries. As this study found, smaller schools in the social sciences such as the school of economics and the school of public policy have higher percentages of global ties compared with most natural sciences and engineering schools. The geographical distribution of ties for HSS is more spread out. However, lack of global visibility may limit Tsinghua HSS's ability to extend its global network and build its legitimacy in the institution that has an internationalization agenda.

Another major discipline hierarchy in Tsinghua is shown in the inter-school network – schools in the NS and ENG are in the center and HSS on the periphery. While there are various reasons that limit the cross-boundary ties of HSS, the shape of the network can be a representation of the disciplinary imbalance within Tsinghua. Despite the institutional goal of enhancing its HSS

part, Tsinghua's HSS is not an integrating component of the social cohesion of the university. However, there are some structural features found in the network that may contribute to the evolving of the inter-school network of the university in the long run.

While the school of social sciences is "periphery" in the degree centrality graph, the school is found "central" in betweenness centrality graph. The school of social sciences has played a "bridging" role in structurally connecting two clusters of schools that have limited connections in between and have distinctive disciplinary cultures – schools in the sciences and engineering and schools in the social sciences and humanities. The inter-school ties generated by the school of social sciences function as "weak ties" (Granovetter, 1973) that become bridges to interconnect different subgroups in the social network. The weak ties could allow access to wider resource heterogeneity (Lin, 2002) and thus could also allow for more interdisciplinary research in the future. In a university like Tsinghua with such a discipline imbalance, the bridging role that schools like the school of social sciences play is important as it not only fosters cross-discipline communications and collaborations, but also raises the institutional recognitions of discipline differences. The increase of local visibility and recognitions of HSS would benefit the institution's world-class agenda.

However, in investigating the cross-school work of social science faculty, this research also found that the school of social sciences is not leading, but participating in the collaboration. The "bridging" role that the school of social sciences play is important for the institution, but may not be helpful for the actual development of HSS. The participatory role rather than leader's role that the school of social sciences plays in the inter-school network is a shadow of HSS's status and resources in Tsinghua. In collaboration, especially in cross-school work, the control of critical resources (grants, talents) provides an important advantage to the resource-rich partners (Pfeffer

& Salancik, 2003), so the collaboration occurs on terms favorable to the partner who controls the critical resources. The collaboration across school boundaries can be contingent on the power relationships among the collaborating organizations.

As Kezar and Lester (2009) noted, fostering collaborations requires institutions to integrate structure, rewards, resources, hiring, and formalize the network for collaboration, which leads to rethinking overall organizational structures, processes and design. Such institutional behaviors as the building of multidisciplinary research centers/institutes, funding interdisciplinary research, encouraging faculty to do interdisciplinary research will largely contribute to the formation and persistence of collaborative ties across disciplinary boundaries. In Tsinghua, there have been many research labs/institutes recently built with the mission of promoting research across disciplines in most recent years. The table shows the ten interdisciplinary labs/institutes of Tsinghua (one is under construction). These interdisciplinary research institutes were a joint effort of the university, schools and departments, and some external sponsors in the industry. With the increasing interdisciplinary knowledge and research, the mission of building these institutions is to foster an interdisciplinary platform for faculty to collaborate and produce innovative work. Since these institutions have just started, to what extent and by what mechanisms they contribute to faculty collaboration is yet to be discovered given the 2014-18 publication data. It can be predicted that ties between some schools (e.g. life sciences and information science and technology) will be increased due to the functioning of these centers in the years to come. As far as it shows at present, there is limited visibility of schools and departments in the HSS in such new interdisciplinary centers of Tsinghua. The department of psychology and the department of sociology have participated in two interdisciplinary institutes, which will likely strengthen the school of social

sciences' "bridging" role in connecting the science and engineering cluster and HSS cluster in the inter-school network.

Table 5.2 University interdisciplinary research centers/labs in Tsinghua

Institute Name	Year of Establishment	Associated Schools/departments
Tsinghua Laboratory of Brain and Intelligence	2017	Life sciences, Information science and technology, Psychology
The Future Lab	2017	Arts and Design, Information science and technology
Lab of Intelligent and Connected Vehicles	2017	Automotive Engineering, Information science and technology, Civil Engineering, Aerospace Engineering, Mechanical Engineering
Center for Flexible Electronics Technology	2017	Chemistry, Information science and technology, Civil Engineering, Aerospace Engineering, Mechanical Engineering
AI Motive Systems	2017	Computer Science, Mechanical Engineering, Automotive Engineering, Medical Sciences, Aerospace Engineering, Chemical Engineering
Institute for Brain Research	2013	Life sciences, Medical sciences, Materials science, Information sciences and technology
Center for Biomedical Engineering	2019	Life sciences, Medical sciences, Engineering
Institute for Artificial Intelligence	2018	Informational Science and Technology, Mechanical engineering
Tsinghua University Institute for Data Science	2018	Information science and technology, social sciences
AIR	2020 (in planning)	Vehicle mobility, Information science and technology

There are large differences across academic disciplines with respect to the extent of coauthorship in scholarly publishing (Jung, 2012). For Trowler (2001) who raised the concept of *"academic tribes and territories"* and scholars following this line of research on academic culture, disciplinary culture were influential in determining whether researchers operated alone or in large groups, and what the object of their research was. Some scholars documented that joint authorship is much more common in hard sciences than in soft sciences, as social scientists might be more sensitive to institutional and disciplinary boundaries than those in other sciences and engineering (e.g. Jung, 2012; Kyvik, 2003). The low and high paradigms (Collins, 1994; Kuhn, 1970) also

contribute to the understanding of the social organizational of different disciplines. Higher-paradigm fields have greater mechanical solidarity, while lower-paradigm fields are more reliant on interpersonal contact to generate mechanical solidarity (Rawlings & McFarland, 2010). The high-low paradigm argument was supported by the evidence found in schools of Tsinghua. While acknowledging the influence of disciplinary cultural difference on collaboration behaviors, the findings of the research suggest that the national and institutional cultures intensify the disciplinary hierarchy in collaborative networks and contribute to the imbalance of discipline within the institution and nation.

While the hierarchy of discipline exists in the global network of research, the discipline imbalance is severe in China (Marginson, 2011). In 2016, the combined proportion in social sciences and psychology of all papers was 10.7% in the U.S. and 10.1% in the EU, but only 1.3% in China (NSB, 2018). China's share of NS publications accounts for 18.6% of all global publications in 2018 (NSB, 2018), whereas the share for HSS publications in Scopus database is only 3% in 2018.

The extreme discipline skew in the share of global publications in China is evidenced in Tsinghua's case – less than 2% papers collected in this research are in the HSS cluster. Tsinghua's (Web of Science) publications were heavily relied on its natural sciences and engineering cluster during the 2014-18 window.

Both national and global drivers are at play in the rise of science and higher education in China. The national focus on hard sciences and engineering fed the content of much international benchmarking and built up China's connections to global sciences. The internationalization agenda is embedded in such "national/global synergy" that emphasizes international benchmarking and publications. Social scientists are squeezed between conformity to state requirements and

conformity to global academic requirements, for the agenda of internationalization requires them to publish more in American-led journals and to conform to foreign topics rather than develop indigenous ideas. Under such national academic culture, humanities and social sciences work are under-valued and do not share the same level of collegial protection as do the physic sciences (Xie, 2018). If using global discipline rankings to indicate visibility, Tsinghua's HSS have not shown much of the progress in its ranking "performance" during the past ten years. As Yang (2011) thought a decade ago, it was hard for China's HSS to achieve the global visibility of its natural science and engineering peers in the short term for many reasons such as its local orientations, language barriers in publishing international journals, research paradigm discrepancies between the Chinese and the West, and so forth.

The national/global synergy affects the institutional efforts being made to develop disciplines in Chinese universities. Only a handful of top universities in Chinese mainland, including Peking University, Fudan University, and Nanjing University, "make a determined effort to resource the full range of globally common disciplines, including the non-science fields, at an adequate level" (Marginson, 2018). Among the 22 National Key Disciplines selected at Tsinghua (2007), ranking first nationwide, only one is in the social sciences or humanities category – business administration. The rest of the disciplines are in the Sciences and Engineering. In the most recent national HE initiative, the "Double First-Class university and discipline plan" (2015), Tsinghua has 34 disciplines selected into this plan that aims to develop elite Chinese universities and their departments into world-class institutions by 2050, of which one is in humanities and six in the social sciences related discipline. The School of Economics has four disciplines selected, which shows its status among HSS cluster in Tsinghua.

The national academic culture emphasizing hard sciences and the related internationalization agenda shape the institutional culture of Tsinghua. The institutional cultures that lack respect for differences between the hard and social sciences (Clark, 1987; Becher & Trowler, 2001) continue to marginalize the social sciences. In Tsinghua, a university with the institutional culture that values efficiency, innovation, and entrepreneurship (Rhoads et al, 2014), HSS research were rendered unimportant as they cannot contribute much to the global research performance of the institution. The hierarchy of broad discipline is at play in Tsinghua – natural and engineering sciences at the top and the social sciences at the bottom. Social scientists at Tsinghua are marginalized in the environment where science and engineering faculty could enjoy an ingrained superiority (Xie, 2018).

Implications for Policy and Practice

Of a variety of reasons for choosing Tsinghua University as the case of this study, the most important one would be that Tsinghua plays a leading role in China's rise in global science, the higher education internationalization reform, and other university reforms in many ways. Although institutional practices and policies in different universities may vary, Tsinghua's case can serve as a template that shows how China envisions world-class universities and engages local and global audiences by illuminating the ongoing organizational changes and China's rising visibility in global science. Further, Chinese universities and other universities in developing economies that are trying to achieve status in global higher education system can utilize Tsinghua's case as a reference to reflect on their own academic networks. The findings of this study can serve as a local practical guide for policymakers and university leaders when they set up agendas and policies on the allocation of research resources, knowledge production, faculty evaluation, and so forth.

The findings are important in capturing discipline hierarchy in both intra- and inter-organizational collaboration networks of Tsinghua. By visualization, this study hopes to raise the institutional recognition of the disciplinary differences in culture and the power dynamics between schools in the center of the network and schools on the periphery. The findings show Tsinghua's humanities and social sciences (HSS) cluster is not an integral part of the university's research network. HSS are participating in, not leading, the limited collaborative projects in which they were involved. For universities with traditionally strong NS & ENG clusters like Tsinghua, it is hard for its HSS to initiate more collaborative ties with NS & ENG peers and become an integral part of the university in nature, given the great difference in disciplinary knowledge and culture and the gap in status and resources. It is inherently difficulty for newcomers to establish ties in local networks (Dahlander & McFarland, 2013). Tsinghua's world-class status will not be convincible locally or globally without a developed HSS cluster (Yang & Welch, 2012b). The several cross-school ties within the HSS cluster and the structural role that the school of social sciences play in the inter-school network suggest some ways to develop the HSS cluster in Tsinghua by research collaboration. The university may create platforms for units in HSS to share their research. It may be helpful to incentivize cross-boundary collaborative projects by using university funding specific for HSS collaborations. The collaboration within HSS will allow individual HSS department or school reaching to more areas in the network. In a broad sense, the increase in collaboration within HSS will be helpful to raise the local status of HSS and lift the research impact of HSS of Tsinghua.

An implication follows for interdisciplinary collaborations. There are a few schools in Tsinghua that have very dense faculty networks where faculty often collaborate with each other more often, which suggests that faculty in these schools tend to have more consensus on school

policies and norms on research. The compact networks bring organizations productivity and prestige, but may restrict the expansion of networks or the creation of novel research. The building of several interdisciplinary centers demonstrates Tsinghua's endeavor and input to foster novel and interdisciplinary research, however the outcome in generating novel research is yet known at this point. These organizations reward collaboration by bringing visibility to collaborations that do not get the recognition of disciplinary journals (Dahlander & McFarland, 2013). The interdisciplinary centers would likely create new space for knowledge production and new network.

It is clear in the findings that Tsinghua's global network is embedded in the geography of the world's higher education systems. If Tsinghua is going to reform the publishing policy that regards SCI and SSCI as the "gold standards," its collaboration networks, especially at the global level, might change. To what extent Tsinghua and other Chinese universities promote scientific nationalism over scientific globalism would likely affect global collaboration. Also, as Tsinghua's major collaborative partner for academic collaboration, U.S. institutions' goals or preferences towards collaborating with Chinese universities would also greatly affect the prospect of Tsinghua's global collaboration. Institutions should consider that the global political climate will likely cast shadow on the global collaboration in many forms, though most collaboration has been driven bottom-up by scientists in the past.

A university's research coauthorship network is a part of the organization's larger network involving different forms of institutions such as industry, government, education joint programs, institutions of exchange students and scholars, and so forth. There could be more organic links established between research networks and other types of organizational networks. Universities can try to think of ways to integrate different forms of collaboration to stimulate more opportunities

for knowledge exchange and flows within and outside Tsinghua. The influence of such organizational collaborative links on coauthorship network needs to be further examined.

Implications for Future Research

Some future studies emerged from the findings of Tsinghua's global networks. First, future study can focus on Tsinghua's global ties by investigating the ways in which these partnerships were established, maintained, paused, or abandoned with more information added such as the source and amount of collaborative project funding, rank order of the coauthors, and the share of coauthors. The disciplinary differences in global collaboration should be highlighted. Second, a study should connect research networks with other types of organizational collaboration in Tsinghua. For example, Tsinghua faculty coauthored with UC Berkeley faculty a lot and there is a Tsinghua-Berkeley institute and associated joint master's programs. It would be interesting to see if these organizational collaborative platforms would have a relationship with research collaboration by faculty or university. Third, it is imperative to have a closer look at the ways in which current U.S.-China political tensions might affect research and collaboration. A longitudinal research on collaboration patterns between Tsinghua or/and other Chinese universities and American HEIs will provide important historical contexts for conceptualizing the current situation.

Future scholarship can extend the findings on inter-school networks and further explore the rationales and mechanisms behind the formation and persistence of cross-school ties. Both individual factors such as homophonous educational backgrounds or structural status and several organizational contributing factors such as multidisciplinary platforms will be considered. Also, the performance of the recently built multidisciplinary research centers can be evaluated on whether and in what ways these organizational platforms can contribute to novel and interdisciplinary research.

Following the trajectory of this dissertation research, future studies can expand one-case study to multi-case study to compare how collaboration networks changed over time for multiple universities in China with different prestige trajectories. In such studies, comparisons would focus on how varied organizational culture, prestige, and policy may change coauthorship patterns. Comparing Tsinghua's case with other Chinese universities that have strong HSS cluster may be helpful for us to understand the effects of discipline hierarchy reflected in coauthorship. Also, it would be interesting to compare the network patterns in universities from different national higher education systems and cultures. As Tsinghua is among the highest ranked universities in the world, a comparative study on network patterns between Tsinghua and other Chinese national flagship universities and other first-tier universities in the world may contribute to the scholarship of global higher education and knowledge production.

This dissertation research has some limitations that I note in motivating future work. First, this study utilized the coauthorship data scraped from Web of Science databases. The results clearly cannot represent all work of Tsinghua faculty, especially for humanities and social sciences faculty, because of a lack of Chinese publications and other types of coauthorship than article-based publications. Thus, the results can only be applied to understand the networks generated by Web of Science data. As WoS database wins official recognition in China (Li & Li, 2015) which collects all important journals that Tsinghua value for faculty publications, the results of this study are still meaningful because they show networks with ties that are most valued by the institution. Future studies could collect new sets of data to compliment the WoS database. To examine coauthorship in HSS cluster, Chinese publications can be collected via CSSCI database, which covers the most influential Chinese HSS journals issued in mainland China and dates to the year of 1998 (Li & Li, 2015). Comparisons can be made on the coauthorship network taken from

Chinese publications and that from English publications. The results can provide evidence for the debate in Chinese HSS over the balance between internationalization and indigenization of knowledge.

Second, while this research has contributed to a structural understanding of the coauthorship network of university, there are nuances that this study has not pursued. In this research, coauthorship is defined as an undirected tie between coauthors and every coauthor on a paper gets equal credit in the network. Working in big teams will contribute greatly to the expansion of network, but the actual collaboration with one another may be limited and it depends on what role the author plays on such a team. Such factors as the number of the authors, order of coauthors, and the main source of funding will be considered in future studies. Further, this study shows how a network is spread out, but does not uncover the overall influence of the ties in the knowledge production system. The citations of the papers or the H index of scholars may be helpful to capture the influence of networks.

Lastly, this study thinks through coauthorship by categories of university or sub-organizational units. It highlights ways that research networks are shaped by organizational factors, but it seems to render individual actions unimportant in collective behaviors. Group behavior is not the simple aggregation of individual behaviors and individual action is not solely dependent on organizational norms (DiMaggio & Powell, 1982), thus the problems of "over-socialization" or "under-socialization" (Granovetter, 1985) should be warranted in conceptualizing network studies. An investigation on the interaction between individual and organizational factors on the behaviors of collaboration is needed. For one, faculty may discipline themselves to implement the norms and work around the performance assessment guided by the school or university, but how they reflect on past collaboration and make sense of their coauthorship behaviors and strategies should be

important elements contributing to our understanding of the ties being made or maintained. Future studies can see how faculty members navigate themselves in the organizational networks. Qualitative methods such as interviews can be used to understand how faculty make sense of their collaborative behaviors and outcomes. For another, the individual-organization interaction should be viewed in a dynamic network. This dissertation uses five years' data of one Chinese university between 2014 and 2018. The short period of data took a screenshot of Tsinghua's current research network, but do not have the strength to examine the possibly changing patterns of Tsinghua over the time. Future studies could collect longitudinal data from now on and monitor the changing patterns within university and cross boundaries. Longitudinal collaboration data would help figure out 1) the structural changes by establishing or cutting individual connections over the time (Powell et al., 2005); 2) if the dynamic networks contributed by individual and organizational collaborative behaviors will result in new organizational norms (Luo et al., 2008).

Bibliography

Abbasi, A., Hossain, L., & Wigand, R. (2011). Social capital and individual performance: A study of academic collaboration. *ArXiv Preprint ArXiv:1112.2460*.

Ahuja, G. (2000). Collaboration Networks, Structural Holes, and Innovation: A Longitudinal Study. *Administrative Science Quarterly*, *45*(3), 425. https://doi.org/10.2307/2667105

Antony, J. S., & Nicola, T. (2020). The Tricky Terrain of Global University Partnerships. In *Successful Global Collaborations in Higher Education Institutions* (pp. 75–86). Springer.

Barabási, A. L., Jeong, H., Neáda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientiÿc collaborations. *Physica A*, 25.

Barabási, A.-L., & Albert, R. (1999). Emergence of scaling in random networks. *Science*, *286*(5439), 509–512.

Beaver, D., & Rosen, R. (1979). Studies in scientific collaboration Part III. Professionalization and the natural history of modern scientific co-authorship. *Scientometrics*, *1*(3), 231–245.

Berg, S., Duncan, J., & Friedman, P. (1982). *Joint Venture and Corporate Innovation.* Cambridge, MA: Oelgeschlager, Gunn and Hain.

Bian, Y. (1997). Bringing Strong Ties Back in: Indirect Ties, Network Bridges, and Job Searches in China. *American Sociological Review*, *62*(3), 366. https://doi.org/10.2307/2657311

Biancani, S., & McFarland, D. A. (2013). Social Networks Research in Higher Education. In M. B. Paulsen (Ed.), *Higher Education: Handbook of Theory and Research* (Vol. 28, pp. 151–215). Springer Netherlands. https://doi.org/10.1007/978-94-007-5836-0_4

Bloor, D. (1991). *Knowledge and social imagery*. University of Chicago Press.

Borgatti, S. P., & Foster, P. C. (2003). The network paradigm in organizational research: A review and typology. *Journal of Management*, *29*(6), 991–1013.

Borgatti, S. P., & Ofem, B. (2010). Social network theory and analysis. *Social Network Theory and Educational Change*, 17–29.

Bourdieu, P. (1986). *The forms of capital*.

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy*, *33*(4), 599–616. https://doi.org/10.1016/j.respol.2004.01.008

Bozeman, B., & Gaughan, M. (2011). Job satisfaction among university faculty: Individual, work, and institutional determinants. *The Journal of Higher Education*, *82*(2), 154–186.

Breiger, R. L. (2004). *The analysis of social networks*. na.

Brieger, R. L. (1976). Career attributes and network structure: A blockmodel study of a biomedical research specialty. *American Sociological Review*, 117–135.

Burt, R. S. (1987). Social contagion and innovation: Cohesion versus structural equivalence. *American Journal of Sociology*, *92*(6), 1287–1335.

Burt, R. S. (2004). Structural Holes and Good Ideas. *American Journal of Sociology*, *110*(2), 349–399. https://doi.org/10.1086/421787

Castells, M. (2011). *The rise of the network society* (Vol. 12). John wiley & sons.

Clark, B. R. (1987). *The Academic Life. Small Worlds, Different Worlds. A Carnegie Foundation Special Report.* ERIC.

Clark, B. R. (1989). The academic life: Small worlds, different worlds. *Educational Researcher*, *18*(5), 4–8.

Coleman, J. S. (1988). Social Capital in the Creation of Human Capital. *The American Journal of Sociology*, *94*, S95–S120.

Collins, R. (1994). Why the social sciences won't become high-consensus, rapid-discovery science. *Sociological Forum*, *9*(2), 155–177.

Corbitt, B. J., & Cheong, F. (2009). A Social Network Analysis of the Co-authorship Network of the Pacific Asia Conference on Information Systems From 1993 to 2008. *Pacific Asia Conference on Information Systems (PACIS), 13*.

Corley, E. A., & Sabharwal, M. (2007). Foreign-born academic scientists and engineers: Producing more and getting less than their US-born peers? *Research in Higher Education*, *48*(8), 909–940.

Crane, D. (1972). *Invisible colleges; diffusion of knowledge in scientific communities*.

Crane, D. (1977). Social structure in a group of scientists: A test of the "invisible college" hypothesis. In *Social networks* (pp. 161–178). Elsevier.

Cummings, J. N., & Kiesler, S. (2007). Who works with whom? Collaborative tie strength in distributed interdisciplinary projects. *Third International E-Social Science Conference*.

Dahlander, L., & McFarland, D. A. (2013). Ties That Last: Tie Formation and Persistence in Research Collaborations over Time. *Administrative Science Quarterly*, *58*(1), 69–110. https://doi.org/10.1177/0001839212474272

De Stefano, D., Vitale, M. P., & Zaccarin, S. (2010). The scientific collaboration network of Italian academic statisticians. *45th Scientific Meeting of the Italian Statistical Society, Padua, Italy*, 16–18.

DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, 147–160.

Dirlik, A. (2012). Transnationalization and the university: The perspective of global modernity. *Boundary 2*, *39*(3), 47–73.

Durbach, I. N., Naidoo, D., & Mouton, J. (2008). Co-authorship networks in South African chemistry and mathematics. *South African Journal of Science*, *104*(11–12), 487–492.

Easterby-Smith, M., & Malina, D. (1999). Cross-cultural collaborative research: Toward reflexivity. *Academy of Management Journal*, *42*(1), 76–86.

Foucault, M. (1977). Discipline and punish: The birth ofthe prison. *London: Allen Lane*.

Freeman, R. B., Ganguli, I., & Murciano-Goroff, R. (2014). Why and wherefore of increased scientific collaboration. In *The changing frontier: Rethinking science and innovation policy* (pp. 17–48). University of Chicago Press.

Friedkin, N. E. (1991). Theoretical Foundations for Centrality Measures. *American Journal of Sociology*, *96*(6), 1478–1504.

Gargiulo, M., & Benassi, M. (2000). Trapped in Your Own Net? Network Cohesion, Structural Holes, and the Adaptation of Social Capital. *Organization Science*, *11*(2), 183–196. https://doi.org/10.1287/orsc.11.2.183.12514

Gossart, C., & Özman, M. (2009). Co-authorship networks in social sciences: The case of Turkey. *Scientometrics*, *78*(2), 323–345. https://doi.org/10.1007/s11192-007-1963-x

Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology*, *91*(3), 481–510.

Granovetter, M. (2017). *Society and economy*. Harvard University Press.

Granovetter, M. (1977). The Strength of Weak Ties. In *Social networks* (pp. 347–367). Elsevier.

Haeussler, C., & Colyvas, J. A. (2011). Breaking the ivory tower: Academic entrepreneurship in the life sciences in UK and Germany. *Research Policy*, *40*(1), 41–54.

Haiqi, Z., & Hong, G. (1997). Scientific research collaboration in China. *Scientometrics*, *38*(2), 309–319. https://doi.org/10.1007/BF02457416

He, T. (2009). International scientific collaboration of China with the G7 countries. *Scientometrics*, *80*(3), 571–582. https://doi.org/10.1007/s11192-007-2043-y

Hu, C., Wotipka, C. M., & Wen, W. (2016). International students in Chinese higher education: Choices, expectations, and experiences by region of origin. In *Global perspectives and local challenges surrounding international student mobility* (pp. 153–178). IGI Global.

Huang, F. (2020). *China is choosing its own path on academic evaluation*. https://www.universityworldnews.com/post.php?story=20200226122508451

International Students-Tsinghua University. (2020). Retrieved July 2, 2020, from https://www.tsinghua.edu.cn/en/Admissions/International_Students.htm

Jeong, S., Choi, J. Y., & Kim, J. (2011). The determinants of research collaboration modes: Exploring the effects of research and researcher characteristics on co-authorship. *Scientometrics*, *89*(3), 967–983. https://doi.org/10.1007/s11192-011-0474-y

Jung, J. (2012). Faculty Research Productivity in Hong Kong across Academic Discipline. *Higher Education Studies*, *2*(4), p1. https://doi.org/10.5539/hes.v2n4p1

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, *26*(1), 1–18. https://doi.org/10.1016/S0048-7333(96)00917-1

Kezar, A. (2014). Higher Education Change and Social Networks: A Review of Research. *The Journal of Higher Education*, *85*(1), 91–125. https://doi.org/10.1353/jhe.2014.0003

Kezar, A., & Lester, J. (2009). Promoting grassroots change in higher education: The promise of virtual networks. *Change: The Magazine of Higher Learning*, *41*(2), 44–51.

Knorr-Cetina. (2009). *Epistemic cultures: How the sciences make knowledge*. Harvard University Press.

Kolaczyk, E. D., & Csárdi, G. (2014). *Statistical analysis of network data with R* (Vol. 65). Springer.

Kollasch, A., Rios-Aguilar, C., Torres-Olave, B., & Rhoades, G. (2016). Exploring Social Network Ties of U.S. Academics: The Importance of Employee Status, Institutional Type, Discipline, and Geography. In D. M. Hoffman & J. Välimaa (Eds.), *Re-becoming university?* (pp. 283–308). Springer Netherlands. https://doi.org/10.1007/978-94-017-7369-0_11

Kronegger, L., Ferligoj, A., & Doreian, P. (2011). On the dynamics of national scientific systems. *Quality & Quantity*, *45*(5), 989–1015.

Kuhn, T. S. (1970). *Criticism and the growth of knowledge: Volume 4: Proceedings of the International Colloquium in the Philosophy of Science, London, 1965* (Vol. 4). Cambridge University Press.

Kuzhabekova, A. (2011). *Impact of co-authorship strategies on research productivity: A social-network analysis of publications in Russian cardiology.*

Laband, D. N., & Tollison, R. D. (2000). Intellectual Collaboration. *Journal of Political Economy*, *108*(3), 632–662. https://doi.org/10.1086/262132

Lau, Joyce, & Liu, J. (2020). China Moves Away From 'Publish or Perish'. Inside Higher Ed. Retrieved July 30, 2020, from https://www.insidehighered.com/news/2020/03/06/china-moves-away-publish-or-perish

Lazarsfeld, P. F., & Merton, R. K. (1954). Friendship as a social process: A substantive and methodological analysis. *Freedom and Control in Modern Society*, *18*(1), 18–66.

Leahey, E. (2016). From Sole Investigator to Team Scientist: Trends in the Practice and Study of Research Collaboration. *Annual Review of Sociology*, *42*(1), 81–100. https://doi.org/10.1146/annurev-soc-081715-074219

Lee, J. J., & Maldonado-Maldonado, A. (2018). Not enough diverse academic research is being published. *University World News*, *14*.

Lee, Jenny J. (2004). Comparing institutional relationships with academic departments: A study of five academic fields. *Research in Higher Education*, *45*(6), 603–624.

Lee, Jenny J., & Haupt, J. P. (2019). Winners and losers in US-China scientific research collaborations. *Higher Education*, 1–18.

Leydesdorff, L., & Wagner, C. S. (2008). International collaboration in science and the formation of a core group. *Journal of Informetrics*, *2*(4), 317–325. https://doi.org/10.1016/j.joi.2008.07.003

Lin, N. (2002). *Social capital: A theory of social structure and action* (Vol. 19). Cambridge university press.

Little, J. W. (2010). *Social network theory and educational change*. Harvard Education Press.

Liu, X., Bollen, J., Nelson, M. L., & Van de Sompel, H. (2005). Co-Authorship Networks in the Digital Library Research Community. *ArXiv:Cs/0502056*. http://arxiv.org/abs/cs/0502056

Luke, D. A. (2015). *A user's guide to network analysis in R*. Springer.

Marginson, S. (2018). National/Global Synergy in the Development of Higher Education and Science in China since 1978. *Frontiers of Education in China*, *13*(4), 486–512. https://doi.org/10.1007/s11516-018-0027-8

Marginson, S., & Rhoades, G. (2002). Beyond national states, markets, and systems of higher education: A glonacal agency heuristic. *Higher Education*, *43*(3), 281–309.

Marginson, S., & Wen, W. (2019). 大学科研的全球扩张. 教育研究, *9*, 11.

Markovsky, B. (1998). 11 SOCIAL NETWORK CONCEPTIONS OF GROUP SOLIDARITY'|. *The Problem of Solidarity: Theories and Models*, 343.

McDowell, J. M., & Melvin, M. (1983). The determinants of co-authorship: An analysis of the economics literature. *The Review of Economics and Statistics*, 155–160.

McFadyen, M. A., & Cannella Jr, A. A. (2004). Social capital and knowledge creation: Diminishing returns of the number and strength of exchange relationships. *Academy of Management Journal*, *47*(5), 735–746.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001). Birds of a Feather: Homophily in Social Networks. *Annual Review of Sociology*, *27*(1), 415–444. https://doi.org/10.1146/annurev.soc.27.1.415

Merton, R. K., & Zuckerman, H. (1973). Age, aging, and age structure in science. *The Sociology of Science: Theoretical and Empirical Investigations*, 497–559.

Meyer, J. W., & Rowan, B. (1977). Institutionalized organizations: Formal structure as myth and ceremony. *American Journal of Sociology*, *83*(2), 340–363.

Milgram, S. (1969). Interdisciplinary thinking and the small world problem. *Interdisciplinary Relationships in the Social Sciences*, 103–20.

Milojević, S. (2010). Modes of collaboration in modern science: Beyond power laws and preferential attachment. *Journal of the American Society for Information Science and Technology*, *61*(7), 1410–1423.

Moody, J. (2004). The Structure of a Social Science Collaboration Network: Disciplinary Cohesion from 1963 to 1999. *American Sociological Review*, *69*(2), 213–238. https://doi.org/10.1177/000312240406900204

Moody, J., & Paxton, P. (2009). Building Bridges: Linking Social Capital and Social Networks to Improve Theory and Research. *American Behavioral Scientist*, *52*(11), 1491–1506. https://doi.org/10.1177/0002764209331523

Moody, J., & White, D. R. (2003). Structural Cohesion and Embeddedness: A Hierarchical Concept of Social Groups. *American Sociological Review*, *68*(1), 103. https://doi.org/10.2307/3088904

Nee, V., & Ingram, P. (1998). Embeddedness and beyond: Institutions, exchange, and social structure. *The New Institutionalism in Sociology*, *19*, 45.

Niu, F., & Qiu, J. (2014). Network structure, distribution and the growth of Chinese international research collaboration. *Scientometrics*, *98*(2), 1221–1233. https://doi.org/10.1007/s11192-013-1170-x

Numprasertchai, S., & Igel, B. (2005). Managing knowledge through collaboration: Multiple case studies of managing research in university laboratories in Thailand. *Technovation*, *25*(10), 1173–1182.

Oh, W., Choi, J. N., & Kim, K. (2005). Coauthorship Dynamics and Knowledge Capital: The Patterns of Cross Disciplinary Collaboration in Information Systems Research, *Journal of Management Information Systems*, 22:3, 266-292. http://doi.org/10.2753/MIS0742-1222220309

Pfeffer, J., & Moore, W. L. (1980). Power in university budgeting: A replication and extension. *Administrative Science Quarterly*, 637–653.

Pfeffer, J., & Salancik, G. R. (2003). *The external control of organizations: A resource dependence perspective*. Stanford University Press.

Piette, M. J., & Ross, K. L. (1992). An analysis of the determinants of co-authorship in economics. *The Journal of Economic Education*, *23*(3), 277–283.

Portes, A. (1998). Social capital: Its origins and applications in modern sociology. *Annual Review of Sociology*, *24*(1), 1–24.

Powell, W. W., White, D. R., Koput, K. W., & Owen-Smith, J. (2005). Network Dynamics and Field Evolution: The Growth of Interorganizational Collaboration in the Life Sciences. *American Journal of Sociology*, *110*(4), 1132–1205. https://doi.org/10.1086/421508

Rawlings, C. M., & McFarland, D. A. (2011). Influence flows in the academy: Using affiliation networks to assess peer effects among researchers. *Social Science Research*, *40*(3), 1001–1017. https://doi.org/10.1016/j.ssresearch.2010.10.002

Rhoads, R. A., Shi, X., & Chang, Y. (2014). *China's rising research universities: A new era of global ambition*. JHU Press.

Rhodes, K. (2014). *UC Berkeley and Tsinghua University launch research and graduate education partnership | Berkeley News*. https://news.berkeley.edu/2014/09/06/uc-berkeley-and-tsinghua-university-launch-research-and-graduate-education-partnership/

Sawyer, S., & Crowston, K. (1999). ICT in the real estate industry: Agents and social capital. *AMCIS 1999 Proceedings*, 5.

Seabright, M. A., Levinthal, D. A., & Fichman, M. (1992). Role of individual attachments in the dissolution of interorganizational relationships. *Academy of Management Journal*, *35*(1), 122–160.

Shin, J. C., & Cummings, W. K. (2010). Multilevel analysis of academic publishing across disciplines: Research preference, collaboration, and time on research. *Scientometrics*, *85*(2), 581–594. https://doi.org/10.1007/s11192-010-0236-2

Shin, K.-Y. (2007). Globalization and the National Social Science in the Discourse on the SSCI in South Korea. *Korean Social Science Journal*, *1*(1), 93–116.

Science and Engineering Indicators (2020). *National Science Board.*

Science and Engineering Indicators (2018). *National Science Board.*

Small, M. L. (2009). *Unanticipated gains: Origins of network inequality in everyday life*. Oxford University Press.

Tang, L., & Shapira, P. (2011). China–US scientific collaboration in nanotechnology: Patterns and dynamics. *Scientometrics*, *88*(1), 1–16. https://doi.org/10.1007/s11192-011-0376-z

Taramasco, C., Cointet, J.-P., & Roth, C. (2010). Academic team formation as evolving hypergraphs. *Scientometrics*, *85*(3), 721–740.

Tierney, W. G., & Rhoads, R. A. (1993). *Enhancing Promotion, Tenure and Beyond: Faculty Socialization as a Cultural Process. ASHE-ERIC Higher Education Report No. 6.* ERIC.

Tollefson, J. (2018). *China declared world's largest producer of scientific articles*. https://www.nature.com/articles/d41586-018-00927-4

Tomassini, M., Luthi, L., Giacobini, M., & Langdon, W. B. (2007). The structure of the genetic programming collaboration network. *Genetic Programming and Evolvable Machines*, *8*(1), 97–103.

TraorÉ, N., & Landry, R. (1997). On the determinants of scientists' collaboration. *Science Communication*, *19*(2), 124–140.

Trowler, P. R. (2001). *Academic tribes and territories*. McGraw-Hill Education (UK).

UC Berkeley and Tsinghua University launch research and graduate education partnership | Berkeley News. (2014). Reporter: Karen Rhodes. Retrieved July 2, 2020, from

https://news.berkeley.edu/2014/09/06/uc-berkeley-and-tsinghua-university-launch-research-and-graduate-education-partnership/

Vafeas, N. (2010). Determinants of single authorship. *EuroMed Journal of Business*, *5*(3), 332–344.

Välimaa, J., Papatsiba, V., & Hoffman, D. M. (2016). Higher education in networked knowledge societies. In *Re-Becoming Universities?* (pp. 13–39). Springer.

van Rijnsoever, F. J., & Hessels, L. K. (2011). Factors associated with disciplinary and interdisciplinary research collaboration. *Research Policy*, *40*(3), 463–472. https://doi.org/10.1016/j.respol.2010.11.001

Wagner, C. S. (2018). Science in the Age of Knowledge Abundance. In C. S. Wagner, *The Collaborative Era in Science* (pp. 1–17). Springer International Publishing. https://doi.org/10.1007/978-3-319-94986-4_1

Wagner, C. S., & Leydesdorff, L. (2005). Network structure, self-organization, and the growth of international collaboration in science. *Research Policy*, *34*(10), 1608–1618.

Wagner, C. S., Park, H. W., & Leydesdorff, L. (2015). The Continuing Growth of Global Cooperation Networks in Research: A Conundrum for National Governments. *PLOS ONE*, *10*(7), e0131816. https://doi.org/10.1371/journal.pone.0131816

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications* (Vol. 8). Cambridge university press.

Watts, D. J. (1999). Networks, dynamics, and the small-world phenomenon. *American Journal of Sociology*, *105*(2), 493–527.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. *Nature*, *393*(6684), 440–442.

White, D. R., & Harary, F. (2001). The cohesiveness of blocks in social networks: Node connectivity and conditional density. *Sociological Methodology*, *31*(1), 305–359.

Wingfield, N. (2015). *University of Washington and Chinese University Unite to Form Technology Institute—The New York Times*. https://www.nytimes.com/2015/06/19/business/university-of-washington-and-chinese-university-unite-to-form-technology-institute.html

Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science*, *316*(5827), 1036–1039.

Xie, M. (2018). Living with internationalization: The changing face of the academic life of Chinese social scientists. *Higher Education*, *75*(3), 381–397. https://doi.org/10.1007/s10734-017-0145-x

Xu, J., & Chau, M. (2006). The social identity of IS: Analyzing the collaboration network of the ICIS conferences (1980-2005). *ICIS 2006 Proceedings*, 39.

Xu, X., Rose, H., & Oancea, A. (2019). Incentivizing international publications: Institutional policymaking in Chinese higher education. *Studies in Higher Education*, 1–14. https://doi.org/10.1080/03075079.2019.1672646

Yan, E., Ding, Y., & Zhu, Q. (2010). Mapping library and information science in China: A coauthorship network analysis. *Scientometrics*, *83*(1), 115–131. https://doi.org/10.1007/s11192-009-0027-9

Yang, R., & Welch, A. (2012a). A world-class university in China? The case of Tsinghua. *Higher Education*, *63*(5), 645–666. https://doi.org/10.1007/s10734-011-9465-4

Yang, R., & Welch, A. (2012b). A world-class university in China? The case of Tsinghua. *Higher Education*, *63*(5), 645–666. https://doi.org/10.1007/s10734-011-9465-4

Yang, R., Xie, M., & Wen, W. (2019). Pilgrimage to the West: Modern transformations of Chinese intellectual formation in social sciences. *Higher Education*, *77*(5), 815–829.

Yin, R. K. (2017). *Case study research and applications: Design and methods*. Sage publications.

罗家德, 王竞, 张佳音, & 谢朝霞. (2008). 社会网研究的架构——以组织理论与管理研究为例. 社会, *28*(6), 15–38.

西蒙·马金森& 文雯. (2019). 大学科研的全球扩张. 教育研究, *9*, 11.

清华大学教育基金会. (2018). Retrieved July 2, 2020, from http://www.tuef.tsinghua.edu.cn/column/infomation