

**Triple Helix Relations in Local and International Scientific Collaborations:
A Case Study of Thailand, the United States, and China**

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Abstract

Local and international scientific collaborations are crucial for innovation and sustainable development. However, there is a gap in understanding how these collaborations affect national innovation ecosystems. This study examines the dynamics of Triple Helix Relations, focusing on collaborations within Thailand and its international partnerships with the United States and China from 2006 to 2022. I use Shannon's mutual information, enhanced by Loet Leydesdorff, to analyze the synergy among various local sectors and conduct interviews with eighteen researchers and policymakers, utilizing Latour and Woolgar's cycle of credibility. The study delves deeply into the complexities of collaboration dynamics and motivations. The analysis reveals nuanced patterns of collaboration, spanning both within Thailand and across international boundaries.

I distinguish collaborations based on the nationality of partners (Thai-China vs. Thai-U.S.) and subject areas (engineering, medicine, agricultural and biological sciences). The findings show significant variation in collaboration patterns depending on these factors. Universities are the main contributors to scientific publications, while the Thai government is more active in medicine and collaborations with the United States. Industry is more engaged in agricultural, biological sciences, and engineering, especially with China.

One recurring theme that emerges from our interviews is the importance of relationship networks as significant assets in collaborative endeavors. Different credibility resources and networks yield varying levels of negotiation power and influence dynamics in different collaborative settings. Understanding these dynamics could assist smaller countries like Thailand in devising strategies to maximize the benefits of international collaborations. Despite the opportunities globalization presents, I observe a decline in local collaborative synergy among Thailand's three sectors, university, government, and industry. Local collaborations are mostly bilateral, indicating a need for greater involvement from the third sector to foster sustainable growth and development.

This study demonstrates the use of STS concepts and various analytical tools, such as co-authored publications and Shannon's mutual information, to showcase collaboration trends and synergy among local sectors in Thailand. The study also includes case studies from diverse countries to consider different conditions affecting collaboration dynamics. Emphasizing recent data, the study aims to capture the evolving landscape of international and local scientific collaborations comprehensively.

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(GENERAL AUDIENCE ABSTRACT)

Scientific collaborations, both local and international, are vital for driving innovation and sustainability worldwide. However, there remains a significant gap in our understanding of how these collaborations impact national innovation ecosystems. This study examines the connections in research collaboration among local sectors within Thailand and the international collaborations involving Thailand, the United States, and China from 2006 to 2022. This study uses tools such as co-authored citations, Shannon's mutual information, and interviews with several researchers and policymakers to gain an understanding of research collaboration dynamics and motivations.

I found that collaboration varies depending on the research partners involved and the areas of study. For example, universities publish most scientific papers in general, while the government is more active in medicine and with the United States. On the other hand, industry is more active in agriculture, biology, and engineering, especially when working with China. The interviews also showed that having connections with other researchers is crucial for successful collaborations. Different networks and credibility resources give different levels of power and influence in these partnerships. Understanding this can help smaller countries like Thailand make the most of their international collaborations.

Despite the benefits of working globally, it is noticed that local collaborations in Thailand are decreasing, mainly sticking to bilateral partnerships between sectors. This shows the need for more involvement from different sectors to promote sustainable economic growth. The study also shows how using different tools helps us understand collaboration trends better. By looking at real-life examples from different countries, this study hope to provide a clear picture of how scientific collaborations are changing over time.

DEDICATION

I dedicate this dissertation to my family. My deepest gratitude goes to my beloved parents, Kansiri and Jira Raksaphaeng, for giving me the freedom to follow my dreams and live my life, even though it has taken me far from them to the other side of the world.

I also dedicate this work to my husband, Roel, our son, Theo, and my mother-in-law, Eleni, who have been my unwavering pillars of support and encouragement throughout this journey. Their understanding, patience, and love have made it possible for me to devote countless hours, day and night, to pursuing my degree and completing this dissertation over the past decade.

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Chapter 1

Introduction

Scientific collaborations have become a prevalent strategy employed by nations globally to enhance their science and technology capacities. Although there exists a substantial body of literature on scientific collaborations, there remain areas that have not been thoroughly investigated. It is crucial to acknowledge the complexity inherent in these activities, encompassing multiple components and factors. Moreover, ongoing changes in the global system have given rise to new questions and considerations.

This study aims to explore the interplay of international scientific collaboration and local collaboration between key sectors—universities, government, and private industries—with a particular emphasis on fostering sustainable economic growth within a knowledge-based economy. The study employs both quantitative and qualitative analyses to understand the attributes of various scientific collaborations as well as the motivations and decision-making processes of scientists regarding collaborative research activities. The study analyzes case studies of local collaboration in Thailand and international collaboration between Thailand and the United States and Thailand and China through the lens of Triple Helix and the Cycle of Credibility concepts. This study aims to deepen the understanding of the real-world outcomes of scientific collaboration, particularly within collaborations between developed and developing countries, the varied characteristics of research collaborations across different contexts, and the social factors influencing them. This research endeavors to fill existing gaps in Science, Technology, and Society (STS) and related fields concerning scientific collaborations, providing valuable insights for policy and practice that have the potential to foster enhanced economic development.

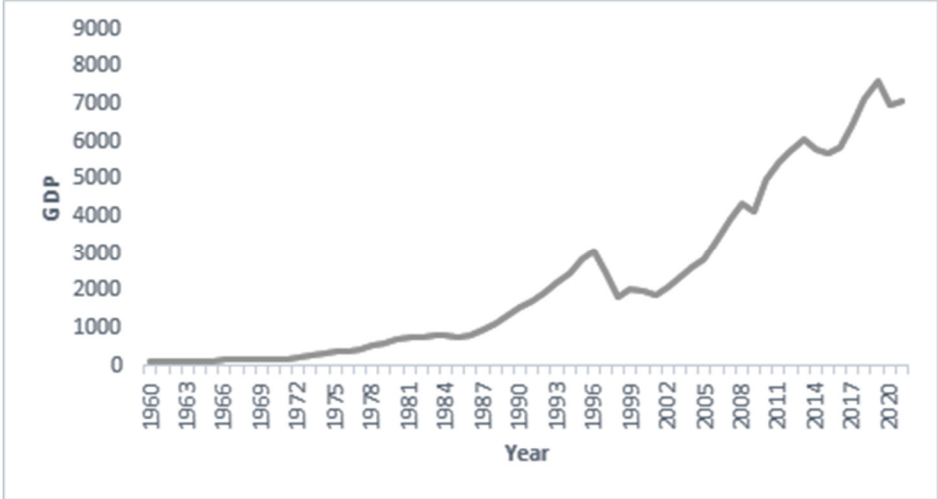
Furthermore, the selection of case studies is motivated by the recognition of scientific collaborations as a mechanism for advancing sustainable economic development, particularly in developing countries. These case studies offer an opportunity to gain insights into the practical aspects of scientific collaborations, such as how international collaboration contributes to national research capacities, how countries with different capacities collaborate and benefit from each other, and the nuances of research collaboration outcomes across various disciplines. To provide a better understanding of the rationale in selecting these case studies, the next section briefly discusses the situation and challenges currently facing Thailand, highlight why studying research collaboration is worthwhile, and explain why Thailand serves as a valuable case study for exploring this area.

Thailand's Path to a Higher-Income Economy Through Scientific Collaboration

Thailand, a small Southeast Asian nation, has made remarkable social and economic progress in recent years. Through successful development and poverty reduction initiatives, Thailand's GNP per capita experienced steady annual growth, surpassing US\$3,976 by 2011 but remaining below US\$12,275, marking its transition from a low-income to an upper-middle-income nation (World Bank Group, 2012; World Bank, 2022) (see Figure 1). By 2022, Thailand's economy ranked 2nd in Southeast Asia and 20th globally in GDP, driven by services, industry, and agriculture, while also improving its Human Development Index to 66th place and establishing itself as a leading medical hub (Dimitropoulou, 2022; NESDC, Gross Domestic Product: Q2/2022, 2022).

Figure 1

Thailand's GDP per capita (current US\$)



Note. The World Bank, GDP per capita (current US\$) – Thailand (2021).

Due to its consistent expansion, maintaining an annual growth rate exceeding 5% for nearly six decades, spanning from 1952 to 2010, Thailand held an optimistic outlook on its journey toward achieving high-income status. In the 2018 National Strategy, the Thai government established an ambitious target of attaining high-income status by 2037 (Royal Thai Government, 2022). Nevertheless, economic growth began to decelerate after 2011, with Thailand's growth rate slipping below 4%. Much like many other emerging economies, Thailand grapples with economic growth uncertainties, finding a hard time escaping the middle-income status. This scenario is not uncommon, with various instances, particularly in Latin America, of nations encountering stagnation upon reaching middle-income status. This predicament is commonly referred to as the "middle-income trap." According to Lee (2020), the trajectory of economic growth is far from linear. Throughout this journey, countries witness transformative shifts in trade dynamics, the exchange of ideas and innovations, financial systems, and urban

development. Simultaneously, new concerns, including inequality, poverty, and government corruption, come to the forefront as countries strive to navigate their course toward high-income status. For Thailand to escape the middle-income trap, the country needs to achieve sustainable growth and reach advanced economies' per capita income levels (Lee, 2020). According to Barro (1991) and Bandaogo (2020), critical determinants for achieving this per capita income growth encompass factors such as human capital, the investment rate, and total factor productivity (TFP).

Thailand's economic development has evolved through three stages: agriculture (Thailand 1.0), light industry (Thailand 2.0), and advanced industry (Thailand 3.0). However, the country now faces several economic challenges, including slowed growth from its export-led model and productivity stagnation. Thailand's latest economic development model, Thailand 4.0 endeavors to establish an economy rooted in value, propelled by innovation, technology, and creativity. One way for Thailand to improve its competitiveness and long-term economic development is to collaborate with international partners, a strategy used by many East Asian countries to transition from middle-income to high-income status (Gill et al., 2007).

According to Gill et al. (2007), international and regional integration has proven to be a strategic approach adopted by numerous East Asian countries striving to transition from middle-income to high-income status. International collaborations have become an important part of many Thai agencies' strategic plans and priorities, and are promoted through exchange programs, research collaborations, talent mobility programs, and other initiatives. Additionally, the Thai government has encouraged universities and the corporate sector to take a more active role in the country's research and innovation processes to promote self-reliance and sustainable development.

International and domestic scientific collaborations are critical not only for scientists in their pursuit to expand the frontiers of scientific knowledge but also for policymakers and economists who are enthusiastically dedicated to propelling the economic growth of nations. In this context, several pivotal questions emerge. First and foremost, it's crucial to unravel the role that scientific collaborations play in this equation. How does the exchange of knowledge through collaboration with other countries translate into tangible benefits for a nation like Thailand? The interplay between international and local dimensions of scientific knowledge production is equally critical, prompting us to explore how these two spheres are interconnected and complementary. And how the nation optimizes the outcomes derived from these collaborative efforts to drive progress and prosperity.

Objectives and Scope of the Study

Because of its complex nature, understanding collaboration is a challenging task, and comprehending its implications in the real world is even more difficult. This study addresses this broad and complex challenge by focusing on the relationship between international collaboration and Triple Helix relations among local sectors to better understand scientific collaboration. According to the triple-helix theory, an innovation system requires mutually reinforcing relations among university, industry, and government sectors. The objective of this study is to comprehend the relations between local and international collaborations and assess their impacts on the national strategy to develop the national science and innovation system. This study utilizes the case study of Thailand's local collaboration and its international collaborations with the United States and China to reveal variations in collaboration dynamics. The study will also examine the way that North-South disparities mediate collaborative relationship and their effects. Moreover, I analyze research collaborations in three specific areas of study to explore the influences of

epistemic characteristics of different fields on collaborative activities. Both quantitative (co-authored citation analysis) and qualitative methods (interviews) are used in this study. The research questions are:

1. What are the connections between local and international research collaborations, with a comparative analysis of Thailand, the United States, and China?

2. How do social factors and strategic considerations influence the pursuit of scientific collaborations?

To answer the questions, I find that STS can provide valuable insights into understanding the complex interplay between cognitive and subjective elements. To assess the influence of international research partnerships on local collaborations, I utilize The Triple Helix Framework. This framework focuses on the interactions and dynamics among essential stakeholders in local cooperation, including universities, industry, and government. These interactions are pivotal for nurturing a country's long-term capacities. The second concept used in this study is the Cycle of Credibility which offers a lens through which I can examine scientists' decision-making processes and the strategies they employ to facilitate collaboration. This involves the conversion of various forms of capital—economic and epistemological—which encompass arguments, data, personnel and equipment, financial resources, recognition, and publications.

The Triple Helix Framework underscores the structural importance of stakeholder interactions for building national capacities. The interactions among sectors identified in the Triple Helix Framework are influenced by the individual actions and decisions of scientists. The Cycle of Credibility explains how these scientists leverage various forms of capital to contribute to and sustain these interactions, thereby reinforcing the Triple Helix dynamics. The concept

adds depth by elucidating how these relationships are practically maintained and enhanced through scientists' strategic actions. Both concepts provide a comprehensive analytical toolkit to assess how international research partnerships influence local collaborations, from both systemic and individual perspectives.

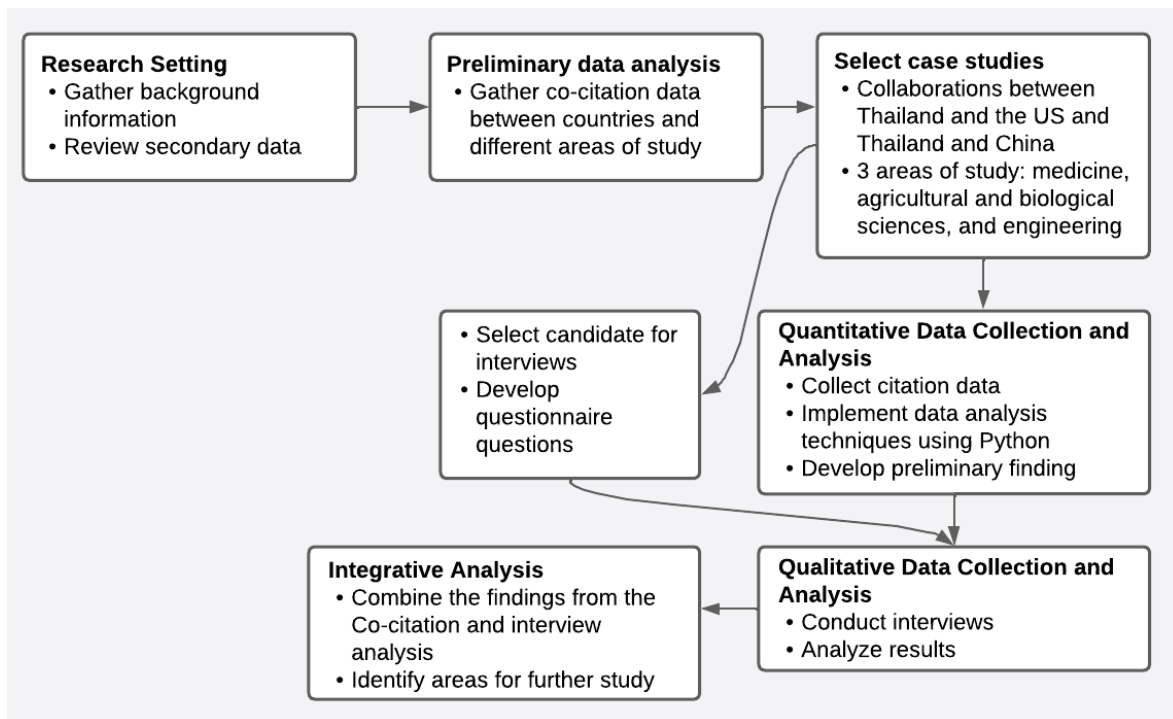
For the methodology, I investigate Triple Helix relationships among local sectors utilizing an analysis based on Shannon's entropy (Shannon, 1948). This measure quantifies the average level of surprise or unpredictability associated with a random variable, commonly utilized in information theory to assess the information contained in a message or data source. The analysis is centered on both the quantity and dynamics of co-authored publications resulting from these scientific collaborations using Leydesdorff's mutual information model. The study employs co-authorship data from Scopus to analyze collaborative research between Thailand and other countries, particularly the United States and China. It examines trends in co-authored publications across different disciplines and identifies Medicine, Engineering, and Agricultural and Biological Sciences as focal areas for in-depth analysis.

I then conducted semi-structured interviews with 18 researchers from different settings and disciplines. Seven are engineers, five are agricultural and biological scientists, four are medical scientists, and two are chemists. Eight come from academia, six from government, and four from the private sector. Five participants are Thai researchers working on local collaborations, nine on international collaborations between Thailand and the United States, and four on Thailand-China projects. I try to include the selection of informants representing various organizational and social backgrounds, ensuring a comprehensive understanding of collaborative dynamics.

The interviews are analyzed using the Triple Helix and Cycle of Credibility frameworks which emphasize collaborations among different sectors and researchers' investments in types of credibility resources. Through semi-structured interviews, we aim to elucidate the factors driving these collaborations and their impact on scientific knowledge production. The study employs the Cycle of Credibility framework to explore how credibility is established and exercised in different collaborative contexts. The below flowchart (see Figure 2) illustrates the mixed-methods research process employed in this study.

Figure 2

Research process



Chapter structure

This chapter delineates the primary focus and objectives of the study, identifying the specific issues I aim to address. I provide a brief discussion of the theoretical frameworks that underpin the research. Additionally, I outline the methodological approaches employed to achieve the research goals, including the specific techniques and tools used for data collection and analysis. Chapter 2 delves into what I have learned about scientific collaboration, identifies knowledge gaps, and presents relevant information. I explore the historical development and evolution of scientific collaborations, emphasizing their importance for countries worldwide. I discuss the definition, establishment, and management styles of scientific collaborations. A key focus is on partnerships between the Global North and South, highlighting their benefits and challenges. I also examine South-South Collaboration as an opportunity for Global South countries to enhance visibility and address unique issues collectively.

Chapter 3, Conceptual Frameworks, outlines the theoretical foundations guiding the investigation. The chapter begins with the Triple Helix framework, pioneered by Henry Etzkowitz and Loet Leydesdorff, which emphasizes collaboration among government, academia, and industry in fostering innovation. These interactions shape the innovation process and contribute to developing a society's knowledge base. Research suggests that this interplay correlates with economic growth indicators (Ivanova, 2021), offering an alternative means to assess economic development. The chapter also discusses literature examining the links between local and international scientific collaboration and provides examples of how the Triple Helix model can analyze the impact of international collaboration on local research systems.

The final segment of the chapter addresses research within the Cycle of Credibility concept. This concept, rooted in the sociology of science, examines the role of social structures

and processes in shaping scientific activities. The Cycle of Credibility is introduced as an analytical tool to understand scientists' behaviors and motivations, particularly regarding the exchange and conversion of various forms of credibility. This framework is applied across different scientific fields, considering factors such as data, arguments, publications, recognition, funding, and resources.

Chapter 4, the research question and methodology chapter, emphasizes the research questions I try to answer and details the use of co-authorship analysis to study scientific collaboration, particularly within the Triple Helix model, which involves interactions among universities, industries, and governments. This chapter elaborates on the Triple Helix model's implications for understanding collaborative research efforts. It also delves into Leydesdorff's method for examining Triple Helix relations using Shannon entropy, highlighting the importance of synergy and uncertainty reduction in evaluating collaboration effectiveness. Additionally, the chapter discusses the interview process, and the strategies used to recruit and interview the participants, as well as the analysis through conceptual frameworks such as the cycle of credibility.

Chapter 5, the case study chapter, explores Thailand's transition towards becoming a high-income country amidst challenges like the middle-income trap. Key initiatives, such as Thailand 4.0 and the establishment of The Ministry of Higher Education, Science, Research and Innovation (MHESI), aim to foster innovation and research. Collaboration with international partners, particularly the United States and China, is crucial to Thailand's development. While Thailand has longstanding ties with the United States, especially in military and economic areas, China's emergence as a global economic powerhouse has intensified bilateral trade and

collaboration. Thailand carefully navigates its triangular relationship with these superpowers, seeking balanced engagement with both.

In the result and discussion chapters, I delve into the results of both the quantitative and qualitative analyses. It comprises three primary segments: quantitative findings (Chapter 6), qualitative findings (Chapter 7), and integrative analysis (Chapter 8). Integrative analysis synthesizes insights gleaned from both the mutual information analysis and interviews, offering a comprehensive perspective. The final chapter (Chapter 9) provides a summary of the answers to the research questions, discuss the implications of the findings, address the limitations of this study, and offer suggestions for future research.

Chapter 2

Literature Review: Scientific and International Collaborations

Scientific collaboration fosters the exchange of ideas, expertise, and resources among researchers, leading to the generation of new knowledge and discoveries. As collaboration becomes increasingly essential for addressing complex scientific challenges and driving innovation, researchers from diverse fields study its determinants, dynamics, impacts, and effectiveness. Chapter 2 delves into scientific collaboration, identifying knowledge gaps and relevant information for this study. The chapter explores the historical development and evolution of scientific and international collaborations, emphasizing their global importance. The chapter discusses the definition, establishment, and management styles of collaborations, and highlights the benefits and challenges of Global North-South partnerships. Additionally, it examines South-South Collaboration as a means for Global South countries to enhance visibility and address unique issues collectively.

Scientific Collaboration and Its Historical Significance

Scientific collaboration is now a common practice, but it is worthwhile to explore its evolution and historical significance which reveals the strong relationship between social actors and the development of science. Collaborative efforts among scientists have been integral to scientific progress, manifesting in diverse forms throughout history and consistently playing a crucial role in advancing science. Although research collaboration has been a subject of extensive study, the predominant focus of these studies has been on collaboration within the twentieth century. In contrast, scientific collaboration has been a fundamental component of modern science from its very beginning. In the 17th-century scientific revolution, collaborations

among individuals driven by the pursuit of understanding nature through experimentation were often facilitated and sponsored by affluent patrons. These collaborations were notably free from the institutional, political, or disciplinary constraints that became more prevalent in later eras (Wagner & Fukuyama, 2008). Collaborative papers are also not new; the first co-authored paper was published in 1665 (Beaver & Rosen, 1978).

Although individual scientists and philosophers collaborated previously, scientific collaboration became common only in the 18th century, known as "the Age of Academies" (Rörsch, 2014). Beaver and Rosen (1978) suggest that scientific collaboration originated with the dawn of modern science and early professionalization. To gain recognition and support, scientists created community coherence by setting standards for practices and training, as well as defining scientific goals and problems. Recognized leaders received more societal support and had the authority to reallocate resources. This professionalization led to stratification and hierarchy within the scientific community, paving the way for formal scientific training, modern research laboratories, specialization, and professionalization. Throughout the history of science, the production of scientific knowledge has consistently intertwined with various social entities.

Scientific collaboration became a very important mechanism not only for knowledge production but also for gaining and maintaining recognition. Beaver and Rosen (1978) suggest that collaboration acts as "a social regulator" (p. 69). Stratification and domination within the scientific community give rise to a hierarchy where individuals who are deemed more outstanding or recognized by the elite have greater access and control over resources such as information, support, and facilities. This recognition subsequently boosts visibility, enhances access to resources, and ultimately contributes to heightened productivity, additional acknowledgment, and professional advancement. Scientific communities were established not

only to discover universal knowledge but also to forge a network of scientists engaging within a specific social order (Whitesides, 2020).

During the nation-state consolidation between the 19th and 20th centuries, science underwent significant changes. As it became more specialized, new disciplines emerged, and governments began funding civilian laboratory research. Experiments previously conducted in private residences shifted to universities and institutes, and accreditation for scientific and engineering professions was established (Wagner & Fukuyama, 2008). Scientific collaboration played a crucial role during World War II, as Whitesides (2020) notes. International research cooperation and cross-sector collaboration were essential for countries to compete with rivals. Allies worked together to develop key wartime technologies like radar, aviation, and submarines. Governments expanded funding and formed partnerships with academia and industry to accelerate research and innovation, advancing scientific development through sectoral collaborations.

Whitesides (2020) examines the intricate relationship between post-war politics and the global development of science and technology, highlighting their mutual influence. Countries, particularly the United States, used scientific collaboration as a diplomatic strategy. Both allied and rival nations worked together to advance science and technology for national benefit and to prevent future wars. This era saw powerful nations forming alliances with smaller countries through medical and technical aid, and international organizations under the United Nation system were established to promote internationalism and democratic discourse. Science and technology were managed collectively in this new global order, but conflicts linked to global politics and national interests persisted. The post-World War II competition in science and technology led to the Cold War, and local scientific activities and international collaborations

were often influenced by national interests. Despite these conflicts, influential scholars like Bertrand Russell and Albert Einstein continued to advocate for and participate in collaborations across national boundaries, promoting the idea that scientists should collaborate as "human beings" rather than national representatives (Whitesides, 2020, p. 73).

Building on this historical perspective, Wagner and Fukuyama (2008) describe the modern scientific network as an emergent forest system, evolving without direction from any central authority. This metaphor highlights how science has become more interconnected across disciplines and countries. The emergence of this new network has opened fresh possibilities, enabling smaller and economically disadvantaged countries to participate for various reasons—some willingly to advance their own interests, others out of necessity. The network system, coupled with advancements in communication technology, facilitates the rapid dissemination of knowledge, ideas, and the movement of people. This interconnectedness underscores the enduring relevance of international collaborations highlighted by Whitesides, demonstrating how contemporary scientific practices continue to reflect and build upon the collaborative foundations laid in the post-war era.

Throughout history, it is evident that both sectoral and international scientific collaboration has wielded a substantial influence on world order and politics. In contemporary society, its importance has further intensified due to the emergence of global challenges like climate change, food security, and epidemics—complex issues that extend beyond the capacity of a single country to address (Powell, 1956). The role of international collaboration has seen significant growth in recent decades, driven by the impacts of globalization and advancements in communication technology. This evolution in scientific collaboration enables smaller nations, such as Thailand, to actively participate in global scientific endeavors as integral contributors to

the expansion of scientific knowledge and as valued members of the global governance community.

The Definitions of Scientific Collaboration

According to Price (1963), in 1900, eighty percent of published papers had a single author, with the remaining being predominantly authored by pairs. However, after 1980, there was a rapid increase in the number of collaborative papers, particularly those with three authors. The trend of collaboration in science has gathered significant attention from researchers seeking to comprehend its definition and key components.

Katz and Martin (1997) provide a comprehensive analysis of various facets of scientific collaboration. They define collaborations as instances where two or more individuals or organizations work together, each taking responsibility for significant components of scientific projects, with their contributions acknowledged in publications. While Katz and Martin's definition is specific, other scholars adopt a broader perspective. Bozeman and Boardman (2014) describe collaboration as “the social process whereby human beings pool their experience, knowledge, and social skills to produce new knowledge, including knowledge as embedded in Technogym” (p. 2). This definition encompasses a wide range of activities where scientists interact to share experiences, knowledge, and skills, even if these interactions do not always lead to joint publications. However, this broader definition restricts collaborators to individuals, excluding organizations that provide support and resources but are not classified as collaborators.

Katz and Martin (1997) suggest certain criteria to differentiate collaborators from other participants in a project. Collaborators are those who work together, are named in the research proposal, and bear responsibility for key components of the research. They may include

individuals responsible for pivotal steps, such as conceiving the original idea or hypothesis, and may involve the original project proposer, fundraiser, or project manager. Across various definitions of collaboration, the central elements consistently include shared interests and goals, with collaborators pooling resources such as budgets, equipment, and facilities to achieve common objectives (Wuchty et al., 2007).

Scientific collaborations manifest in diverse forms and scales. This research aims to enhance understanding of both international and local scientific collaborations and their impact on a nation's capacity and economy. Consequently, the focus centers on collaborations at the national and sectoral levels, recognizing them as pivotal frameworks within contemporary society.

The Formation of Scientific Collaboration

Exploring the formation of scientific collaboration provides a profound understanding of the motivations and collaborative processes at play. Scientific collaborations are established for diverse reasons, as noted by Owusu-Nimo and Boshoff (2017) and Freeman et al. (2015). These collaborations may originate from personal, professional, or student-supervisor relationships, or commence through mutual acquaintances.

Home institutions and funding agencies can instigate collaboration by matching potential partners. Professional activities, such as conferences, workshops, seminars, and exchange programs, can spark collaborative relationships. Additionally, some collaborations begin informally, arising from casual conversations at social events, in coffee rooms, or on online platforms. Interpersonal connections play a crucial role in scientific collaboration at all levels. Although this study primarily focuses on exploring scientific collaborations at the national and

sectoral levels, examining factors at the individual level is advantageous. The interactions among individual scientists significantly influence the dynamics of scientific collaborations.

Structures of Scientific Collaborations

Another area of study that is found helpful for the project is the structure of collaborations. Despite the Thai government overseeing scientific research, there is a concerted effort to encourage diverse forms of scientific collaborations, with numerous agencies possessing a degree of autonomy. The following findings from Shrum et al. (2007) provide valuable insights into the spectrum of scientific endeavors in Thailand. The study delineates the structure of scientific collaboration across different dimensions, with a specific emphasis on multi-organizational collaboration. Their primary focus was on fields such as physics, space science, geophysics, and oceanography. The findings, however, are broadly applicable to understanding collaborations in diverse fields, highlighting how organizational structures and management styles influence various types of collaboration. The researchers identified five clusters of contexts that foster scientific collaboration:

1. **Dominant Sector/Conventional Collaboration** is initiated by scientists collaborating within the same type of organization, without needing to deviate from established norms or facing external pressures. This type of collaboration is straightforward and advantageous.
2. **Dominant Sector/Unconventional Collaboration** is driven by necessity, such as career advancement or securing vital resources. These collaborations may involve conflicts and adjustments, but the benefits outweigh the drawbacks, leading to collective achievements like securing funding or essential equipment.

3. Entrepreneurial Funding Collaboration is initiated by the necessity for substantiating the existence of an organization or position. Collaborators might deviate from their usual routines and operations to engage in essential collaboration, especially when standard practices fail to yield progress.
4. Business-as-Usual collaboration arises from the need to overcome constraints without dominant sectors, collaborators often lack prior experience working together and do not necessarily encounter organizational conflicts.
5. External Brokered Collaboration is initiated by an external authority or instigator, leading to unconventional combinations of organizations and individuals. Objectives include leveraging new infrastructure, funding opportunities, and addressing emerging problems.

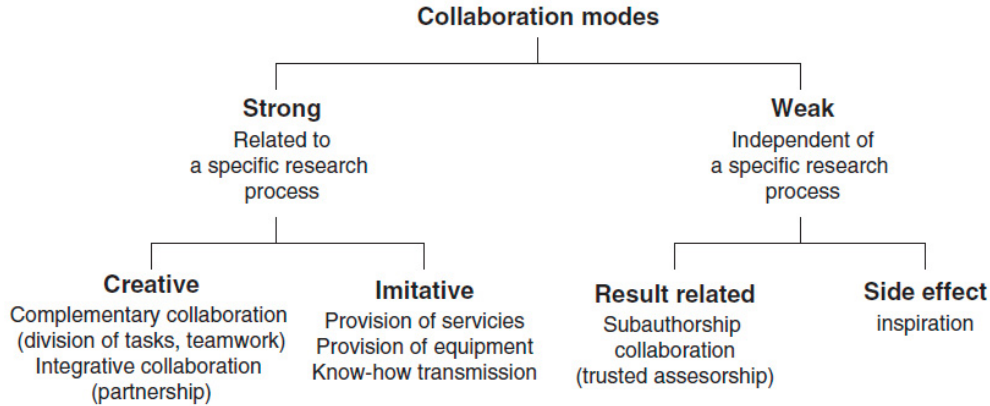
These clusters could be beneficial for the study, allowing us to explore the organizational and management styles at play and their effects on both local and international collaborations. It is intriguing to investigate whether types of clusters dominate in collaborations involving specific countries and disciplines. Additionally, examining how management styles are linked to collaboration dynamics, researcher interactions, and knowledge-production activities is essential.

Another concept related to the structure of scientific collaboration is the mode of collaboration and the invisible college. As the structure of science has transitioned from a national-based system to a network-based system, scientists now establish connections on local, regional, and global scales. Building on previous research, Olechnicka et al. (2019) categorize collaborations into strong and weak types (see Figure 3). In strong collaborations, characterized by close cooperation, there are creative and imitative forms. Creative collaboration involves

intensive interactions where tasks are divided to achieve shared objectives, managed by coordinators or the researchers themselves. In imitative collaboration, the principal investigator sets goals and performs creative work, while partners contribute routine tasks and share expensive equipment or facilities, like observatories. Research credit typically accrues to lead partners, and this type can also involve advisory roles (Olechnicka et al., 2019).

Figure 3

Collaboration modes



Note. From Olechnicka et al. (2019)

A notable weak collaboration is the "invisible college," described by Crane (1988), Price (1963), Price and Beaver (1966), and Wagner and Fukuyama (2008). This concept refers to a collective of individuals and institutions dedicated to advancing scientific knowledge and forming a mobile, interconnected community. Invisible colleges are common in competitive specialties, where members communicate, share findings, and collaborate, often extending internationally. This network addresses the unequal distribution of scientific knowledge, expanding science from an international to a global scale. It encourages interdisciplinary

collaboration, leading to new areas of study. However, challenges include difficulties for newcomers to join and brain drain, where skilled workers move abroad, hindering local scientific and technological progress. For Thailand, integrating the concept of the invisible college could enhance its competitive edge in science and technology by connecting its researchers with the international community. This study examines how Thai researchers establish or expand their networks to foster collaborations with foreign partners, identifying various types of collaborations and assessing their impact on local and international scientific partnerships.

International Scientific Collaboration

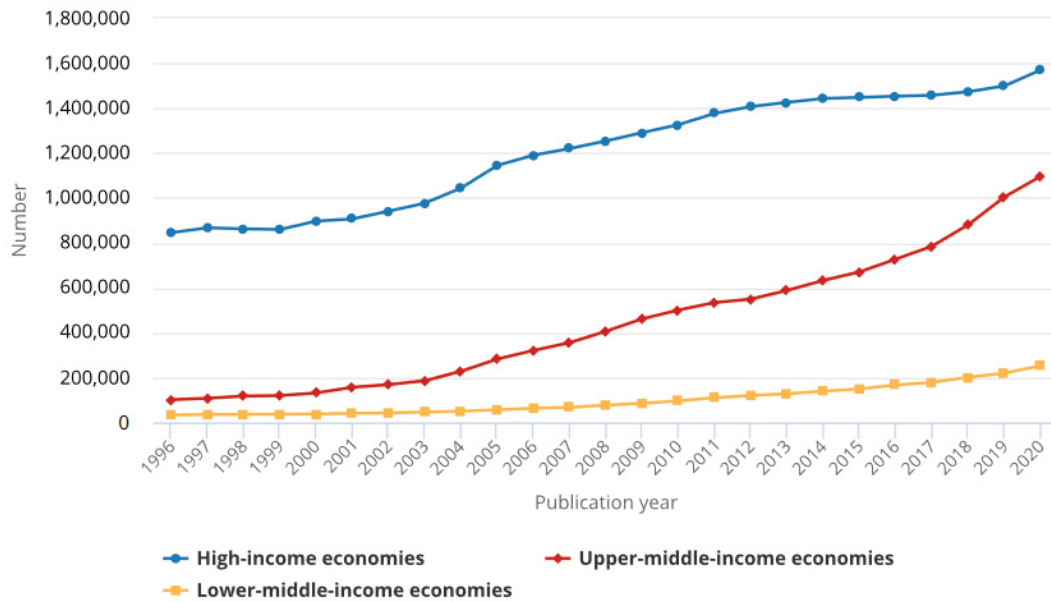
International scientific collaboration is defined as collaboration that occurs when participants are from different countries (Sonnenwald, 2007, p. 648). Such collaboration involves the sharing of knowledge, workforce, and technology beyond national boundaries. The National Science Foundation (2021) notes that the number of publications from countries across all income levels has been on the rise, with a particularly notable increase in upper-middle-income economies (see Figure 4). There is evidence indicating a rise in international co-authored publications, accompanied by the emergence of new relationships among collaborating countries. One contributing factor is that upper-middle-income countries have enhanced their research capabilities through various efforts, notably by increasing research budgets.

International collaboration, as proposed by Adams (2013), marks the fourth age of the research enterprise, succeeding the individual, institutional, and national ages. It is noteworthy that the majority of international collaborations are bilateral rather than multinational. This fourth age of research leads to a distinction between international and domestic research. While countries can gain from global knowledge exchange, there might be a trade-off with national scientific growth. Numerous researchers have explored the dynamics of the relationship between

international and local collaborations, and this will be further discussed in the subsequent section.

Figure 4

S&E articles, by income group: 1996 - 2020



Note. From “Publications Output: U.S. Trends and International Comparisons,” by National Science Foundation (2021)

Scientific collaborations offer various advantages to the stakeholders involved. As discussed above, Thailand is actively working to enhance its scientific capacity to overcome the middle-income trap. Existing literature delves into the benefits and costs associated with scientific collaboration, providing valuable insights that can assist researchers in this study in evaluating what Thailand stands to gain. Specifically, it helps provide an understanding of how the country can leverage scientific knowledge to enhance its economic standing.

Many research projects entail substantial budgets covering facilities, equipment, personnel, operations, and more. The financial demands of such projects are often beyond the means of a single country, especially for smaller nations. International cooperation enables countries with shared interests and goals to pool resources and collectively address the expenses associated with these projects (Olechnicka et al., 2019). Additionally, with technological advancements, the costs associated with conducting fundamental research, as well as those related to travel and communication, have decreased. Consequently, collaboration has become more cost-effective (Katz & Martin, 1997), making collaborative efforts with other scientists or organizations more feasible for the entire scientific community. This increased affordability and accessibility have enabled non-elite scientists and institutes to actively participate in collaborations.

Sharing knowledge and skills is a crucial aspect of collaboration. Collaborations spanning communities and disciplines facilitate the flow and expansion of knowledge and expertise, contributing to discoveries and innovations (Katz & Martin, 1997). Ordonez-Matamoros et al. (2011) additionally propose that the greater the diversity among partners, the more opportunities there are for learning and fostering creativity. These intellectual exchanges not only generate new ideas, solutions, and approaches but also provide opportunities for collaborators to identify errors and enhance accuracy through mutual feedback (Beaver, 2001). In the context of international collaboration, each country brings its own set of capacities, skills, and scientific traditions, allowing collaborators to address weaknesses and cultivate each other's strengths (Powell, 1956). Furthermore, collaboration serves as an effective means of acquiring skills or tacit knowledge that cannot be transferred through formal training (Collins, 2013).

There is a well-documented correlation between collaboration and productivity (Price & Beaver, 1966; Freeman et al., 2015; Ordonez-Matamoros et al., 2011). For instance, international collaborations have enabled researchers to build a body of knowledge about vaccines. When COVID-19 unexpectedly spread around the world, existing collaborations quickly adapted and developed COVID-19 vaccines based on previous knowledge and efforts (ISTC, 2022). Price and Beaver (1966) found that three of the four most productive researchers are among those who actively collaborate with others. They also discovered interesting productivity variations among different group sizes, noting that the highest productivity was found in single-author publications and co-authored publications from very large groups, while medium-sized groups were the least productive. They suggest that "if the good of science is measured in terms of papers produced, the gain can be maximized by having scientists work either singly and without collaboration or in very large, interrelated groups" (p. 1017).

In addition to the size of a research team, the connections and exclusivity of these connections are important considerations. Advanced communication technology facilitates communication and mobility among scientists, enabling them to take advantage of greater numbers of connections while spending less research manpower. The increased productivity is a benefit of the division of labor. Participating in collaborative projects allows researchers to be more focused and devote more time and energy to their contributions (Olechnicka et al., 2019). However, it is important to note that a greater number of co-authored publications does not necessarily imply that an individual has a greater capacity to generate new knowledge.

International collaborations offer significant advantages, such as increasing the visibility and impact of research (Katz & Martin, 1997; Coccia & Bozeman, 2016). Wuchty et al. (2007) found that while solo-authored publications initially had more citations, team-authored

publications now dominate the citation distribution. Guerrero Bote et al. (2012) discovered that the more countries evolved in collaboration; the more citations received. However, benefits are not equally distributed between partners. Low-impact countries gain more from collaborating with higher-impact countries, while those with low-impact neighbors benefit less from regional collaborations. Collaborating internationally can mitigate this "neighborhood effect," amplifying the impact of collaborative efforts. Moreover, scientific collaboration opens access to additional research funds and enhances researchers' profiles, making them more competitive for future funding and new networks (Katz & Martin, 1997).

Bozeman and Boardman (2014) explore the benefits of research collaboration within the Scientific and Technical Human Capital (STHC) framework, which includes an individual's scientific, technical, and social skills, along with accessible resources. Their study suggests that collaboration enhances STHC, benefiting the scientific community by addressing novel problems. Collaborative efforts significantly develop collective skills and resources, fostering a more capable environment for tackling complex issues. International research collaboration is crucial for advancing a country's economy by allowing scientists to acquire new knowledge and skills. This raises questions about the knowledge areas essential for Thailand's development and whether these influence Thai researchers' choices of collaborators and projects. Understanding the priorities of Thai science and the strategies used by Thai institutions to maximize collaboration benefits is also essential.

While scientific collaboration results in several benefits, engaging in collaboration entails certain costs, such as the added expenses associated with travel and project management. Collaborative efforts with multiple parties typically require more time and involve additional administrative tasks, necessitating the participation of a larger number of individuals (Katz &

Martin, 1997). Empirical evidence supports the shift in scientific work from individual endeavors to collaborative initiatives. Wuchty et al. (2007) found that, over time, the average number of team members involved in scientific collaborations has increased.

Meißner et al. (2022) identified seven significant issues in research collaboration, including challenges related to the diverse nature of partners, such as different perspectives, motivations, working styles, and organizational diversity. Commitment problems arise when partners prioritize their work over collaborative efforts, and uncertainties such as the risk of a partner dropping out or denying a funding extension also pose challenges. Communication issues, including miscommunication or lack of engagement, fairness problems like conflicts related to authorship, management challenges, and relationship issues, such as overly demanding relationships or social distance, further complicate collaborative research efforts. Moreover, Freeman et al. (2015) propose that challenges in collaborations encompass issues such as insufficient time for communication, limited flexibility in research execution, difficulties in coordinating team members' schedules, and more. The process of receiving credit for collaborative work can be intricate and may lead to disputes.

Collaboration often leads to disproportionate benefits for leading contributors while hindering others. Agrawal et al. (2015) found that star researchers tend to produce more publications due to their broader networks and better access to collaborators. With the rise of international collaboration and improved communication technologies, star scientists can capitalize on more opportunities. This reflects Merton (1968)'s "Matthew Effect," where established scientists gain more recognition and resources, reinforcing their success. The uneven distribution of labor can also limit the career advancement of junior collaborators (Burroughs Wellcome Fund & Howard Hughes Medical Institute, 2004).

Collaborations are influenced by various factors, including intellectual, technical, economic, and social drivers (Price, 1986). A crucial factor is the fluctuation in funding patterns and levels (Katz & Martin, 1997). Bozeman and Corley (2004) emphasize that the extent of grant funding significantly affects scientists' inclination to engage in future collaborations. Larger grants enable broader collaboration efforts, fostering diversity and involving partners from multiple countries. Furthermore, knowledge accumulates and scientific disciplines progress continuously. To achieve substantial advancements, researchers require not only more knowledge but also increased effort and time. Coping with the growing burden of knowledge can be facilitated by refining individual expertise and expanding collaborative patterns with other scientists (Conti & Lui, 2015). Other factors that may influence research collaborations include a country's or organization's need for more scientific personnel and the enhancement of their workforce.

Research collaboration comes with costs and benefits, and I believe these factors influence collaborative activities among scientists. This study employs the concept of the cycle of credibility in this study, I believe that this concept encompasses these factors and provides a dynamic understanding of cost and benefit exchanges and evaluation. The concept is discussed in detail below.

Modern Technology vs. Personal Connection in Scientific Collaboration

Advancements in technology have significantly reduced the costs of travel and communication, facilitating knowledge-sharing and meaningful dialogue among scientists. However, unequal access to these technologies creates disparities in collaborative opportunities (Wagner & Fukuyama, 2008). Despite advanced communication technology, geographical location and a common language remain significant factors in modern science (Sohn, 2016;

Chinchilla-Rodríguez et al., 2018; Choi et al., 2014). Research indicates that many researchers refer to work conducted by nearby institutes, and more discoveries emerge from collaborations among individuals from the same regions or who share common languages. Science, as a social activity, heavily relies on relationships among the actors involved.

Face-to-face communication plays a crucial role in building trust among collaborators, an essential component of successful collaboration. Meeting in person fosters trust and familiarity, which technology alone cannot achieve. Long-distance relationships and technology-enabled communication can be effective, but they are most successful when partners have previously worked together. Collaborators who only interact through information and communication technology (ICT) often struggle to build trust due to the lack of personal experience and distinct organizational rules and cultures (Robert et al., 2009). Robert and colleagues found that "swift trust" influences how team members develop future relationships and trust during collaborative projects. Unlike knowledge-based trust, which is built on personal experience, swift trust is based on roles, organizational rules, third-party recommendations, generalized attitudes, and stereotypes. Although new personal experiences can be gained after working together, swift trust still affects the formation of new experiences. Additionally, ICT-based communication increases perceived risk while decreasing the willingness to trust.

Many studies argue that trust and prior acquaintance are highly beneficial in collaboration. However, Gulati (1995) caution that personal relationships can result in less formal and authoritative governance of collaboration may lead to inequity-based cooperation due to personal trust. Given this body of literature, it would be intriguing to examine the role of technology in various types of research collaborations. Specifically, this study is interested in

understanding how Thai researchers utilize ICT and manage trust among collaborators, especially those from diverse countries and sectors.

Measurement of Collaboration

Understanding scientific collaboration can be achieved by quantifying and developing measures of these interactions. A commonly adopted approach is scientometrics, which employs quantitative methods such as citation and co-authorship indexes to investigate the trends and patterns of research collaboration. Other indicators include the number of patents, employment of researchers and graduates, and R&D spending (Zheng et al., 2014; Yoon & Park, 2017).

Citation analysis has numerous applications, with some researchers adopting it as a tool to examine international scientific collaborations. For instance, Ribeiro et al. (2018) found that the United States, United Kingdom, Germany, and China are the leading countries actively engaged in international collaboration. Conversely, Zheng et al. (2014) suggest that Spain, Israel, Russia, Singapore, and Taiwan are more selective in their collaboration partners. Some researchers focus on the unique characteristics of collaborations in specific regions, such as Arab countries, Latin American countries, and BRICS countries (Finardi, 2015; Narvaez-Berthelemot et al., 1992). Wagner et al. (2017) examined international collaboration across six specialties within broader fields (Physics, Biology/Medicine, Environmental/Geo, Engineering, Agriculture, and Mathematics) and found that despite distinct epistemic cultures, these specialties are converging toward similar levels of international activity.

International collaboration has become a standard practice worldwide, growing increasingly complex and crucial in modern society. This study aims to investigate international research collaboration and contribute to the body of knowledge in this area. By employing

coauthored publication analysis, I examine the patterns and relationships between local and international scientific collaborations. Coauthored publication analysis will be discussed in detail in Chapter 3, Methodology.

Global North-South Science

A topic often discussed in the literature on international scientific collaboration is the partnership between countries from the Global North and South. This study investigates these collaborations both locally and globally, focusing on case studies from Thailand, the United States, and China. These case studies provide insights into the dynamics between countries with varying scientific capabilities. Initially, scientific discoveries were perceived as universal properties meant to be shared equally among scientific communities. However, various factors contribute to inequality, especially between the Global North and South. This imbalance is a focal point in the literature of the Science and Technology Studies (STS) community contributing to the ongoing discussion and research on the subject. Therefore, this section focuses on the ongoing discussion and research on the subject.

North – South Scientific Collaborations

Although the countries of the global North and South are diverse, there are common considerations. The global North typically refers to developed countries or metropolises, while the global South includes nations reliant on the developed world culturally, politically, and economically (Connell et al., 2017). Wagner and Fukuyama (2008) suggest indices like GDP per capita, gross tertiary science enrollment ratio, scientist and engineer numbers, research institutes, R&D spending, patents, scientific publications, and international co-authored publications to evaluate countries' readiness for participation in scientific collaboration. While some developing

nations may be well-prepared, others are working to improve their conditions. Consequently, developed countries often take the lead in collaborative activities, leaving many developing nations facing challenges in accessing and applying knowledge from international collaboration (Boshoff, 2009; Wagner & Fukuyama, 2008).

Over time, collaboration between the Global North and South has evolved, marked by changing dynamics. In the 1950s and 1960s, collaborative projects often exhibited asymmetrical relationships, described by Costello (2000) as the "semicolonial model" in developing countries. This model involved practices like "postal research," where Western researchers requested samples from developing country counterparts and conducted studies primarily in the North. Additionally, "Parachute research" was common, where Northern researchers briefly visited developing countries for sample collection. Such practices prioritized expedience over ownership, sustainability, and local research capacity development. For instance, in South America, cooperation mechanisms in development projects like HIV drug trials predominantly aimed at promptly addressing development issues (Edejer, 1999).

Since the 1979 United Nations Conference on Science and Technology for Development in Vienna, there has been a shift towards establishing equitable partnerships in collaboration. Suggestions for achieving this include focusing on mutual interests, making collaborative decisions, ensuring transparency, and securing commitments from all involved parties (Gaillard, 1994). Binka (2005) observed a promising trend in international networks facilitating effective north-south research collaboration. For instance, the INDEPTH network connects demographic and health surveillance systems across 19 countries, fostering long-term collaboration between scientists and institutions from the North and South. This network facilitates equal information sharing and result dissemination, enabling members to collectively achieve common goals.

Despite efforts to achieve equality in research collaborations, a body of literature on north–south collaborations is quite pessimistic, focusing on the inequality and power relations between partners, as well as the domination of partners from the North. For instance, Connell et al. (2017) argue that early North-South collaborations were characterized by "scientific colonialism," in which Northern countries exploited local people and knowledge solely to obtain results for their publications, with very few returns benefiting the Southern countries to solve local problems. In many collaborative projects, local priorities are overlooked, and local talent is diverted away from local issues (Edejer, 1999). Countries with greater financial resources have more influence in establishing priorities and protocols. For young scientists, publishing in global North journals can help them gain recognition and advance their careers. However, to do that, researchers from the South need to follow the intellectual paths set by the North; otherwise, they may have a hard time getting their papers published (Connell et al., 2017). Unfair collaborations can lead to various risks and abuses, including scientific colonialism, military and commercial exploitation, and brain drain (Gaillard, 1994; Binka, 2005; Sonnenwald, 2007). Despite many efforts to find solutions for mutual benefits in research partnerships, unfair practices remain a concern today.

In addition to losing control over research priorities, the inequality in the division of labor between northern and southern partners is also evident. According to Connell et al. (2017) and Gaillard (1994), as funds and advanced technology come from Northern countries, and samples, such as infected populations, are mostly in Southern countries, the nature of the model creates a division of labor and authority. Researchers from developing countries are more involved in the implementation and execution stages of collaborative projects, such as data collection and field experimentation. Researchers from developed countries, on the other hand, have more

responsibility for research planning and dissemination. As a result, Northern partners publish more papers and give more conference presentations.

According to the research findings, collaborating with more advanced countries does not necessarily ensure benefits for less developed ones. There are specific actions and efforts required for smaller countries like Thailand to acquire the anticipated benefits from collaborations with more advanced counterparts. A challenge for north-south collaborations is that institutes in developing countries have limited capacity to effectively participate in and sustain meaningful scientific activities with partners from more developed countries. As a result, collaborations between countries in the north and south must include capacity building as part of their efforts (Chandiwana & Ornbjerg, 2003). To promote and support research activities in less developed countries, more advanced countries could provide technical assistance, overseas training, institution building, and collaborative research partnerships (Gaillard, 1994).

Bender (2022) explores how social interactions and structural dynamics in research collaborations, particularly between partners from the global North and South, shape knowledge production and collaborative impacts on society. The study reveals those inequalities among actors, including disparities in information availability, resource allocation, and decision-making authority, influence partner interactions. Kotze and Dymitrow (2022) further illustrate how these imbalances impact day-to-day collaboration. Interviews with researchers from Northern Europe and East Africa highlight challenges such as power dynamics in meetings due to unequal representation, difficulties in communication exacerbated by distance and technology disparities, and limited opportunities for Southern researchers to conduct studies abroad. Unequal travel opportunities due to budget constraints and visa restrictions contribute to disparities in information access.

In addition to interactions between collaborators during day-to-day activities, Dannecker (2022) contends that funding schemes and positionalities of collaborative actors also produce and reproduce power structures and impact knowledge productions during collaborative projects. Understandably, the funding agency would want to exert influence over projects through project requirements. However, any inequity should be addressed and avoided from the start of the project, or it will harm the entire project. For instance, according to Dannecker (2022), in a project collaborated among institutes in European countries and Southeast Asia, some guidelines appear to have a hidden agenda by giving the northern partners more responsibilities related to funding management, giving them more power in decision-making.

Felt et al. (2016) analyzed proVISION, an Austrian funding scheme for transdisciplinary sustainability research, uncovering three models of knowledge production between scientists and societal actors. The first model, the linear translation model, separates scientific and societal realms, with knowledge transferred from science to society without significant interaction. In the second model, scientific and societal actors interact at specific points, with societal actors acting as advisors or gatekeepers due to their experiential knowledge. The third model involves temporary shared epistemic arenas, like workshops, promoting mutual learning. However, power imbalances persist, with scientific actors dominating debates and decision-making. This inequality is evident in collaborations between developed and developing countries, where developing-country collaborators often have limited influence despite being end users.

Building equity in collaborations

Collaborative efforts undoubtedly offer numerous benefits to all parties involved. However, evaluating the quality of research in collaborative endeavors is not a straightforward task. Belcher et al. (2015) note that traditional disciplinary research has established criteria for

assessment, while transdisciplinary research (TDR) is context-specific, problem-oriented, and involves multiple actors, making evaluation challenging. They propose four TDR quality principles: relevance, credibility, legitimacy, and effectiveness. TDR should address relevant societal problems and be transparent, defensible, and scientifically credible. It must be fair and ethical, involving all stakeholders and considering diverse interests and values. Additionally, TDR should resolve real-world problems, not just aim for publication.

Bender (2022) suggests that inequalities in collaborative projects must be addressed to achieve saliency, credibility, and ethical fairness. Disparity in social relations is caused by differences in collaborators' historical and geopolitical social relationships. As a result, all parties involved in the project should be represented to foster mutual awareness and acceptance of differences among partners, as well as to ensure that no single person acts as a gatekeeper and attempts to influence how the study is planned and executed (Bender, 2022). Furthermore, Edejer (1999) suggests that considering the project's long-term consequences is an important practice. According to an interview in Connell et al. (2017), researchers from the global North must see and understand specific knowledge from multiple perspectives. “You might approach with some notion, but you may well leave with a very different notion! You could not just walk in with a research design” said the interviewee (p. 51).

Faure et al. (2021) identified ten key themes affecting equity in international collaborations between the global North and South. These include the power imbalance driven by financial resources, the importance of recognizing local knowledge, and building capacity through training. Ensuring Southern researchers take lead roles, retain ownership of collected samples, and have clear agreements from the start is crucial. Local interests must be prioritized, and trust in fund management is vital for balanced relations. Addressing economic disparities,

acknowledging all contributions, and maintaining transparent communication are also essential for fostering equitable partnerships. Another strategy for promoting equality in collaboration is to have multiple agendas in the project. Connell et al., (2017) contend that, in some cases, local conditions of nature and social environment can help the Southern researchers produce distinctive agendas for collaborative projects. For instance, unique environmental factors allow local researchers to develop a distinctive analysis model from those developed by researchers from the global North because they do not have the same environmental conditions. Or a South African research team insisted on participating in a research project initiated by a Northern country and allowing them to use local samples if they allowed them to be co-PIs [Principal Investigators] and use the fund to hire their own staff.

South-South Scientific Collaborations

Most research collaborations in developing countries are primarily between countries from the North and South. Although South-South collaboration has entered the political agenda, North-South collaboration is most likely to continue to be mainstream. One reason is that collaborating with more advanced countries can provide a country with more benefits than collaborating with countries in the South (Boshoff, 2009). This practice not only limits collaboration among South countries but also limits domestic collaboration opportunities. Another reason that could explain the invisibility of collaboration in South countries in international sources is that co-authored research papers are only a partial measure of collaborative research activity. Collaborations between South countries could be in other forms besides co-authored publications; therefore, many south-south collaborations are excluded from international publication databases.

South-South cooperation, according to Boshoff (2009), should be encouraged. Collaborative efforts and strategic blending of the best of Southern research could boost the international visibility of developing-region science and the South's participation in global science. Furthermore, the South is acutely aware of its own regional issues and constraints. South-South cooperation may result in more effective solutions to developing-country problems. Furthermore, encouraging South-South research collaboration could aid in attracting talented scientists and researchers to stay or return to their home countries. Several countries in the global South form collaborations to help each other promote their scientific capacity. For example, national research centers in Zimbabwe, Zambia, Malawi, and Tanzania collaborate under initiatives aimed at addressing uncoordinated and ineffective resource pooling among countries in the region (Chandiwana & Ornbjerg, 2003).

Despite inequalities in North–South collaborations, many low- and middle-income countries continue to seek opportunities to collaborate with more developed countries. One reason is that it is widely accepted that international research collaborations increase productivity. However, Ordonez-Matamoros et al. (2011) and Ordonez-Matamoros et al. (2010) discovered contrasting results. According to their research in Colombia, collaborations between southern and southern countries result in 2.2 times the productive capacity when compared to working with northern partners. According to one of the interviewers, their northern research partners do not care about their financial constraints, so Colombian collaborators cannot contribute much to a specific project. Surprisingly, the researchers also discovered that working with northern partners is positively associated with the team's likelihood of working on local issues. According to their citation analysis, the word "Colombia" appeared more frequently in

co-authored publications by Colombian researchers and researchers from the global North than in publications by south-south partners.

Another thing to consider is that not all countries in the Global South are the same. Researchers (Boshoff, 2009; Pineda et al., 2019) believe that the lessons learned from North-South collaboration can be applied to South-South collaboration as well. There are differences between the countries of the South. Some countries in the region are more advanced than others, and South-South collaborations may result in unequal power relations.

This section discusses scientific collaborations between countries, particularly those with differing economic circumstances and research capacities. By using Thailand-U.S. and Thailand-China collaborations as comparative case studies, I examine the dynamics and challenges inherent in North-South and South-South collaborations. In the next chapter, I delve into the STS conceptual frameworks that proved useful in this study. I first explore the concepts of knowledge-based economics and the Triple Helix model. Then, we discuss the Cycle of Credibility concept, which helps us understand scientists' decision-making in engaging in collaborative activities.

Chapter 3

Conceptual Framework: The Triple Helix Concept and the Cycle of Credibility

In Chapter 2, I discussed the importance of scientific collaboration as a mechanism for nations to enhance their global competitiveness and economic standing. As Thailand strives to overcome the middle-income trap, the nation is promoting scientific collaboration on both domestic and international fronts. The effort raises questions regarding the potency of scientific collaboration as a development strategy and the challenges faced by Thai researchers. For instance, what are the interconnections between international and local collaborations? How is knowledge generated elsewhere effectively translated and integrated into the local scientific community? How do researchers decide on their strategy for participating in specific collaborative projects or choosing partners?

This chapter explores two frameworks: the Triple Helix concept and the Cycle of Credibility. These frameworks help examine the dynamics between international and local collaborations to understand how researchers choose to engage in these efforts. Each section reviews previous studies to highlight the frameworks' relevance to the current research.

Knowledge-based Economy and Triple Helix Framework

The preceding chapter delves into the realm of scientific collaboration, particularly on an international scale. This section shifts its focus to concepts relevant to examining domestic collaboration. I propose that the Triple Helix (TH) framework, developed by Henry Etzkowitz and Loet Leydesdorff in the 1990s, is instrumental in answering the research questions. The TH framework emphasizes the interactions and dynamics among key actors in a research and innovation system: universities, industry, and government. Collaborations among these sectors

are crucial for nurturing a country's long-term capacity. Here, I explore the framework, its applications, and the rationale for selecting it for the study. To provide context, I begin by discussing the evolution of the knowledge-based economy and alternative innovation models.

Economic Models and Knowledge-based Economy

The Agricultural and Industrial Revolutions marked the beginning of efforts to develop tools and methods for procuring essential resources for human sustenance and progress. Today, we may be experiencing an information revolution. In this economic landscape, there is a clear shift towards economies grounded in knowledge-intensive activities, where knowledge is the key asset driving productivity and economic growth. Previously compartmentalized systems, such as those governing knowledge production, wealth generation, and control, are now exhibiting tendencies toward integration at various structural levels. This trajectory is reinforced by heightened investments in research and development, innovation, and human capital. The economies of many nations are aligning themselves with this trajectory, advancing in a unified direction.

According to Godin (2005), the term "knowledge-based economy," coined by the Organization for Economic Cooperation and Development (OECD), is an umbrella concept that focuses policymakers' attention on science and technology while introducing new statistical implications. This economy is characterized by a novel interaction between sectors in the production, dissemination, and application of economically useful knowledge. It led to the separation of tacit and codified knowledge and efforts to quantify national systems using statistics. Organizations like the OECD, the National Institute of Statistics, and UNESCO have since developed indicators, metrics, and policy implications (Godin, 2005; Leydesdorff, 2010).

In a knowledge-based economy, alongside market mechanisms and regulations, organized knowledge production emerges as a third coordination mechanism. This economy has three sub-dynamics: driving wealth through economic growth, using science and technology for innovation, and public and private policymaking overseeing their interactions. These sub-dynamics shape and transform institutional arrangements in the knowledge-based economy. The emergence of a new knowledge infrastructure has been observed worldwide, including in developing countries like Thailand. While structural evolution may present certain challenges and differences in less developed countries, transformation has played a significant role in fostering economic development within these nations (Chung, 2014; Williams & Woodson, 2012).

New university-industry-government relationships

The emergence of a knowledge-based economy necessitates institutional reforms. Before the 1990s academic revolution, universities mainly provided education and conducted government-supported basic research. World War II and the Cold War prompted universities to rethink their role, increasing their involvement in knowledge capitalization and innovation commercialization (Leydesdorff, 1995). According to Audretsch et al. (2002), universities now supply research personnel and potential employees. When industries lag in innovation, they hire consulting firms to assist in boosting its innovation. However, the firms' work is project-based, with little long-term continuity. In contrast, universities offer both continuity and innovative ideas, with faculty maintaining research memory and students introducing fresh perspectives (Etzkowitz & Leydesdorff, 2000). The coexistence of faculty and students significantly shapes the output, culture, and applicability of research. These organizational changes have broken down disciplinary boundaries, leading to interdisciplinary centers and labs that foster

collaboration. Universities engage with industries through technology transfer institutions and are influenced by external factors like the U.S. Bayh-Dole Act of 1980 (Etzkowitz & Zhou, 2018).

The shift away from traditional educational institutions raises a critical question: Should universities produce knowledge solely to advance science, national development, or industrial R&D? The pressure on universities to prioritize industrial applications and profit can lead to conflicts of interest. However, universities have successfully solved numerous industrial problems, which would have been impossible without financial support. Carty (1916) argues that universities are a talent source for both public and private sectors, necessitating assistance and funding from both. The combination of research and academia became common in the late nineteenth century (Etzkowitz, 1994).

As universities expanded their roles to include research, industries also increased their focus on knowledge production. By the late nineteenth century, industries recognized scientific knowledge as crucial for technological development and competitiveness. Research support was not limited to universities; it extended beyond academia. Companies invested in research to generate new knowledge in specific areas, integrating research and training. For example, AT&T established Bell Laboratories to research wire communications technology, aiming to solve business problems. Additionally, some businesses contracted laboratories and funded university research. R&D enhances a firm's capacity to absorb new technologies, contributing to economic growth (Audretsch et al., 2002). Numerous studies demonstrate the effectiveness of private sector R&D in driving economic growth.

Audretsch et al. (2002) state that the relationship between government and science has been integral since America's founding. The Constitution proposed that science remain free from

direct government control, yet leaders recognized the importance of scientific advancements for national welfare. Consequently, the government could indirectly influence science by promoting its progress. For instance, during the Cholera epidemic of the 1820s, countries needed new technical knowledge to combat the outbreak, leading to greater recognition of direct government involvement in science. The U.S. government began funding private-sector research and providing grants to individual scientists and engineers, establishing numerous institutes dedicated to scientific knowledge production. Following World War II, leading countries built national and industrial infrastructure to support scientific and technological progress, with governments becoming major supporters of science and technology. When the private sector struggles or underinvests in research, the government steps in to prevent or correct market failures. Government roles include enacting patent laws, providing tax breaks, funding research, and creating an environment conducive to collaborative research (Audretsch et al., 2002).

Alternative economic models and triple helix framework

Experts and scholars have developed models to capture and explain the process of innovation development and diffusion. Early models, like the discovery-push and demand-pull paradigms, followed linear approaches (Godin, 2015). The concept of hierarchy in understanding world politics has been present since ancient Greek times, influencing both social practices and intellectual ideologies. This is evident in the preference for pure science over applied research. Feibleman (1961) distinguishes "pure science," or "basic research" and "applied science" by stating that the first is to know, and the latter is to do. However, they are not mutually exclusive; applied science relies on pure science, suggesting a one-way relationship between the two.

The relationship between pure research, applied research, and economic development has practical implications in policy and practice. Vannevar Bush's "Science: The Endless Frontier"

asserts that "basic research is the pacemaker of technological progress, leading to socioeconomic development" (p. 19). This perspective has long guided American policy, emphasizing the role of basic science in driving economic growth. John Gibbons, former director of the U.S. Congressional Office of Technology Assessment, echoed this sentiment in 1986, stating that basic research underpins technological development, economic prosperity, improvements in health, national defense, and advances in knowledge (U.S. Congress, Office of Technology, 1986, iii).

The linear model of research, progressing from basic research to production, is also prevalent in industry (Stevens, 1941). Surveys conducted by organizations and scholars have sought to classify research activities and understand their coordination with industrial utilization. These efforts resulted in the widely recognized three-stage model: basic research → applied research → development. This model has been instrumental in calculating research expenditure and resource allocation. Once integrated into statistical indicators, methodological rules, and policy, the model became a widely accepted framework (Godin, 2006, p. 660).

Nelson (1994) explores the relationship among science, technology, and institutions, highlighting how technological progress spawns new scientific domains, legal frameworks, and organizational paradigms. He critiques linear models for oversimplifying the complexity of knowledge development and acquisition, as they focus solely on the performance of individual formal institutions without accounting for interactions. Emphasizing the centrality of knowledge in the economy, the OECD underscores the need to comprehend knowledge networks and national innovation systems (OECD, 1996). Sociologists and economists have responded with more nuanced models such as the Markov chain and spiral models to address these complexities.

Recognizing the limitations of the linear model and the evolving relationship between scientific knowledge and society, innovation models have shifted from linear to non-linear frameworks. These non-linear models feature multiple starting points, heightened sector interactions, and increased actor involvement (Etzkowitz & Zhou, 2018). Expanding on the spiral model's emphasis on university-industry interaction, Etzkowitz (1994) introduces government as a pivotal player in science-based economic development.

Leydesdorff (1994) developed the Triple Helix model from an evolutionary perspective to capture the dynamics of science and technology in society. He contrasts biological evolution, driven by natural selection, with cultural evolution, driven by conscious and intentional actions. Technological advancements impact both the environment and markets, with selections and variations in the system shifting over time. Selections at one point can become new variations later. According to Etzkowitz and Leydesdorff (1995), three sources of variation recognized in technology studies are: 1) distinct characteristics and interactions within each industrial sector, 2) different technologies producing unique innovation and diffusion patterns, and 3) systems of innovation integrating and differentiating functions in various ways. These variations are both functional and institutional.

Because analytical categories in evolutionary economics are theoretically constructed, units of analysis in different theories can differ such as firms or technologies (Leydesdorff, 1994). Firms, for example, are frequently used as a unit of analysis by evolutionary economists. In contrast, policy studies researchers typically use national systems or other more abstract forms of units, such as social networks (Etzkowitz & Leydesdorff, 2000).

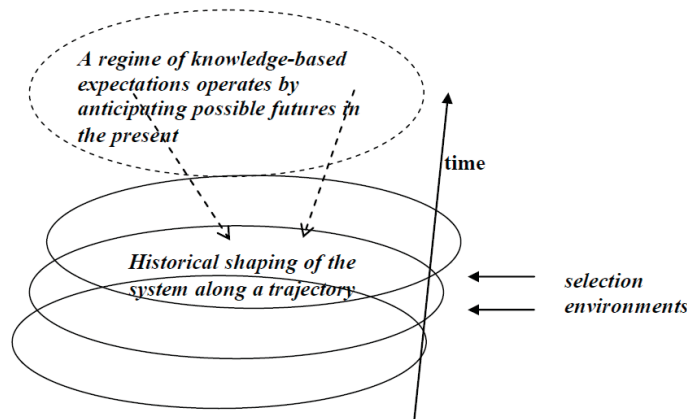
Government, universities, and private companies, the three key sectors in the Triple Helix model, used to operate independently but now collaborate more closely. According to

Leydesdorff (2010) and Ye et al. (2013), this trilateral relationship forms a spiral pattern of linkages and interactions between institutional settings, relationships, and expectations.

Interactions between sectors are influenced by stabilized roles and functional relationships at the current stage, as well as anticipations for possible future relationships. These interactions lead to the evolution of institutional structures within each sector. The nonlinear dynamic models treat variables as fluxes, adding flexibility. These dynamic interactions drive the development of the knowledge base within the social system (Fig. 5).

Figure 5

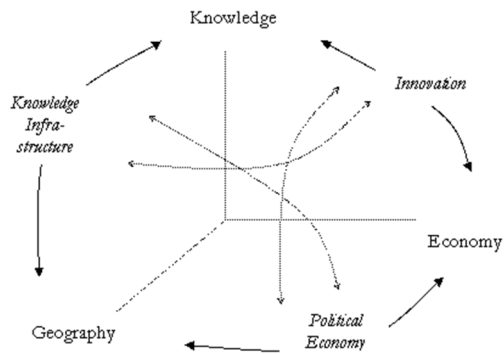
The Evolution of Systems Through Dynamic Interactions Between Historical Relationships and Future Expectations



Note. From Leydesdorff (2010)

Figure 6

Three dimensions of the social system with their three interaction terms.



Note. From Leydesdorff (2010)

Figure 6 illustrates a network of relationships involving three coordinators that such as capital, labor, and innovation, or the interplay between economy, knowledge, and geography. Etzkowitz and Leydesdorff (2000) use this model to examine the interactions among universities, industries, and governments, emphasizing institutional shifts, evolutionary mechanisms, and emerging institutional roles. Within this framework, the three sectors adopt new functions, leading to overlapping domains and intersecting institutional boundaries. The researchers view innovation and national systems as continuously evolving production and distribution networks, where actors in each sector coevolve through intra- and inter-sector interactions. In a knowledge-based society, these interactions drive ongoing system restructuring, potentially giving rise to novel institutional configurations.

Triple helix relationships are approached from two perspectives: a statist model and a laissez-faire model. In the statist model, government governs the interactions between academia

and industry, with a central authority making decisions. Universities primarily focus on workforce preparation, while firms concentrate on production and competition. In the *laissez-faire* model, the three sectors operate independently, with governments playing a limited regulatory role and intervening in the market's failure. Direct links between universities and industries are absent, and collaborations occur through intermediary entities like non-profit organizations (Etzkowitz & Zhou, 2018).

Etzkowitz and Leydesdorff (1995) and Etzkowitz and Zhou (2018) characterize Triple Helix relationships as a novel interconnection among universities, industries, and governments. This model originated back in the 1920s in New England and Boston, amidst industrial decline and government failures to protect the economy. During this period, universities began to take a proactive role in fostering innovation and regional development. They encouraged faculty engagement with private firms and campus initiatives, initiating a transformative shift from production-based to knowledge-based economies. The government's role has evolved to facilitate innovation by collaborating with the private sector, providing support and incentives, and leveraging legal frameworks to encourage creativity. When universities and industries face innovation challenges, the government intervenes to pool resources and bridge gaps in capacity. Industries have adopted a hybrid approach, drawing resources from diverse institutional spheres. Governments now offer formal support to industries through programs and incentives, while also fostering collaborations with academic research groups to harness creativity for innovation. Businesses have broadened their objectives to include not only profit but also political and cultural goals, engaging in academic research and educational activities within the Triple Helix framework.

According to Etzkowitz and Zhou (2018), the evolution of each sector and the co-evolution of university, industry, and government can occur through both direct and indirect influences. Indirect impacts involve the introduction of organizational innovations and cultures among sectors to achieve common goals, while direct influences include legislation, such as intellectual property and tax laws, and targeted funding. In addition to their traditional roles, each sector adopts the functions of the others, fostering a dynamic exchange of roles and responsibilities (p. 40). The non-linear interactions within the Triple Helix model offer alternatives to centralized control, allowing interactions to take place across different levels and among members of different spheres (Etzkowitz & Zhou, 2018). The model offers a new perspective on the social system of science and innovation, emphasizing the current transformations and interactions of actors within innovation systems rather than historical reconstructions (Leydesdorff, 2010).

Interactions between academia, public, and private sectors often face barriers due to differing norms, incentives, and experiences. Bruneel et al. (2010) highlight the tensions: academics focus on publications and career growth, public sector scientists prioritize societal impact, and private sector researchers emphasize economic value, sometimes restricting knowledge sharing. Merton (1973) notes that researchers' social and cultural ties influence their scientific focus. To overcome barriers, prior collaborations, diverse interactions, and trust are key. Some of the insights from the Triple Helix model are supported and expanded upon by other scholars examining the interplay between science, industry, and government. Bozeman and Boardman (2014), for instance, found that scientists and engineers transitioning between industries demonstrate higher productivity in publications and patents, emphasizing the benefits of interdisciplinary collaboration. Xu et al. (2017) highlight the role of technology transfer

offices (TTOs) in bridging sectoral gaps, facilitating technology transfer, and aligning diverse sectoral goals.

Triple Helix and its impacts on scientific performance

One of the key questions in the study is whether local and international scientific collaborations contribute to enhancing Thailand's scientific and economic capacity. This section reviews previous studies that explore the relationship between scientific collaboration and research performance. Most Triple Helix studies focus on innovation and economic outcomes, with very few studies focusing on academic institutions and scientific performance. Zhang et al. (2019) address this gap by exploring the impact of Triple Helix relations on China's scientific performance. They found that China's shift from a statist innovation model to fostering collaboration among industry, universities, and research institutes significantly improved scientific performance, particularly in collaborations between the Chinese Academy of Science (CAS) and universities. Using Leydesdorff and Invanova's mutual information, they analyzed CAS literature and concluded that collaborations with other sectors positively influenced CAS's scientific performance indirectly but significantly, as well as moderately improved the effects of research investments on that performance. Collaborations between CAS and universities have a greater impact on improving CAS's scientific performance than collaborations between CAS and industries. The findings support the Chinese government's efforts to improve S&T performance and increase innovative capacity.

Zhang et al. (2019) affirm that knowledge generation occurs not only through original research but also through interactions among individuals and institutes. The Triple Helix model suggests that knowledge transfer across institutional boundaries happens inadvertently, facilitated by various factors (Alexander, et al., 2016). These interactions can be formal or

informal, with informal exchanges often occurring in boundary-spanning activities like living labs (Azagra-Caro, et al., 2017; van Geenhuizen, 2016). Research by Audretsch et al. (2002) supports this, showing that private firms with informal ties to universities exhibit higher R&D productivity. While informal communication is crucial, Boardman (2009) warns that it can fail without resource interdependence and goal congruence. Formal mechanisms may be necessary to address this. Ultimately, bilateral and trilateral interactions among sectors positively impact participants' performance.

Measuring Triple Helix Relations

Measuring the outcomes of research activities is not straightforward. Econometric analysis, for example, may be able to quantify the returns on R&D activities in the private sector. However, these metrics are incapable of capturing other types of returns, particularly when R&D is spread across multiple sectors or social sectors. Furthermore, Econometric approaches have failed to demonstrate returns of federally funded R&D (Economic Cooperation and Development Organization, 1996). Scientific research and technology development cannot be measured using a linear approach that focuses on the relationships between inputs and outputs. The quantitative analysis of publications was developed to measure the quantity and quality of research results.

Leydesdorff (2003) suggests that Triple Helix relationships can be quantified using network data. Relative frequency distributions, which can be expressed as probability distributions, are used to generate this data. Shannon's (1948) mathematical theory of communication is applicable here. According to Shannon (1948), information does not arise randomly; rather, it emerges from prior communication. Consequently, one can assess the probability of events and the level of uncertainty in outcomes. Leydesdorff (2003) proposes using co-authorship analysis with Shannon entropy as the methodology to investigate the relative

frequency distribution between triple helix sectors. He argues that interactions between/among sectoral actors result in "synergy" and reduce uncertainty within a Triple Helix system. As a result, the value of uncertainty reduction can be viewed as an indicator of the level of synergy among innovation organizations. The calculation for two- and three-dimensional transmission of uncertainty (T values) will be discussed in Chapter 4, Research Questions and Methodology.

According to Leydesdorff (1995), Triple Helix is a normative, theoretical, and analytic framework. While not originally tailored for investigating specific domains or functions, such as national systems or knowledge production, it can be adapted to explore interaction effects between domains and synergies between functions and institutions. For instance, Sun and Negishi (2010) employed mutual information and Shannon entropy to analyze the Japanese research network using the National Citation Report for Japan (NCR-J) spanning from 1981 to 2006. Their findings indicated that Japanese government agencies, universities, and industries are progressively becoming more independent or losing their interrelationships.

The primary objective of the current study is to analyze the dynamics of local and international research collaborations within Thailand, particularly with the United States and China. Additionally, this study aims to investigate how knowledge generated in different contexts and its application contribute to Thailand's sustainable economic development. To achieve this, I employ the Triple Helix model, which serves as a framework for assessing knowledge infrastructure. This model, as outlined by Chung (2014), offers insights into the interactions among local sectors in Thailand. Drawing from evolutionary economics, it helps in comprehending the intricate dynamics among various stakeholders. Furthermore, research indicates that Triple Helix synergy correlates with other indicators of economic growth (Ivanova,

2021). Hence, the framework serves as an additional tool to assess an aspect of economic development.

This model enables us to examine past and ongoing interactions from various perspectives and connect domestic networks to international collaboration. Previous studies, such as those on Triple Helix relations in Korea, Japan, Russia, and China, provide valuable insights that inform the research (Yoon & Park, 2007; Leydesdorff & Sun, 2009; Balzer & Askonas, 2016).

Triple Helix dynamic and international collaboration

The previous sections have examined conceptual frameworks that illuminate the complex dynamics driving scientific progress across boundaries. Although scholars and policymakers have extensively studied scientific collaborations, most research has treated these collaborations in isolation, with less focus on their interconnectedness. This study focuses on the reciprocal impacts of international collaboration and local Triple Helix relationships. This section reviews the literature to highlight the interplay between international and local collaborations, providing a foundation for this study.

According to Adams (2013), the evolution of science has progressed through three ages—focusing on individuals, institutions, and nations—culminating in a fourth age characterized by global-scale research conducted by elite individuals and organizations. Although both international and domestic collaborations are prevalent, they are not fully integrated. In this fourth age, the distinction between international and domestic research has become more pronounced, exacerbating the gap between countries. Nations with greater financial resources and competitive capacities can more effectively participate in and benefit

from global knowledge production, potentially hindering future research collaboration and local capacity development in less affluent countries. Consequently, developing local capacity is crucial for fostering a knowledge-based economy.

While most discussions of Triple Helix relationships focus on local collaboration, Jull Sørensen and Hu (2014) argue that the concept can extend internationally. They propose three stages of the Triple Helix internationalization process: pioneering, exploration, and integration. In the pioneering stage, each Triple Helix actor (industry, government, universities) begins to internationalize with the same sectors. Companies establish R&D partnerships abroad, universities create exchange programs and recruit international students, and governments implement policies to encourage international collaboration. In the exploration stage, partners from different sectors collaborate with their international counterparts, including industry-government (I-G), university-industry (U-I), and university-government (U-G) partnerships, or all three sectors working together across borders. In the stage of integration, Triple Helix actors from multiple countries form independent, transnational networks, operating beyond national borders.

However, the integration of international and Triple Helix collaborations is less common. Ponds (2009) examined domestic and international collaborations across different sectors using research collaborations in the Netherlands between 1988 and 2004 as a case study. The study found that while international collaborations have increased over time, the majority are between academics. Universities are critical players in international research in the Netherlands. Cross-sector collaborations are more likely to occur locally, facing challenges due to disparities in institutional norms, incentive structures, and prior experiences (Bruneel et al., 2010). Additionally, differences in language, norms, and cultures can further complicate international

collaboration. Collaborating within the same country helps overcome these issues, as shared national research systems and legal frameworks facilitate cross-sector interactions. Conversely, academic collaborations are less dependent on such systems.

Besides the barriers caused by differences between partner countries, Ponds (2009) investigates the trade balance in international collaborations to address concerns about international knowledge spillovers from public research. Edler and Boekholt (2001) examine the national and international policies of eight countries (USA, Japan, Netherlands, UK, France, Switzerland, Malaysia, and South Korea) and identify three dimensions to the internationalization of science and research: 1) International exploitation of nationally generated knowledge and technologies; 2) Scientific and technological cooperation and exchange between private and public actors; 3) Knowledge and technology generated by foreign investments.

The first dimension raises concerns about knowledge generated within nationally publicly funded research programs spilling over to other countries, resulting in asymmetric benefits from collaborations. To address this, the studied countries have implemented policy instruments to attract foreign capacity and absorb global knowledge. Measures such as building national reputations, easing immigration for foreign talent, and offering tax incentives help attract foreign researchers and firms, integrating their knowledge into national systems.

As international scientific collaboration has become more prevalent, new knowledge is produced rapidly in globalized contexts. Countries must tap into and integrate this external knowledge into their national systems. Approaches include encouraging individual collaboration through international exchange programs and education, broadly disseminating research results, and building international networks. According to van Geenhuizen (2016), effective knowledge transfer and absorption occur through frequent collaboration, interaction, and administrative

integration. Many countries adapt and exploit existing foreign structures, develop holistic perspectives through strategic dialogues, and engage in broad international networking. To maintain a balanced knowledge trade, policymakers must prioritize managing the exchanges between national academic organizations collaborating with foreign firms and foreign academic organizations collaborating with national firms.

Several studies have explored the roles of local sectors in international scientific collaboration. Choi et al. (2014) shift from a state-centric framework to examine sectoral-level international collaboration among OECD countries. They found that in less wealthy countries, governments are the primary sector engaging with international partners from wealthier nations. Conversely, universities and industries in wealthier countries are the most active in engaging with less wealthy nations. Governments of smaller countries often invite researchers from universities and industries in wealthier countries to foster collaborations and facilitate knowledge transfer. Additionally, industries in developed countries prefer to collaborate with partners in developing countries to circumvent complex regulations at home. In the knowledge-based economy, universities have increasingly become active in research collaboration. Collaborations between governments remain the most common type between non-English-speaking countries, unlike collaborations between English-speaking countries or between English and non-English-speaking countries.

Studies indicate that developed and developing countries have distinct sectors that play critical roles in absorbing foreign-produced knowledge from international collaboration and transferring it to the national system. Government agencies in developing countries often offer more sustainable financial and personnel resources, facilitating the establishment and maintenance of relationships with international partners. Similarly, private companies in

developing countries may acquire valuable know-how and technology from foreign counterparts engaged in international business. Across most countries, universities are the sector most actively involved in global knowledge production. It is at the nexus of interactions among these actors that scientific knowledge is created, transferred, and absorbed. Therefore, understanding knowledge production and the impacts of international and local collaborations necessitates careful attention to the roles and interactions of collaborative actors.

Leydesdorff and Wagner (2008) suggest that international and domestic collaboration networks operate differently. While national systems are subject to oversight and control from institutions and policies, international collaboration tends to function as a self-organizing system. Their study on the growth of the international collaboration network from 1990 to 2005 revealed that more new countries joined the global network each year, leading to a denser network with increasing collaboration attempts. The distance between networks decreased over time, indicating denser connections. The researchers likened the network's evolution to a volcano, with a widening base and a higher, steeper summit at the center.

Interestingly, while the network expanded with new countries joining, the core group of countries shrank, suggesting a more tightly ordered and self-selective group, particularly among scientifically-advanced nations. This dynamic may benefit smaller countries by providing access to the core group, while core countries gain greater access to participants from peripheral nations. Many countries have integrated international research collaboration into their national systems, prompting recommendations for policy changes to leverage global knowledge production. According to Kwon et al. (2011), accessing the global network could prompt significant changes at the national level due to inherent differences. The network effects may influence relationships between local and foreign actors, warranting further study.

Kwiek (2020) introduces the concept of "internationalists" and "locals" to examine actors in research collaborations. Internationalists engage in international projects and have international audiences, while locals generate knowledge locally and focus on solving local issues. The researcher surveyed researchers in Poland and found that internationalists are predominantly male, senior academics from hard science fields, who collaborate domestically more often and are more productive. The findings suggest that internationalists serve as important connectors between local and international systems by participating in both. Their interactions with localists, however, are not explicitly discussed in the study.

As discussed earlier, maintaining a balanced knowledge trade is crucial to prevent the international exploitation of locally generated knowledge and technologies. Researchers employ the Triple Helix model to assess how internationalization influences local research collaboration, assuming that Triple Helix synergy correlates with economic growth indicators (Ivanova, 2021) and that higher synergy levels lead to increased technology transfer rates (Mêgnigbêto, 2015; Xu et al., 2017). However, studies have observed varying impacts of international collaboration on local collaboration across different countries.

Leydesdorff and Sun (2009) used Shannon's entropy to explore how international collaboration influenced Japan and Canada. In Japan, they found that since 1995, as the country expanded its international research efforts, the local collaboration synergy weakened. This shift occurred as universities prioritized global partnerships, leading to less cooperation with local industries. However, international collaborations eventually enhanced local synergy by bridging local sectors through foreign partners, essentially creating a stronger, more interconnected research system at home. In Canada, a similar reduction in domestic synergy occurred as

internationalization took hold earlier than in Japan. As Canadian universities focused more on foreign collaboration, local government collaboration declined.

Mêgnigbêto (2015) expanded on these findings by analyzing collaboration in Korea and West Africa. Korea showed stronger local synergy compared to West Africa, but both countries exhibited more effective knowledge sharing at the global level than domestically. In Korea, international collaborations eventually enhanced local innovation systems, while in West Africa, foreign collaborations dominated, due to persistent national challenges such as underfunded institutions and slow research progress. Despite the differences between these countries, the studies highlight that while international collaborations can weaken local synergies initially, they also offer opportunities to rebuild and strengthen national systems by serving as intermediaries that reconnect local sectors. Both Mêgnigbêto (2015) and Kwon et al. (2011) highlight the potential of internationalization to enhance synergy among local Triple Helix sectors. However, they stress the importance for countries to continue investing in developing local capacities, underscoring the necessity of maintaining a balance between international collaboration and domestic capacity building efforts. Ye et al. (2013) compare China's national research system with those of other countries in the G7 and BRICS groups, revealing that nations with a stronger international orientation, such as Germany, South Korea, and the Netherlands, exhibit less synergy among local actors. Despite variations, most countries increasingly prioritize cross-border relations over time, with only a few exceptions like India. China, like many others, actively participates in the globalization movement. However, distinct patterns emerge among different nations.

Concerns about resource distribution prompt countries to prioritize either local or international collaborations. Nevertheless, scholars like Barnard et al. (2012) highlight positive

connections between local and international research collaborations. Actively engaged researchers with international partners demonstrate resourcefulness, enabling them to establish and maintain relationships at both levels without compromising resources. This proactive approach fosters active collaboration with local peers when opportunities arise.

Contrary to individualistic views, scholars such as Müller et al. (2023) and Bozeman et al. (2001) emphasize that connections with international partners constitute a form of collective social capital. The spill-over effects and personal motivations of star researchers play a crucial role in resource transfer from international to local partnerships. Simultaneously, a robust local scientific system facilitates ties with foreign counterparts, as highlighted by Allison and Long (1990) in the context of departmental effects on individual productivity.

This literature highlights key factors in understanding the dynamics between international and local collaborations. The varying roles and interactions of collaborative actors across sectors and nations require deeper investigation, especially as international collaborations grow annually. Countries may need to revise regulations and redefine roles to support these partnerships, affecting local sector interactions. Globalization's impact on collaboration dynamics differs across nations—some experience a weakening of local synergies, while others benefit from foreign partnerships. Extensive case studies across different countries, with updated data, are essential to understanding how globalization shapes scientific collaboration at both local and international levels. The preceding section examined the primary conceptual and applications of the framework utilized in this study, the Triple Helix framework. Moving forward, the next section turns the attention to the second framework, the Cycle of Credibility. This framework offers valuable insights into understanding the phenomena observed in the case

studies. By leveraging the Cycle of Credibility framework, the study aims to provide comprehensive explanations for the observed dynamics and behaviors within scientific contexts.

STS and Cycle of Credibility

The preceding sections explored the Triple Helix model as the conceptual framework for analyzing collaborations within local sectors. While I believe that the Triple Helix model is useful for identifying and exploring patterns of local and international collaborations in the case study, it falls short in providing an understanding of the motivations and strategies behind these collaborations. Quantitative patterns alone cannot fully explain why and how researchers engage in collaborative efforts.

To gain a deeper insight into the dynamics of scientific collaboration, it is crucial to view it from the researchers' perspective. Various approaches exist for understanding these strategies and motivations. After careful consideration, I chose the Cycle of Credibility as the conceptual framework to achieve this goal. This framework allows us to capture the qualitative aspects of collaboration, such as negotiation, resource exchange, and the establishment of credibility among researchers. This section discusses alternative frameworks and the rationale behind the selection of the Cycle of Credibility. By integrating both quantitative and qualitative methodologies, the analysis aims to provide a comprehensive analysis of scientific collaboration, offering a more nuanced understanding of the factors driving researchers' decisions to engage in collaborative activities.

Sociology of Science and Sociology of Scientific Knowledge

Science is often viewed as the most unbiased depiction of reality. However, social scientists and philosophers have differing views on what constitutes scientific objectivity. The

core principles of scientific objectivity suggest that scientific claims should accurately represent the world and that scientific facts should be free from values, remaining impartial and unbiased. While achieving objectivity in science is possible, it is challenging due to the complex interplay between science and social dynamics, including conflicts, power structures, and biases (Reiss & Sprenger, 2020).

The Sociology of Science explores the social contexts and impacts of science, examining social structures and processes. A key contribution to this field is Robert Merton's study of the relationship between religious affiliation and the development of modern science. Merton's work, along with his other publications, has sparked extensive discussions about institutional foundations, scientific norms, scientists' behavior, and the reward system within the scientific community (Ben-David & Sullivan, 1975).

In 1942, Merton introduced four key scientific norms: communism, universalism, disinterestedness, and organized skepticism. Communism asserts that scientific knowledge results from collective collaboration and should be shared within the scientific community (Merton & Storer, 1998). However, Merton later acknowledged the tension between this norm and the existing reward system (Merton, 1957). Expectations for rewards can divert scientists from contributing to common goods. While some attribute priority disputes to human egoism, Merton argues that these conflicts stem from institutional norms within science. The scientific institution encourages the advancement of knowledge and rewards originality. Successful scientists receive recognition, and priority acknowledgment can motivate them, while a well-structured reward system fosters scientific discoveries.

Several studies and publications in the field of science sociology discuss institution management and functions, the effects of types of organizations and management on scientists'

performance as well as the relationships between discoveries and inventions (Ben-David & Sullivan, 1975). Bourdieu (1999), for instance, posits that recognition leads to scientific authority, a form of social power granting recognized scientists the legitimacy to speak and act. He explores the impact of power and resource distribution among scientists and institutions on the scientific field's structure. In this context, citation analysis becomes a critical tool for assessing research competitiveness, priority, and equality in science. De Solla Price, a pioneer in scientometrics, advanced these methods, making significant contributions to the study of science as a social process. Bourdieu (1999) explores how the structure of scientific fields is shaped by the distribution of power and resources among institutions and scientists. He posits that there is an interaction between the structure of a specific field and the political and scientific struggles between field agents or institutions. The structure of a scientific field—including institutional strategies, resource allocation, and recognition—is also the outcome of past struggles. Merton (1973) similarly discusses how dominant systems of thought within fields influence scientists' decisions and actions. Like other professions, the norms of their respective fields significantly shape scientists' activities.

While the Sociology of Science focuses on institutional norms and rules guiding scientific methods, the Sociology of Scientific Knowledge (SSK) examines how individual scientists produce and interpret scientific truth. SSK studies how scientists' social, political, and professional interests shape their knowledge perceptions.

Knorr-Cetina (1991) contends that the sociology of science fails to understand scientific development by ignoring cognitive aspects and viewing science from an outsider's perspective. In response to criticism of traditional sociology of science, which overlooked the cognitive aspects of science, SSK emerged to integrate the internal, technical dimensions of scientific

activities with a focus on the cognitive nature of science and scientists' behaviors. A prominent branch within SSK is the Strong Program, chiefly associated with David Bloor and Barry Barnes, which posits that scientific knowledge is socially constructed. Laboratory studies, as demonstrated by Latour and Woolgar (1986), focus on the everyday practices of scientists, revealing how scientific facts are produced and controversies resolved in situ. SSK, or the Sociology of Scientific Knowledge, refers to the process of scientific knowledge production as a social construct. However, a notable weakness of social constructionism is its focus solely on scientists' social interests in resolving conflicts, often neglecting independent sets of facts and cognitive factors. I have explored two main schools of thought aimed at understanding the nature, methods, and implications of scientific knowledge, which also encompass how scientists perceive and approach scientific activities. Before delving into the Concept of the Cycle of Credibility which intersects with several schools of thought, particularly those that emphasize the social dimensions of scientific practice, it's useful to consider some additional concepts for the analysis.

Merton's four scientific norms highlight the ultimate goal of science: seeking truth for the benefit of humanity. However, science can also be viewed through an economic lens without losing the goal. Many countries implement policies to encourage scientists to pursue knowledge and uphold these norms. For example, cost-benefit analysis, an economic tool, helps identify knowledge that is particularly beneficial to humanity. Boumans and Davis (2017) argue that individual economic interests could positively drive scientific knowledge production. However, this economic pressure can also lead to competition among scientists, which may have negative consequences.

Merton (1973) suggests that humans are driven by a personal desire to do something they believe is important and beneficial to others. This egoism motivates scientists to advance scientific knowledge and make discoveries. Besides personal satisfaction, institutional recognition is a crucial motivator for scientists, as it pressures them to have their contributions acknowledged. Originality is a major concern for scientific institutions. “When this recognition of priority is either not granted or fades from view, the scientist loses his scientific property” (p. 294). Originality matters not only at the individual and institutional levels but also at the national level. Countries value originality and often claim discoveries as national property or inventions. Thus, both institutional norms and personal drive are significant factors in scientists’ lives.

Latour and Woolgar (1986) provide a detailed view of credibility within the scientific community, emphasizing that scientists gain not only recognition for their past contributions but also trust for future work. This credit, distinct from reputation, is embedded in social relationships among peers. While reputation often relates to personal characteristics like honesty and ability, as described by Bourdieu, credibility pertains to the reliability of a scientist's knowledge claims. Scientists are accountable to their peers for the validity of their assertions, which affects the broader community. Volonté (2006) supports the idea that reputation and credibility, though connected, function differently: reputation reflects personal traits, whereas credibility governs a scientist's capacity to challenge or affirm knowledge claims, playing a critical role in advancing scientific inquiry.

The Cycle of Credibility

This study adopts the cycle of credibility as a framework, proposing that the conversion of credibility resources between scientists not only demonstrates the social and cognitive factors influencing scientific collaboration but also reveals an intersection between local and

international collaborations. Recognizing that examining institutional norms and focusing solely on community activities may not be sufficient to understand scientific knowledge production, Latour and Woolgar (1986) propose the concept of the cycle of credibility and suggest using individual scientists as the unit of analysis. They investigate why scientists invest their time and energy in pursuing knowledge and found that while scientists strive to adhere to scientific and institutional norms, some, particularly early-career scientists, view their work from an economic standpoint, seeing their efforts as investments expecting returns. The Cycle of Credibility is a valuable analytic tool for understanding modern science because it incorporates an economic model of fact production.

Other scholars have attempted to use economic analogies to describe scientists' behaviors but have failed because exchanges in the laboratory are less tangible than market transactions and usually not directly related to money. Additionally, the relationship between scientific norms and scientific exchange can be contradictory. For instance, Bourdieu (1999) views scientific norms as the result of social activities rather than their cause. He suggests that the social activities of the scientific community are shaped by strategies used by scientists to maximize their symbolic profits. However, early attempts to apply economic concepts to scientific activities did not account for the epistemic content of science or the understanding of value creation. They also neglected the motivations that drive scientists to recognize others at their own expense.

Scientists require various resources, such as information and arguments, to complete their projects. The interactions of supply and demand determine the value of these resources, and their value can change based on availability, the number of people involved, and the resources required for production. When deciding on research topics, methods, and collaborators, scientists

consider the potential returns on their investment. This economic perspective provides a comprehensive understanding of the motivations and behaviors driving scientific knowledge production.

Latour and Woolgar (1986) suggest that credit in the scientific community functions like a commodity that can be exchanged, shared, and even stolen. Scientists can accumulate or waste their credit depending on various circumstances. The authors distinguish between credit and credibility in their analysis. Credit refers to the formal recognition given to researchers for their contributions and past accomplishments, often quantified through metrics such as citations, awards, and authorship in publications. On the other hand, credibility is more about the trustworthiness and perceived reliability of a researcher within the scientific community. It involves the recognition of the scientist's expertise, integrity, and ability to produce high-quality, reproducible research. Credibility is the recognition of one's potential to produce future knowledge. Volonté (2006) supports this distinction, noting that the credibility of knowledge claims is directly linked to the credibility of their producers. If a claim fails to gain the scientific community's trust, the scientist's credibility suffers. Conversely, researchers invest their credibility to establish the trustworthiness of new knowledge in the eyes of the public. This process means that credit can be granted even before the validity of claims is verified, making credibility an indispensable currency for scientists.

As debates between sociologists of science and sociologists of scientific knowledge continue over the criteria for examining scientific knowledge production, the cycle of credibility responds to both. Credibility encompasses both economic concepts (such as money, budget, and payoff) and epistemological concepts (such as certitude, doubt, and proof). It applies to both the cognitive aspects crucial in scientific research and the external factors influencing scientific

activities, such as institutions, finance, and policies. Latour and Woolgar (1986) argue that the concept of credibility can be applied to various areas, including scientific investment strategies, epistemological theories, the scientific reward system, and scientific education. Credibility captures the complexities of scientific knowledge production by considering not only the content of knowledge claims but also their reliability over time. This reliability is an ephemeral attribute that can change based on the social dynamics within the scientific community. Furthermore, Volonté (2006) emphasizes that acquiring credibility involves both the cognitive aspects of knowledge and the consistency of scientists and their claims within the community. Credibility, thus, reflects the intricate interplay between the content of scientific knowledge and the social context in which it is produced and validated.

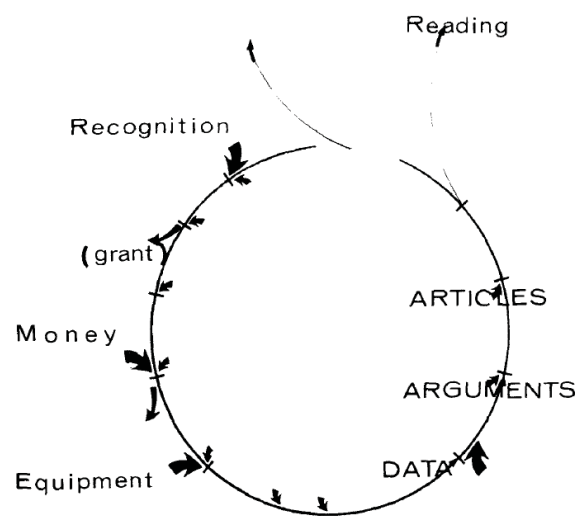
According to Latour and Woolgar (1986), a more precise characterization of scientists is as investors rather than mere seekers of rewards. Drawing from ethnographic observations of a neuroscience laboratory in California, Latour and Woolgar (1986) outline a credibility cycle that demonstrates the dynamic interplay between money, data, prestige, credentials, and research focus (figure 7). Scientific progress emerges from the ongoing cycles of transformation involving different forms of credibility. For instance, scientists adeptly convert recognition into research funds or grants, those funds into essential equipment and skilled staff, and subsequently utilize these resources to generate data and refine research inquiries, ultimately culminating in the dissemination of findings through publications.

Latour and Woolgar (1986) describe scientific reputation or credibility as currency received when others recognize and cite their work. It serves as both a reward and a motivation for researchers to invest in research projects. Scientific credibility can be earned in a variety of ways as a result of previous investments. Credibility sources can be converted into other forms,

resulting in a cyclical process. Scientists' credit or resources are spent during negotiations or convincing to validate a knowledge claim.

Figure 7

Conversion between different types of capitals



Note. From Latour and Woolgar, 1986

In the cycle of credibility, resource exchanges and knowledge production intertwine and cannot be separated. Measuring the return from investing resources owned by scientists is not straightforward. “The success of each investment was evaluated in terms of the extent to which it facilitated the rapid conversion of credibility and the scientist's progression through the cycle” (Latour and Woolgar, 1986, p. 207). Aside from the intensity of capital circulation, the model can support different types of motivation, such as obtaining tenure, assisting humanity, or creating new knowledge.

Many factors must be considered to understand scientists' behavior in capital circulation, including scientists' positions such as postdoctoral fellows or tenured professors, field situations such as the nature of the problem being addressed and the methods used, and geographical locations. These factors are interdependent and influence how scientists evaluate investment and return on investment (Latour and Woolgar, 1986).

Hirsch's (1976) exploration of the positional economy provides key insights when applying economic principles to science. Positional goods range from precious metals like gold to real estate and luxury items, as well as intangible assets such as social status and job positions. Their value increases with scarcity and desirability, shaped by cultural norms. Positional competitions occur in hierarchies, where winners enhance their status at the expense of losers. This competitive landscape can be affected by privatization, which may disadvantage the poor without safeguards for public benefits, highlighting the need to shift from private to communal sectors. In the scientific realm, the Matthew effect—where "the rich get richer"—illustrates disparities in success distribution, highlighting not only the existence of these inequalities but also their persistence as artifacts of the reward system that disproportionately favors established researchers and their achievements. The dynamics of this positional economy influence collaborations, especially when unequal partners compete for data or resources, making it crucial to understand how credibility is converted in these interactions.

Bourdieu (1999) argues that scientific authority, like authority in other realms, is not only shaped by epistemological concerns but also by political interests and conflicts. Merton and Storer (1998) suggest that once scientists receive expected rewards, their focus may shift from seeking recognition to advancing knowledge. Scientists anticipate some profit from their investments. The more important the problems they are solving are, the greater the symbolic

profit they gain (Bourdieu, 1999). This can pose challenges for new entrants, as the accumulation of scientific resources by established scientists raises the barriers to entry (Bourdieu, 1999). Volonté (2006) observes that scientists at different career stages exhibit distinct behaviors, with resources often tied to scientific authority. Bourdieu (1999) characterizes scientific authority as a form of social capital that confers power over the field's mechanisms, convertible into other forms of capital. These dynamics engender different strategies for established and emerging scientists. Those starting out may opt for a cautious approach, confining themselves to established territories for predictable gains, or take a riskier path, innovating to redefine dominant legitimizing principles. Additionally, Merton and Storer (1998) note that scientists perceive awards differently at various career stages.

Bourdieu (1999) posits that the unique structures and circumstances within various scientific fields engender diverse audiences, social dynamics, and competitive landscapes among scientists. Varied epistemic cultures and collective beliefs across disciplines shape the selection of problems, methodologies, and solutions, as well as operational and institutional frameworks (Knorr-Cetina, 1999). This systemic influence extends to researcher interactions, training, resource accessibility, and publication avenues. Analyzing social interactions within scientific domains proves insightful, as they reflect diverse struggles among agents for different forms of capital. The Cycle of Credibility framework elucidates how individual scientists or research groups' behaviors are shaped by their pursuits of reputation and rewards (Hessels et al., 2009; Latour & Woolgar, 1986). Moreover, Merton and Storer (1998) argue that varied reward systems contribute to the class structure of science by offering a stratified distribution of opportunities for scientists to enhance their roles as investigators. Thus, the study aims to explore the mechanisms of credibility conversion across different scientific disciplines. By conducting comparative

analyses, I seek to elucidate how distinct components within each discipline influence scientists' valuation and strategic management of credibility exchanges.

Wouters (1997) proposed a connection between the cycle of credibility and the cycle of citations, highlighting the evolution of scientometrics and citation databases into potent analytical tools. According to the credibility cycle, citations hold significance as they can be transformed into various forms of credibility, particularly resources crucial for advancing further research. Several studies utilize co-authored citations to symbolize collaborative efforts facilitating the conversion of credibility resources.

However, Hessels et al. (2019) point out a limitation of the credibility cycle, noting its exclusive focus on the motivations and behaviors of individual researchers, neglecting the structural dynamics of social communities and collective principles of order. Moreover, the concept's scope is confined to credibility accumulations, overlooking the myriad other goals scientists pursue in advancing scientific knowledge. The researchers propose integrating the collective ordering principle of institutions into the analysis and utilizing the cycle of credibility as a model to delineate the stages researchers navigate throughout their careers.

Despite its limitations, the cycle of credibility has proven useful in aiding researchers' understanding of scientists' behaviors and decisions. Numerous studies have leveraged this concept to shed light on various aspects of academic research. For instance, Packer and Webster (1996) suggest the inclusion of patents as a source of credibility, expanding the scope of the credibility cycle. Hessels et al. (2009) utilize both the cycle of credibility and the science-society contract to delve into the manifestation of 'relevance' in academic research's daily practice. By combining the two concepts, they can learn about the interactions between external pressure and internal attributes of science. Similarly, Hansen (2020) employs the credibility cycle as an

analytical lens to investigate the role of different types of academic events in career advancement. His findings reveal both similarities and differences in credibility cycle conversions across various event types, influenced by informants' seniority and disciplinary differences (figure 8). Early-career academics perceive these events as steppingstones toward advancement, while senior academics strategically select events based on their career goals and expectations. Furthermore, Hansen suggests incorporating networks as another form of credibility, emphasizing their significance in academic research. These studies underscore the versatility and utility of the credibility cycle as a framework for examining the complex dynamics of scientific practice and career progression.

Figure 8

Capitals conversions in different settings

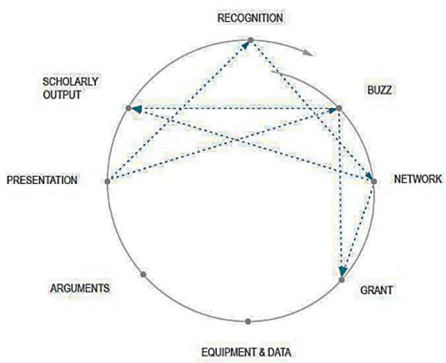


Figure: 6.2: Conversions at congresses

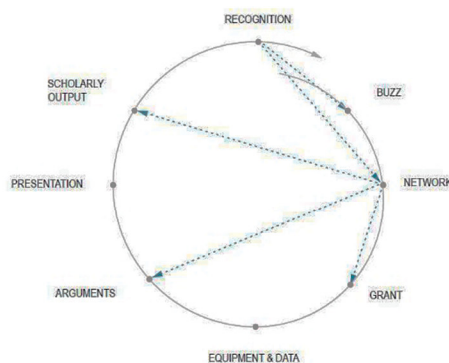


Figure 6.4.: Conversions at symposia

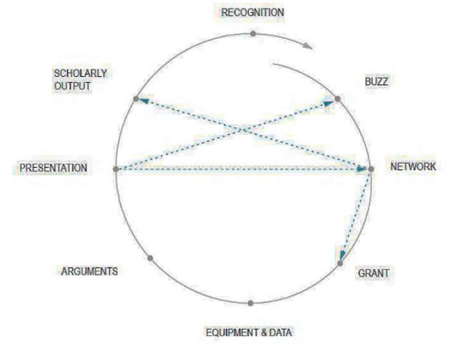


Figure 6.5: Conversions at practitioners' meetings

Note. From Hansen (2020)

The cycle of credibility can be a valuable framework for understanding the drivers of collaboration among researchers, encompassing intellectual, social, and economic motivations.

This concept elucidates the motivations behind collaborative activities and the extent to which international collaborations confer credibility that can be reinvested in future research. For instance, Wagner (2008) highlights that some scientists seek international partnerships to gain additional resources and prestige.

I chose the Cycle of Credibility as the conceptual framework because it offers a unique lens to explore the motivations, drivers, and outcomes of scientific collaboration, such as understanding what researchers gain or lose through their efforts. While typically applied in the context of laboratory science, the Cycle of Credibility can be extended to analyze collaborative activities on a macro level, encompassing diverse partners and countries. This study employs the Cycle of Credibility to examine the expanding landscape of scientific collaboration. I conceptualize the cycle within individual and institutional environments, allowing us to compare the dynamics of credibility conversion across various scientific fields. According to Whitley (1983), numerous studies have shown that scientists, like actors in other domains, are influenced by external factors. However, there is a need for a closer examination of how scientific knowledge is generated and the interplay of these external factors in this process. This approach helps us understand the intricacies of scientific collaboration and the factors that drive researchers to engage in such activities.

Similar to Hessels et al. (2019), this study delves into the credibility economy across different scientific fields, exploring how scientists assess and trade various facets of knowledge production and the underlying mechanisms driving these conversions. The researchers propose extending the cycle of credibility to scrutinize research groups, asserting that these groups operate based on the same principles observed at the individual level. Hessels et al. (2009) emphasize the pivotal role of institutions at each stage of the cycle. Credibility conversions are

not isolated events occurring solely among scientists; they are shaped by the support and limitations imposed by institutions, including universities, organizations, and funding bodies. These entities significantly influence the exchange rate of diverse forms of credibility. Furthermore, non-scientific actors like industry and government intersect with specific points in the cycle. The dynamics of the credibility cycle may evolve with changing social norms and values. For example, the importance of patents as a form of credibility has increased in recent decades (Packer & Webster, 1996).

This study investigates six dimensions of credibility, examining various aspects within each dimension: data (e.g., data types, collection processes, valuation, and decision-making), arguments (e.g., generation of arguments), publications (e.g., labor division, negotiation between collaborators), recognitions (e.g., diverse outputs and recognitions), funding (e.g., sources, management), and staff and equipment (e.g., labor division). In addition to using co-authored citations as a proxy for credibility accumulation in the cycle, I employ semi-structured interviews with researchers and policymakers. This approach allows us to gather insights into the heterogeneous components of the scientific enterprise across different disciplines, facilitating an exploration of credibility conversions and their impact on real-world scientific knowledge production.

In the following chapter, I delve into the quantitative and qualitative methodologies employed in this study. I provide a comprehensive overview of the utilization of Leydesdorff's mutual information to investigate the synergy of local collaboration, outlining the approach to applying this method to analyze the relationships between local and international collaboration. Additionally, I detail the qualitative interviews conducted to acquire insights from researchers and scientists. These interviews offer invaluable perspectives that deepen the understanding of

the observed relationships, enriching the analysis with nuanced insights from those directly involved in scientific collaboration.

Chapter 4

Research Questions and Methodology

Advancements in science and innovation are pivotal for economic growth. Thailand, once an economic tiger, has faced economic challenges in recent years. Despite achieving upper-middle-income status, Thailand struggles to transition to a high-income country. To address this, the Thai government has launched programs focused on promoting scientific collaborations.

There is no singular solution for enhancing a country's economic prospects but establishing robust local and international networks is crucial. Scientific collaboration, widely practiced and promoted by many nations, has been proved to enhance scientific capabilities. Taylor (2016) found that relying solely on domestic or international networks is insufficient; strong connections among local entities and foreign partners are essential. According to the study, there exists a potential interplay between local and international networks.

Our investigation examines the complex dynamics of scientific collaboration, focusing on the interconnections between international and local partnerships. I aim to explore these connections through mutual information analysis within the Triple Helix framework. In the quantitative study, I use publications categorized by countries and sectors within Thailand as units of analysis, focusing on unraveling the relationships between international and local collaborative research activities.

Our first research question is:

RQ1: What are the connections between local and international research collaborations, with a comparative analysis of Thailand, the United States, and China?

Quantitative analysis helps us explore the patterns and connections between local and international scientific collaborations. By examining mutual information values and co-authorship citations, I can better understand the dynamics of scientific collaboration and its impact on the research landscape. To understand the factors shaping these relationships, I find the concept of the credibility cycle valuable. This cycle involves various resources that boost researchers' credibility and provide resources for future research endeavors. Each source of credibility aligns with institutional objectives and personal benefits. I anticipate identifying a connection between local and international research collaborations, where credibility cycles intersect, and expect that, at certain points, credibility resources from one level could bolster the other.

Hence, the second research question is:

RQ2: How do social factors and strategic considerations influence the pursuit of scientific collaborations?

I employ a comparative study focused on Thailand and its collaborations with the United States and China to observe phenomena within their unique contexts. Recognizing the challenges of generalization due to the distinctiveness of each case (Boumans & Davis, 2017), this study does not aim to offer a universal explanation for the entire system or provide recommendations applicable to all cases. As highlighted by Taylor (2016), no universally effective set of institutions or policies has been developed that guarantees consistent outcomes across countries and time periods. While an analysis of aggregate data provides a comprehensive overview, a case study approach allows for country-specific insights. The intent is not to propose a one-size-fits-all solution but to let the data narrate the story of Thai science and its collaborations with two

key partners. The aspiration is that these findings can exemplify how scientific networks impact a nation's science, particularly in the context of developing countries.

An essential aspect of science involves the interactions among diverse stakeholders, including scientists, policymakers, and the general public. Beyond insights derived solely from scientific research, comprehending the human collaboration element of science necessitates knowledge from disciplines such as anthropology, psychology, sociology, and others (Merton & Storer, 1998). The integration of data from both quantitative and qualitative methods in this study aims to offer comprehensive insights. The goal is to provide policy recommendations grounded in research that can effectively address practical challenges in scientific collaboration.

Methodology

To answer the research questions stated above, this study employs a mixed-methods approach, integrating both quantitative and qualitative research. As highlighted by Schoonenboom and Johnson (2017), mixed-methods research serves various purposes. In this study, I use qualitative research to elucidate and complement the findings from the quantitative analysis, provide contextual understanding, and offer a more nuanced illustration of the quantitative data. This research adopts a quantitative-dominant mixed-methods approach, where the analysis is primarily anchored in the results derived from the quantitative data.

Quantitative Study: Co-Authorship Analysis

Various methods are available for assessing research outcomes, with economic analysis often relying on metrics like gross input and gross domestic product (GDP). While these measures effectively quantify returns for private sector research and development (R&D) activities, they may fall short in capturing the broader spectrum of returns from R&D initiatives,

especially those funded by multiple sectors or social sectors, such as federally funded R&D projects (U.S. Congress, OTA, 1986). According to Price (1963), scientific publications before the nineteenth century were primarily limited to books, monographs, and letters. However, scientific papers evolved beyond mere carriers of information to become announcements of new knowledge and discoveries. Researchers began using scientific publications not only to disseminate information but also to claim and reserve knowledge for themselves. This shift led to the quantitative analysis of publications as a method for assessing both the quantity and quality of research outcomes.

Derek de Solla Price played a pivotal role in developing and popularizing bibliometrics, which has since become a valuable tool for informing policy decisions. This shift has spurred increased collaboration and competition among researchers, driven by the desire to publish quickly, build a strong reputation, and secure resources. Given the reliance of scientific research on public funding, policymakers face the critical task of effectively allocating resources. They must decide on the appropriate level of government expenditure on basic research, how to distribute resources across different disciplines or research centers, and other related considerations.

Martin and Irvine (1983) argue that measuring scientists' contributions to scientific knowledge is complex, as researchers are often confronted with only partial indicators. To effectively use citations as a metric, they emphasize the need for selective sample selection, comparing "like with like," and utilizing multiple indicators. This approach acknowledges the nuanced nature of scientific impact and highlights the importance of comprehensive and discerning assessment.

Our focus on studying scientific collaboration stems from recognizing the critical role of scientific knowledge and innovation in driving a nation's economy in a knowledge-based society. As Jaffe and Trajtenberg (1998) highlight, knowledge creation and retention occur at the individual or organizational level, with the exchange and dissemination of ideas contributing to knowledge flows that are challenging to measure due to their abstract nature. Some argue that certain knowledge-intensive products, like patent citations, can serve as 'windows' providing insights into knowledge flows. Similarly, co-authored publications can be considered a proxy for research collaboration and knowledge exchange among researchers from diverse organizations and countries. Merton (1973) notes that variations in publication numbers within specific fields reflect the evolving interests and developments in those disciplines.

As delineated by Moed (2010), citation data can be used for five main functions. First, it examines the contributions of various entities within the scholarly system to the advancement of knowledge. Second, it analyzes characteristics of the scholarly system, including globalization, collaborations, and interdisciplinary research. Third, it maps the structure of scholarly or technological fields using techniques like co-word and co-citation analyses. Fourth, it combines data on scientific publications and patents to assess science's contributions to technological and economic development. Lastly, it measures the impact of scientific research on education, society, and culture.

Our study aligns with the first and second themes. Using co-authorship analysis, which is a part of citation analysis, I aim to investigate the evolving roles of various sectors in Thailand and other nations in the production of scientific knowledge through collaborative research. Additionally, I explore the Triple Helix model, examining its role in contemporary research systems and its connections to international research collaboration. I anticipate that the findings

will offer valuable insights into the contributions of specific participants within the research system and provide a snapshot of the current research landscape.

To understand the dynamics and evolution of collaborative landscapes, researchers employ various tools, such as absolute figures, percentages, and relative metrics, to assess scientific activities. While some studies focus solely on output, others examine both inputs and outputs. This diversity in tools, methodologies, and interpretations can lead to varying results. For example, Beaver and Rosen (1978) used citation analysis to compare the scientific outputs of specific countries, assessing their size and impact. In contrast, Chinchilla-Rodríguez et al. (2009) used publication outputs to measure each country's scientific volume and impact, the extent of collaboration networks, and the national capacity for receiving or transmitting scientific contributions.

Co-authorship analysis is a bibliometric method used to study the collaborative patterns and structures among researchers, institutions, or countries by examining co-authored publications. This type of analysis involves identifying and analyzing the relationships and networks formed through joint authorship on scientific papers. By tracking who is publishing with whom, co-authorship analysis reveals the extent of collaboration, the strength of partnerships, and the impact of collaborative efforts on scientific output (Leydesdorff & Etzkowitz, 1995; Ye, Yu, & Leydesdorff, 2013). Since the 1990s, co-authorship has become a common metric for studying scientific collaboration (Chinchilla-Rodríguez et al., 2009). The trend of increasing multi-authored works, which began in the late 1950s, serves as a proxy for researcher collaborations. From the 1970s onwards, researchers such as Sun & Negishi (2010), Park et al. (2016), and Kim & Park (2015) have increasingly applied social network theories to investigate networks among scientists and communication patterns in various fields. Park et al.

(2016) examined international social networks at the international and institutional levels by analyzing publications co-authored between China and Korea in 2014. They employed three counting approaches: binary matrix, valued matrix (integer counted), and fractionally counted matrix. Using social network analysis metrics like density, degree centralities, H-Index, and average distance, they found that different counting methods produced varying results. This study highlighted the importance of considering methodological differences when comparing countries' scientific dimensions, such as size and resources, in the context of international collaborations. Information science facilitated the use of graph methods for clustering, density, and distance mapping of scientific networks.

Coauthor analysis is a valuable tool for exploring collaborations at sectoral levels. Many studies use institutional co-authored publications to scrutinize Triple Helix relations and their evolution at the country level, as demonstrated by Ye et al. (2013). Other research uses coauthorship network studies to examine the culture of specific collaboration networks, such as the work by Kim and Park (2015). Additionally, Sun and Negishi (2010) investigated the Japanese research network using the National Citation Report for Japan (NCR-J) from 1981 to 2006, employing methods like mutual information and Shannon entropy. Leydesdorff developed a method for examining Triple Helix relations, as outlined in his work (Leydesdorff, 2003). The development of a dynamic knowledge base results from nonlinear interactions between network actors. Leydesdorff and Etzkowitz specify university-industry-government relations as instantiations of Triple Helix dynamics of a knowledge-based economy. Networks can be represented as relative frequency distributions which can be written as a probability distribution. Therefore, the relations between university-industry-government can be written as probability distributions. According to the attribute, Leydesdorff (2003) suggests using Shannon's

mathematical theory of communication to examine triple relations between three variables. Shannon's entropy can be used to calculate the uncertainty of a single variable as well as the dependence or mutual information of two or more variables.

Shannon's entropy is particularly useful in examining Triple Helix relations for several reasons. First, it measures the interactions among variables in a system using three-dimensional transmission, capturing configurational information that arises from systemic network effects rather than individual contributors or their relations. This results in calculating the magnitude and sign of the probabilistic entropy generated by the interactions within the complex system. Second, these indicators enable the quantification of the synergy impact between institutional networks (subsystems) at the national level (overlay system). Third, as Leydesdorff (2003) highlights, the synergy between innovation actors cannot be recognized by simply analyzing publication numbers or growth data. Lastly, these indicators present the synergy of the networks in terms of probability distributions at each moment in time, allowing for an evaluation of their dynamics. The algorithmic indicators of mutual information in three dimensions facilitate the comparison of the current state of the Triple Helix configurations under study.

To calculate mutual information between three variables, I first calculate the self-information of a single variable. According to Shannon, information is related to uncertainty. Information quantifies surprise or the amount of uncertainty we overcome. The more information we have, the greater the uncertainty or entropy. Shannon's entropy measured in bits is a measure of the unpredictability of a variable using the formula:

$$H(X) = \sum_{i=1}^n P_i \log_2 P_i$$

Here:

- $P(x_i)$ is the probability of the i -th value occurring,

\log_2 is the base-2 logarithm

The resulting entropy value is measured in bits. Higher entropy values indicate greater uncertainty or information content, while lower values suggest more predictability or less information. In the context of Leydesdorff's method for examining Triple Helix relations, the entropy calculation is frequently employed on relative frequency distributions of essential elements in a network. This aids in quantifying the diversity or distribution of these elements.

Our primary interest lies in understanding the interactions between sectoral actors within a Triple Helix system that result in "synergy" and reduce uncertainty. This reduction in uncertainty can serve as an indicator of the level of synergy among innovation organizations. Leydesdorff (2003) develops the concept of transmission of uncertainty (transmission T) using Shannon's entropy to calculate the probability distribution across two dimensions, such as in university-government (UG) or university-industry (UI) relations. In a two-way interaction, knowing the value of one variable helps reduce the uncertainty about the other. We can quantify the remaining uncertainty about the value of X after gaining information about the value of Y. The T value represents this remaining uncertainty, or the difference in uncertainty when two probability distributions are combined. The formula for this is as follows:

$$H(X, Y) = - \sum_i \sum_j P(X_i Y_j) \log_2 P(X_i Y_j)$$
$$T(ui) = H(u) + H(i) - H(ui)$$

Where:

- $H(X)$ is the entropy of X,
- $H(Y)$ is the entropy of Y,
- $H(X, Y)$ is the joint entropy of X and Y.

The transmission T thus provides a measure of how much knowing one variable reduces the uncertainty about the other, reflecting the level of synergy between the two interacting variables within the Triple Helix system. A higher T value indicates a greater reduction in uncertainty, which implies stronger synergy between the sectors. It means that the activities in one dimension are more strongly correlated or influenced by the activities in the other dimension.

On the other hand, when considering three-dimensional mutual information (e.g., involving university, industry, and government simultaneously), a higher t value may suggest less synergy. This is because a higher value suggests that the joint information between all three variables together is less than what would be expected from the sum of the joint information between each pair of variables separately. Essentially, it implies that there is not much redundancy or overlap in the information provided by the three dimensions, which could signify less effective collaboration among university, industry, and government.

The calculation for three dimensions is:

$$T(XYZ) = H(X) + H(Y) + H(Z) - H(XY) - H(YZ) - H(XZ) + H(XYZ)$$

When the interfaces of all variables interact, the system can be considered a hypercycle or a self-organizing system, as the diverse transmissions are no longer centralized in a single

location. A negative three-dimensional entropy indicates that the overlay system imparts information to the carrying systems, thereby reducing uncertainty in the present. Lower T values suggest a more self-organized system, where subsystems exhibit greater integration. Conversely, higher T values signify a more centralized system.

The optimal or "good" number of T values that indicate strong synergy can vary based on the specific context and data being analyzed. There is not a universally fixed or standard number of T values considered ideal, as it depends on the characteristics of the data and the desired level of detecting synergy in a specific context. We can examine and compare the T values of various variables, noting that higher T values in two-dimensional mutual information suggest enhanced synergy between two sectors. In contrast, higher T values in three-dimensional mutual information imply lower Triple Helix synergy.

The configurations of the three helixes represent national systems, which can vary significantly between countries and cultures. For example, academic systems in European countries tend to be more traditional compared to those in the United States and Japan, where universities continue to play a central role in their research systems. Many studies suggest that countries with higher three-dimensional synergy often experience more substantial rates of technology transfer (Mêgnigbêto, 2015; Xu et al., 2017). This characteristic is significant for the current study as it allows us to compare Thailand's Triple Helix relationships with those in the United States and China, as well as across different disciplines.

Materials and calculation. In line with the recommendation by Park et al. (2016), co-authorships serve as a viable proxy for assessing collaborative research outcomes in this study. The analysis centers on data extracted from co-authored publications spanning the period of 2007 to 2022, encompassing collaborative efforts between Thailand and the United States,

China, as well as various local sectors in Thailand over a 16-year timeframe. While multiple citation database sources exist, including alternatives such as Scopus (Guerrero Bote et al., 2012), International Scientific Indexing (ISI) (Luukkonen et al., 1993), Web of Science (Ye et al., 2013; Choi et al., 2014), Google Scholar, and local databases, I have opted for Scopus. The following outlines the rationale behind the selection of Scopus.

Scopus, a product of Elsevier, is renowned as a major scientific literature database, encompassing an extensive array of journals. The initial investigations indicate that Scopus offers the highest number of search results, ensuring a more comprehensive dataset. Notably, Scopus is highly accurate, as supported by Gusenbauer (2019) and Gusenbauer & Haddaway (2020). While Scopus provides significant advantages, it is important to acknowledge certain limitations, such as its suboptimal coverage of social sciences and humanities, and publications in non-English languages (Aksnes & Sivertsen, 2019). However, since this research primarily focuses on scientific and technology-related fields, these limitations are unlikely to affect the accuracy of the study. Additionally, given the dominance of English in scholarly discourse in all fields, the potential language barrier is mitigated. Scopus offers query functionalities that enable country-based filtering, a feature absent in platforms like Google Scholar. Due to technical constraints, this study did not incorporate Thailand's domestic journals and data sources. While Thai local sources permit keyword-based searches, they do not facilitate filtering publications based on organization type or participant country. Considering these factors, I have opted to use Scopus citation data.

Melin and Persson (1996) outline several considerations for utilizing co-authorship data. This type of data can be aggregated at various levels, including countries, cities (regions), organizations, groups of scientists, or individuals. It offers the opportunity to investigate

collaborations both on national and international scales. Co-authored articles can be categorized and interconnected for network analysis. In this research, I leverage co-citation data at the country and organizational levels to delve into Thailand's national and international collaborations.

In addition to aggregating co-authorship data at national and international levels, I extend the analysis to discipline-based aggregation to offer valuable insights into collaboration dynamics. Perianes-Rodríguez et al. (2011) investigated collaborations among major companies in Spain by assessing the number of publications in various disciplines across different sectors and identifying the involved companies. Similarly, Hessels et al. (2009) explored the credibility cycle of academic chemistry in the Netherlands, highlighting that each scientific discipline has unique subjects, areas of interest, participants, training methods, and modes of communication.

In this study, I will examine the quantity and trends of research collaborations at both the national and discipline levels, focusing on three distinct disciplines. Conducting a comparative study at the discipline level may reveal diverse manifestations of the credibility cycle, providing a more nuanced understanding of collaboration dynamics across different fields.

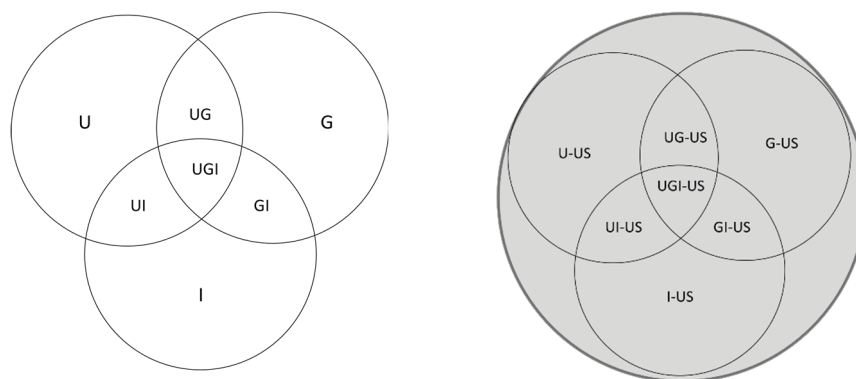
To complete the tasks, we classified the affiliations' addresses of each publication into three collaborative settings:

1. Thai domestic publications (articles published exclusively by Thai institutions, excluding publications affiliated with international partners),
2. Thai-F co-authored publications (articles co-authored by Thai and international institutions),
3. Thai-US co-authored publications (articles co-authored by Thai and U.S. institutions without Chinese institutions' involvement),
4. Thai-China co-authored publications (articles co-authored by Thai and Chinese institutions without U.S. institutions' involvement).

This section demonstrates how to calculate mutual information using co-publication data to answer the research questions in this study. I calculate the mutual information for the three-dimensional relationships among local universities, government, and industry across various collaborative landscapes, including domestic, international, Thailand-U.S., and Thailand-China collaborations. Mutual information indicators, which present the conditional relationships between sectors, can be used to compare different contexts. This allows us to compare the synergies between partners in different disciplines or to compare the synergies of local sectors engaged in local collaborations (Figure 9 left) with those involved in international collaborations such as with the United States (Figure 9 right)

Figure 9

Triple Helix synergies between university, government, and industry in local (left) and International Collaborations (right)



I specifically focus on the "articles" document type to concentrate on research collaboration activities, excluding letters, editorials, comments, and other document types. This deliberate narrowing of the scope aligns with the research objectives and facilitates a more

manageable data size for analysis. The following steps outline the process of gathering data from Scopus:

1. Thai Domestic Publications:

- Initiate a search for documents with "Thailand" as the affiliation country.
- Exclude other countries from the results.
- Restrict the time period to 2006-2022.
- Specify "article" as the document type to obtain Thailand's domestic publications.

2. Thai-US Co-authored Articles:

- Conduct a search for documents with both "Thailand" and "United States" as the affiliation countries.
- Exclude documents involving Chinese affiliations.
- Limit the time period to 2006-2022.
- Choose "article" as the document type to retrieve co-authored articles between Thailand and the United States.

3. Thai-China Co-authored Articles:

- Execute a search for documents with both "Thailand" and "China" as the affiliation countries.
- Exclude documents with affiliations from the United States.
- Set the time period to 2006-2022.
- Choose for "article" as the document type

To obtain the citation and bibliographical information of the articles, Scopus permits the export of information for a maximum of 2,000 documents at a time in CSV format.

Consequently, the export process needs to be iterated multiple times, and the files must be

merged by year. Presented below are the initial findings that informed the decision in selecting case studies for the research:

Table 1 and Figure 10 illustrate the quantity of co-authored publications between Thailand and its top ten partner countries, including the United States, Japan, England, China, Australia, France, Germany, India, South Korea, and Malaysia. There is an upward trend in the number of co-authored articles with all ten countries. Specifically, I focused on the United States and China due to their prominence: Thailand and the United States boast the highest number of co-authored publications, while Thailand and China exhibit the highest annual growth rate (AGR) after India, albeit with a substantially higher publication count. Analyzing Table 2 and Figure 11, the proportions of Thai domestic and international articles (excluding the United States and China) have shown no significant changes from 2006 to 2022.

Table 1. The number of co-authored articles between Thailand and the top ten partner countries

	Total	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	CAGR
USA	23441	724	806	870	890	931	1008	1111	1203	1322	1463	1614	1684	1791	1826	1909	2123	2166	0.07
Japan	14509	461	492	573	584	607	641	692	739	751	841	953	976	1021	1074	1309	1461	1334	0.07
England	11853	271	284	292	317	377	417	476	548	618	710	820	850	1023	994	1144	1371	1341	0.11
China	10411	80	101	154	154	185	200	236	377	478	543	720	656	815	940	1229	1555	1988	0.22
Australia	8105	175	213	261	283	317	369	379	389	404	489	519	535	623	653	710	911	875	0.11
France	5861	81	105	125	186	197	198	228	317	358	415	453	490	502	542	557	560	547	0.13
Germany	6115	96	152	162	149	158	214	231	316	346	394	478	435	541	516	595	664	668	0.13
India	7632	72	85	112	108	128	169	173	259	318	397	553	551	695	732	1036	961	1283	0.20
S. Korea	5186	56	60	93	84	91	135	133	212	255	296	413	432	515	518	665	574	654	0.17
Malasia	5384	82	109	109	111	148	151	185	191	231	322	348	394	492	476	574	635	826	0.16

Note. Data extracted on 5/20/2023

Table 2. The number of Thailand's different types of co-authored articles

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
All Thai publications	4399	4904	5519	6263	6829	7534	8404	8725	9357	9893	10974	11509	13323	14440	16802	20055	22852
Thai Domestic Pub	2342	2615	2962	3550	3886	4383	4961	5023	5303	5503	6072	6341	7548	8059	9324	11033	12636
Thai Inter Pub	2,057	2,289	2,557	2,713	2,943	3,151	3,443	3,702	4,054	4,390	4,902	5,168	5,775	6,381	7,478	9,022	10,216
Thai-US (no China)	706	781	829	843	887	954	1038	1049	1121	1227	1318	1398	1462	1495	1559	1735	1761
Thai-China (no US)	62	76	113	107	141	146	163	223	277	307	424	370	486	609	879	1167	1583
Thai-US-China	18	25	41	47	44	54	73	154	201	236	296	286	329	331	350	388	405
Thai Inter (no US/CH)	1,271	1,407	1,574	1,716	1,871	1,997	2,169	2,276	2,455	2,620	2,864	3,114	3,498	3,946	4,690	5,732	6,467

Note. Data extracted on 5/20/2023

Figure 10

Numbers of co-publications between Thailand and the top 10 partner nations

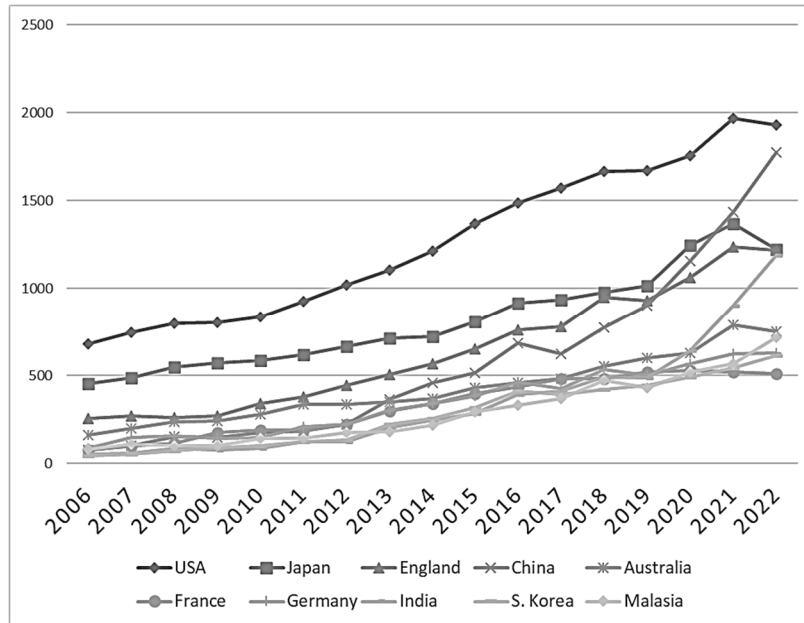
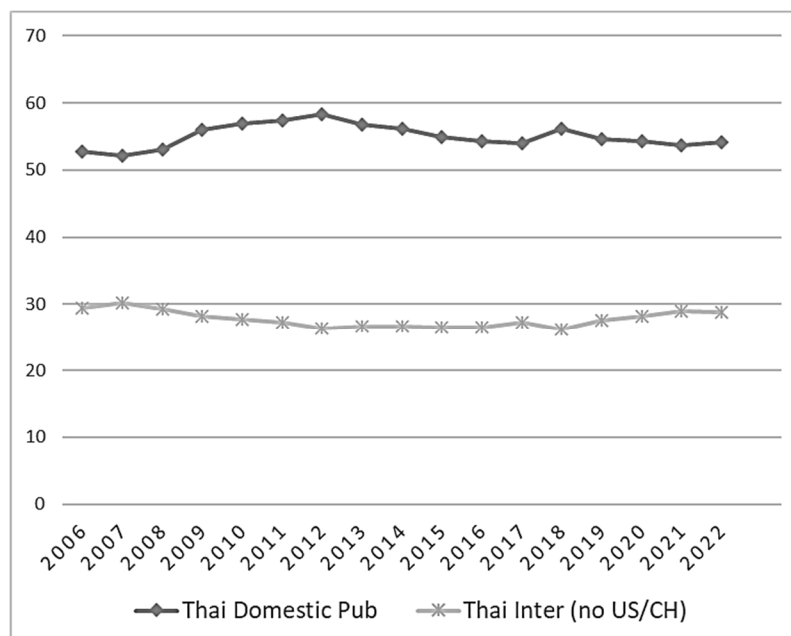


Figure 11

Percentage of Thai domestic/ Thai international coauthored articles (exclude the United States and China)



To identify three subject areas for in-depth analysis, I iterate the process, employing a subject filter based on Thailand's top ten subject areas, which include Medicine, Agricultural and Biological Sciences, Biochemistry, Genetics and Molecular Biology, Engineering, Chemistry, Material Science, Physics and Astronomy, Environmental Science, Immunology and Microbiology, and Chemical Engineering. In Figure 12, the percentage proportions of co-authored articles between Thailand and the United States exhibit variations across these ten disciplines. Most disciplines show a slight downtrend, with only Medicine displaying an uptrend. Conversely, in Figure 13, all the percentage proportions of co-authored articles between Thailand and China are consistently on an uptrend in all disciplines.

Figure 12

The proportions of Thai – U.S. Co-authored Publications (No China) in 10 disciplines

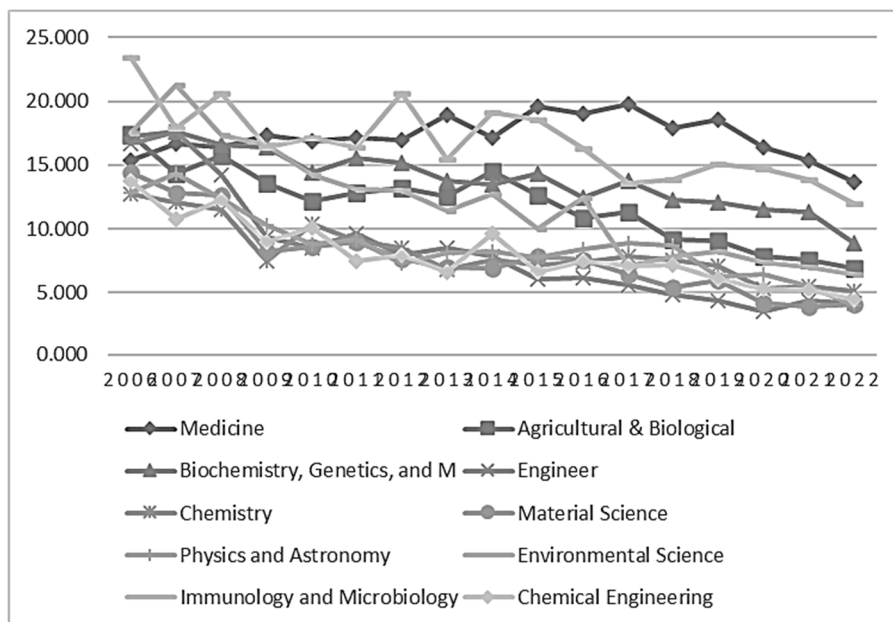
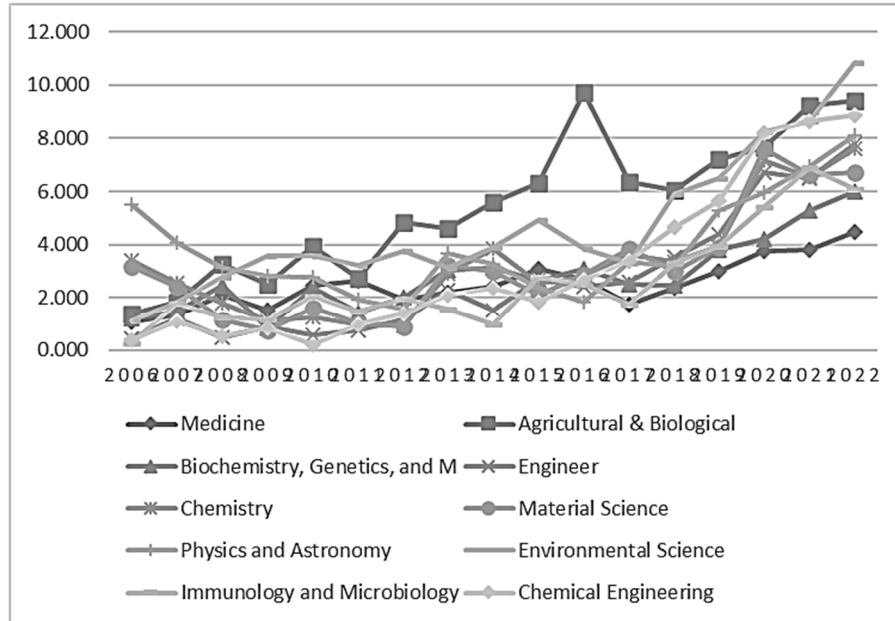


Figure 13

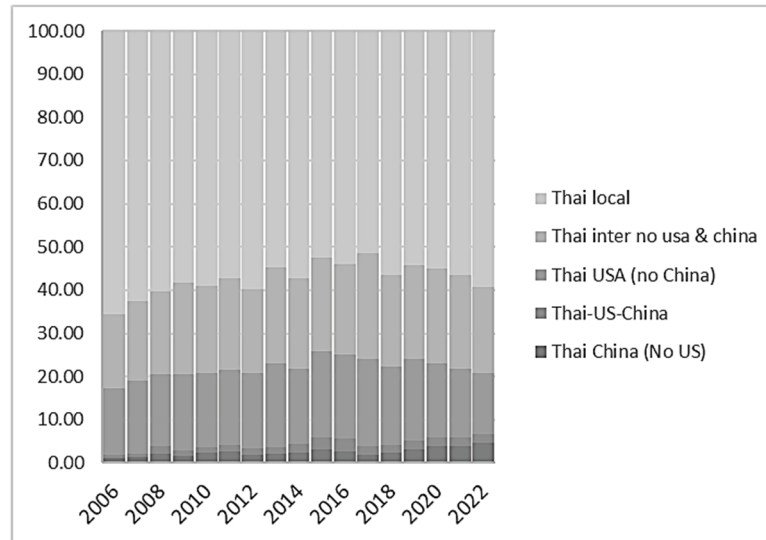
The proportions of Thai – China Co-authored Publications (No U.S.) in 10 disciplines



I chose to concentrate on Medicine, Engineering, and Agricultural and Biological Science because they exhibit distinct characteristics:

Figure 14

The proportions of Thai local publications, international publications, and co-authored publications between Thailand - the United States and Thailand - China in medicine

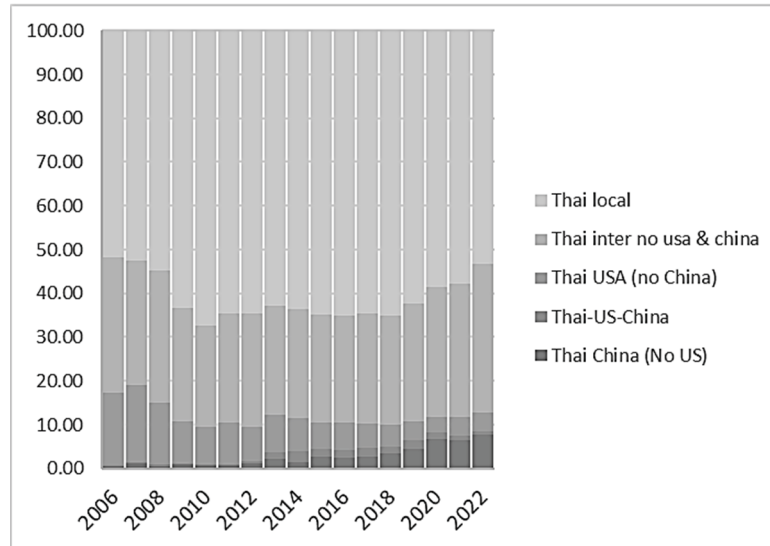


Rationale for selecting medicine (Figure 14 and Table 3):

1. Medicine stands out as the most prominent field in Thailand, consistently yielding the highest number of publications annually.
2. Collaborations with both the United States and China have remained relatively stable which is different from other fields.
3. Local sector collaborations within this field have demonstrated an increasing trend, especially in recent years.

Figure 15

The proportions of Thai local publications, international publications, and co-authored publications between Thailand - the United States and Thailand - China in Engineering

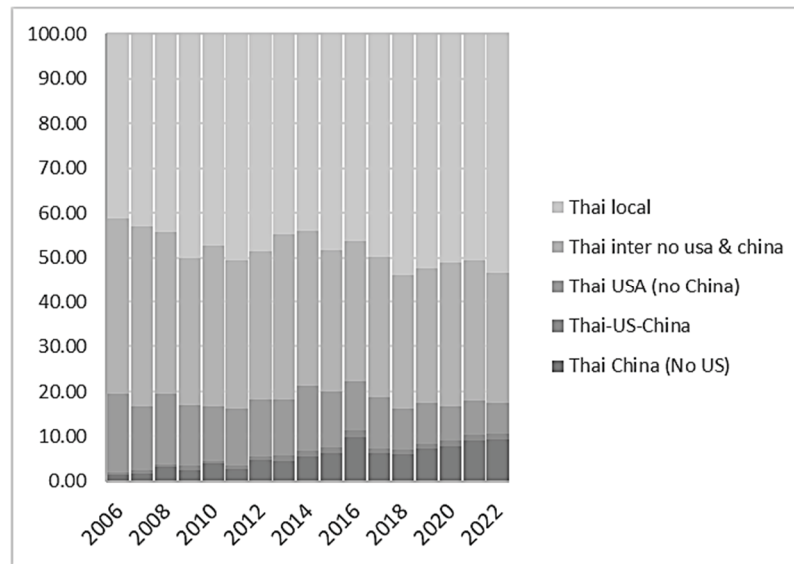


Rationale for selecting engineering (Figure 15 and Table 3):

- 1) Collaboration with the United States has notably declined, contrasting with an upward trend in collaboration with China.
- 2) It represents a technologically oriented applied field.

Figure 16

The proportions of Thai local publications, international publications, and co-authored publications between Thailand - the United States and Thailand - China in agricultural and biological sciences



Rationale for selecting agricultural and biological science (Figure 16 and Table 3):

- 1) Collaboration with China has significantly increased.
- 2) There is also a noticeable surge in collaboration among local sectors.

Table 3

The changes in the percentage proportion of different types of publications in various fields from 2006 to 2022.

Local Publications				Thai - US Publications (No China)			
	2006	2022	Change		2006	2022	Change
Environmental Science	33.96	48.17	14.21	Medicine	15.36	13.71	-1.64
Agricultural and Biological	41.29	53.32	12.03	Biochemistry and genetics	17.22	8.86	-8.36
Biochemistry and genetics	42.75	55.49	12.74	Physics and Astronomy	12.80	3.96	-8.84
Engineer	51.58	52.79	1.22	Chemistry	12.78	5.13	-7.65
Material Science	45.66	50.75	5.09	Chemical Engineering	13.73	4.46	-9.26
Chemistry	46.28	50.98	4.70	Immunology and Microbiology	23.48	11.98	-11.50
Chemical Engineering	49.41	51.53	2.12	Agricultural and Biological	17.42	6.95	-10.47
Immunology and Microbiology	36.68	50.12	13.44	Environmental Science	17.54	6.45	-11.09
Physics and Astronomy	44.21	39.65	-4.56	Material Science	14.38	4.10	-10.28
Medicine	64.91	56.87	-8.04	Engineer	16.67	4.22	-12.45

Thai - China Publications (No US)				Thai - China-US Publications			
	2006	2022	Change		2006	2022	Change
Chemical Engineering	0.39	8.86	8.47	Physics and Astronomy	0.00	9.69	9.69
Environmental Science	1.12	10.85	9.73	Immunology and Microbiology	0.79	1.57	0.77
Agricultural and Biological	1.37	9.42	8.05	Environmental Science	0.37	0.87	0.50
Engineer	0.45	7.80	7.35	Medicine	0.70	1.84	1.14
Immunology and Microbiology	0.26	6.11	5.84	Engineer	0.23	0.79	0.56
Material Science	3.20	6.70	3.51	Chemistry	0.00	0.51	0.51
Chemistry	3.40	7.63	4.24	Biochemistry and genetics	0.91	1.67	0.76
Biochemistry and genetics	1.21	5.98	4.77	Material Science	0.00	0.62	0.62
Medicine	1.08	4.49	3.41	Agricultural and Biological	0.69	1.13	0.45
Physics and Astronomy	5.49	8.09	2.61	Chemical Engineering	0.00	0.70	0.70

Another supporting rationale for choosing these three disciplines is their placement in distinct knowledge clusters proposed by Yan (2014). In his study, he investigates the knowledge flow among various disciplines and identifies seven knowledge hubs or domains, namely (a) biochemistry & molecular biology, (b) medicine, general & internal, (c) economics, (d) chemistry, multidisciplinary, (e) materials science, multidisciplinary, (f) physics, multidisciplinary, (g) engineering, electrical & electronics, and (h) psychiatry. The disciplines within each hub are interconnected by shared concrete research concepts, theories, or methods. The three disciplines selected in this study—medicine, agricultural and biological sciences, and engineering—are classified into different hubs, indicating their diversity in scientific cognitive properties.

Data Treatment. Initially, I downloaded data in response to search queries for publications featuring at least one author from Thailand. Additionally, I restrict search queries to three distinct disciplines. The raw data is in the form of Excel worksheets (Fig. 17).

Figure 17

The raw data in the form of Excel worksheets

Authors	Author(s) ID	Title	Year	Cited	Link	Affiliations
Choophun N.; Ch	58030365100; 5	Natural R	2022	1	https://w	Department of Materials Engineering, Faculty of Engineering, Kasetsart University, Bar
Gao Y.; Ren G.-C.	57255799300; 5	Two New	2022	0	https://w	Center of Excellence in Fungal Research, Mae Fah Luang University, Chiang Rai, 57100,
Phengnoi P.; Thal	57210980418; 5	Characteri	2022	0	https://w	Department of Chemical Engineering, Faculty of Engineering, Burapha University, Saer
Siritongsuk P.; Th	57192409223; 5	Synthesis	2022	0	https://w	Department of Biochemistry, Faculty of Science, Khon Kaen University, Khon Kaen, 400

Figure 18

Example of categorization of addresses into local and international publications

Faculty of Veterinary Medicine,
Rajamangala University of Technology
Tawan-Ok, Chonburi, 20110, Thailand;
Department of Pathology, Faculty of
Veterinary Science, Chulalongkorn
University, Bangkok, 10330, Thailand

Thailand's domestic publications

Research Network of NANOTEC–KU on
NanoCatalysts and Nanomaterials for
Sustainable Energy and Environment,
Kasetsart University, Bangkok, 10900,
Thailand; Institute of Materials
Chemistry, TU Wien, Vienna, 1060,
Austria

Thailand's international publications

Department of Agricultural Science,
Faculty of Agriculture, Natural
Resources and Environment,
Naresuan University, Phitsanulok,
65000, Thailand; College of Natural
and Applied Science, University of
Houston-Victoria, 3007 N. Ben Wilson,
Victoria, 77901, TX, United States

Thai-U.S. coauthored publications

Department of Entomology and Plant
Pathology, Faculty of Agriculture,
Chiang Mai University, Chiang Mai,
50200, Thailand; CAS Key Laboratory
for Plant Diversity and Biogeography
of East Asia, Kunming Institute of
Botany, Chinese Academy of Science,
Yunnan, Kunming, 650201, China

Thai-China coauthored publications

Next, utilizing Python code, I categorized each entry into four distinct groups: Thailand's domestic publications, Thailand's international publications, Thai-U.S. coauthored publications, and Thai-China coauthored publications (Figure 18). The Python code examined the affiliations' addresses and countries. If no countries other than "Thailand" were found, the entry was classified as *Thailand's domestic publications*. If there are countries other than "Thailand" were found, the entry was classified as *Thailand's international publications*. If there were one or more addresses in both "Thailand" and the "United States" with no address from "China", the entry was classified as *Thai-U.S. coauthored publications*. If there were one or more addresses in both "Thailand" and "China" with no address from the "United States," the entry was classified as Thai-China coauthored publications.

For the next step, I employ Python code to gather data on Thailand's sectoral collaborations. The Python script is designed to extract Thai affiliation titles from the affiliation lists and categorize them into groups based on keywords. For academic affiliations, keywords like "university," "college," etc., are utilized; for government affiliations, keywords such as "ministry," "of Thailand," "national," etc., are employed, and for industry affiliations, keywords like "ltd," "inc," "company," etc., are used. Affiliations titles that do not align with these keywords undergo manual review, research through search engines, and classification; some new keywords may be introduced during this process. Unidentified affiliations are placed in an unrecognized list, which is excluded from the analysis. Additionally, affiliations with incorrectly spelled names or those containing only mailing addresses are handled appropriately.

After categorizing the publication data based on the sectors of each author's affiliations, each publication is assigned to specific sectors or cross-sectoral collaborations (U, G, I, UG, UI,

GI, and UGI). Subsequently, I count the number of publications in each group for each year spanning from 2006 to 2022 (Table 4).

Table 4

Data sets categorized by types of collaborations among local sectors, both including and excluding international partners from the system.

Domestic Publications	Intl. Publications	Thai-US Publications	Thai-China Publications
1) All disciplines U G I UG UI GI UGI	1) All disciplines U G I UG UI GI UGI	1) All disciplines U G I UG UI GI UGI	1) All disciplines U G I UG UI GI UGI
2) Medicine U G I UG UI GI UGI	2) Medicine U G I UG UI GI UGI	2) Medicine U G I UG UI GI UGI	2) Medicine U G I UG UI GI UGI
3) Engineering U G I UG UI GI UGI	3) Engineering U G I UG UI GI UGI	3) Engineering U G I UG UI GI UGI	3) Engineering U G I UG UI GI UGI
4) Agricultural and Biological Science U G I UG UI GI UGI	4) Agricultural and Biological Science U G I UG UI GI UGI	4) Agricultural and Biological Science U G I UG UI GI UGI	4) Agricultural and Biological Science U G I UG UI GI UGI

Leydesdorff developed a software for computing mutual information or T values in the case of large datasets, operating on nominal values such as industry codes, region names, or classifications. The program uses variables denoted as "w," "x," "y," and "z," and the new record contains uncertainties in these four dimensions (Hw, Hx, Hy, Hz), joint entropies (such as Hwx, Hwxy, Hwxyz, etc.), and all possible transmissions (Twx, Twxy, Twxyz, etc.) among them. To proceed this step, I create another Python function to generate input in the format required by the software.

To explain how I determine mutual information value, I apply Shannon's entropy to the sample publication data below (Table 5):

Table 5

Sample data generated by Python using 10 publications

Publication	Thai University	Thai Government	Thai Industry
1	1	0	1
2	1	1	1
3	0	1	1
4	1	1	0
5	1	0	0
6	1	1	0
7	0	1	0
8	0	0	1
9	1	0	1
10	1	1	0

Table 5 shows the data extracted from ten publications. Thai affiliations' addresses in each publication were classified into various sectors: university (U), government (G), and Industry (I). Each variable is assigned a value of "1" irrespective of the frequency of sector

occurrences in the address list. For example, in publication 1, the variable (U) is assigned a value of "1" even though there are three universities listed as coauthors' affiliations. The first variable (U) has seven times of the value of "1", and three times of value of "0".

The uncertainty $H(U)$ in this distribution is:

$$H(U) = - (7/10) \log_2(7/10) - (3/10) \log_2(3/10)$$

Table 6

Calculation H value (uncertainty) of each variable.

	U	G	I
P(X1)	0.70	0.60	0.5
Log2(PX1)	-0.51	-0.74	-1
P(X2)	0.30	0.40	0.5
Log2(PX2)	-1.74	-1.32	-1
-P(X1) log2 P(X1)'	0.36	0.44	0.5
-P(X2) log2 P(X2)'	0.52	0.53	0.5
- Σi P(Xi) LOG2 P(Xi)'	0.88	0.97	1

According to the sample publication data, I have $H(U) = 0.88$, $H(G) = 0.97$, and $H(I) = 1.00$

I repeat the process using Shannon's formula to get all the values I need to calculate mutual information of the three-dimensional relationship.

Table 7

Uncertainty (H) and mutual information (T) values of two- and three-dimension relationships.

H(U)	0.881291
H(G)	0.970951
H(I)	1
H(U,G)	0.934068
H(U,I)	0.970951
H(G,I)	0.992774
H(U,G,I)	0.970951

T(U,G)	0.918173
T(U,I)	0.91034
T(G,I)	0.978176
T(U,G,I)	0.925399

Since the actual publication data could be several tens of thousands of papers every year in each category, for convenience, I use a program (th4.exe) provided by Leydesdorff (<https://www.leydesdorff.net/software/th4/>) which facilitates the computation of variables' values in case of large sets (Leydesdorff, 2021).

Application of Mutual Information Value. Mutual information values are valuable for the study, as they have been effectively used in previous research to answer various research questions. For example, Leydesdorff (2003) compared the three-dimensional transmission among different countries. According to Table 9, he found that Japan, with the lowest T(uig) value, is significantly more networked than the other countries in the study. He suggests that this is due to the more active interactions between Japanese universities and companies, as indicated by Japan's higher number of university-industry coauthored publications compared to other countries.

Table 8

University-industry-government relations for various countries and regions using ISI's Science Citation Index 2000.

	number	% titles retrieved	T(ug) in mbits	UI	UG	IG	UIG	Univers	Industry	Govern
All	676511	93.3	-77.0	16270	108919	4359	5201	543123	41242	232096
USA	232571	92.5	-74.4	7200	37834	1782	2666	200149	18154	66416
EU	257376	93.0	-50.1	4455	52112	1485	2028	206747	11192	101545
UK	68404	93.1	-63.1	1719	13098	394	690	54823	3970	26202
Germany	61017	94.7	-43.4	1028	14003	407	664	51283	2799	23701
France	41112	90.3	-52.1	439	11593	452	530	26133	1928	26595
Scandinavia	30939	95.8	-31.6	490	8477	162	371	26542	1263	13005
Italy	28958	89.9	-29.4	362	7133	87	262	25633	905	10526
Netherlands	18357	95.3	-25.4	372	4482	106	259	16379	863	6593
Japan	67715	97.9	-92.1	4147	12492	954	1311	56534	9732	21664
PR China	22116	99.5	-14.9	237	4610	68	114	18196	480	8583
Taiwan	8390	97.4	-17.1	148	2163	19	52	7454	250	3120
Singapore	2931	99.0	-23.9	104	476	7	17	2598	145	809
S. Korea	12038	98.3	-40.1	351	2341	87	91	10345	676	3978

Note. From Leydesdorff (2003).

Ye et al. (2013) also utilized mutual information to compare the integration of Triple Helix actors in G7, BRICS, and INS countries. They collected time series data to study the dynamics of these countries' Triple Helix networks over time (Table 9). Their findings indicate that most countries tend to have less negative T values over time, with the exception of some countries like India. They suggest that globalization has eroded local Triple Helix relations since the mid-1990s. Additionally, they examined the T values of bilateral relations between local sectors in China (Figure 19). The lower T(ug) values reveal that Chinese universities and the government have become uncoupled since the period 1980-1985, resulting in weakened national integration of Triple Helix relations.

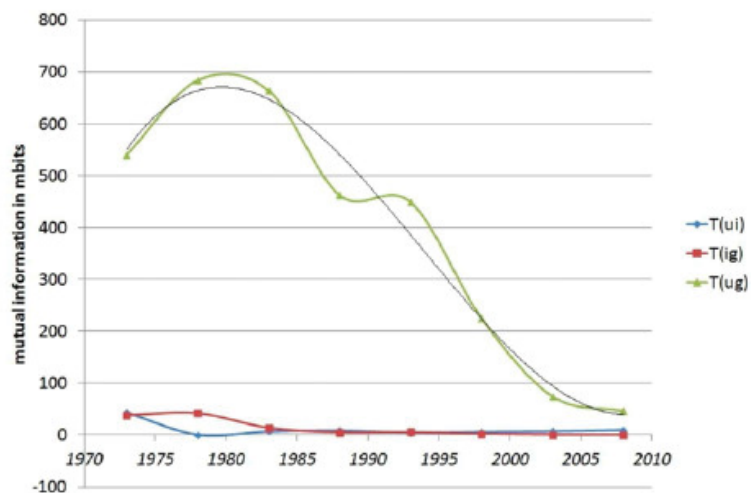
Table 9

Development of the configurational information of the G7, BRICS, and INS countries during the period 1971–2010

	USA	UK	FRANCE	GERMANY	ITALY	CANADA
1971–1975	–82.03	–104.2	–120.9	–25.41	–29.75	–105.1
1976–1980	–88.34	–101.8	–115.6	–93.11	–24.83	–111.8
1981–1985	–89.75	–96.07	–128.2	–40.21	–25.97	–106.3
1986–1990	–85.7	–81.15	–119.1	–109.3	–29.37	–87.51
1991–1995	–92.37	–77.05	–105.4	–28.33	–29.59	–68.27
1996–2000	–53.03	–47.69	–98.43	–22.71	–28.89	–49.81
2001–2005	–43.18	–39.77	–93.58	–22.55	–32.05	–43.65
2006–2010	–33.71	–34.41	–72.72	–18.35	–31.71	–35.22
	JAPAN	BRAZIL	RUSSIA	INDIA	CHINA (CAS as G)	CHINA (CAS as U)
1971–1975	–113.2	–52.05	<i>n.a.</i>	–101.9	–173.9	–173.9
1976–1980	–114.8	–68.52	<i>n.a.</i>	–95.23	–76.78	–79.16
1981–1985	–116.5	–118.4	<i>n.a.</i>	–106.7	–80.53	–80.11
1986–1990	–114.3	–106.3	<i>n.a.</i>	–113.1	–55.75	–49.68
1991–1995	–106.6	–79.09	–61.54	–118.7	–47.13	–44.35
1996–2000	–96.55	–52.32	–54.46	–125.3	–40.03	–28.83
2001–2005	–87.16	–38.27	–45.23	–124.2	–30.29	–15.34
2006–2010	–80.01	–30.97	–56.92	–118.7	–32.11	–15.87
	SOUTH AFRICA	INDONESIA	NETHERLANDS	SOUTH KOREA		
1971–1975	–79.44	–229.7	–26.16	–252.6		
1976–1980	–97.29	–157.9	–38.24	–48.52		
1981–1985	–88.21	–157.6	–44.66	–45.96		
1986–1990	–69.52	–233	–43.38	–17.21		
1991–1995	–47.32	–135.9	–53.3	–27.9		
1996–2000	–36.88	–132.7	–47.1	–19.91		
2001–2005	–32.17	–125	–35.58	–23.81		

Note from Ye et al. (2013)

Figure 19 *Mutual information in bilateral relations of China, 1971–2010*

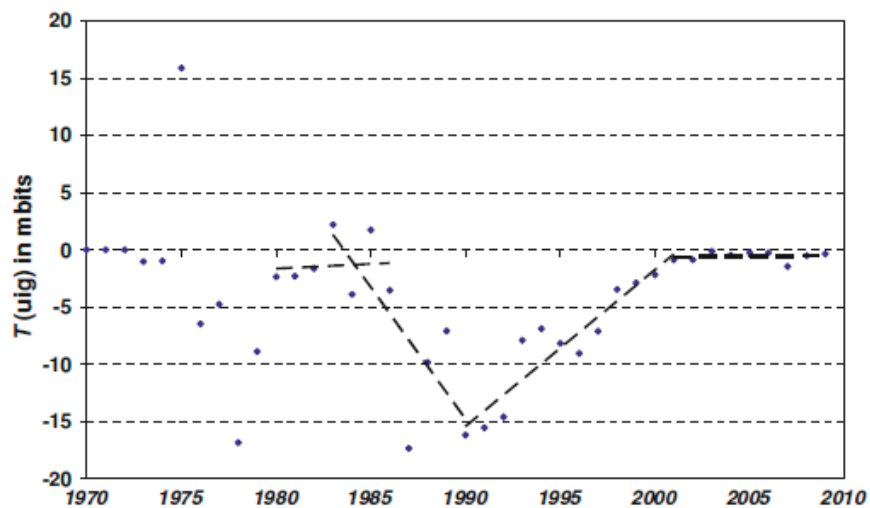


Note Ye et al. (2013)

Another example is a study by Kwon et al. (2011). The researchers compare the synergy of the Korean research system by excluding and including foreign co-authors as the fourth dimension. They found that between 1990 - 2000, Korean domestic actors' synergy decreased as $T(u_{ig})$ values increased. However, when including foreign collaboration as a dimension of the system, uncertainty decreases, implying that the local system has become more integrated (Figures 20 and 21). The researchers suggest that the international dimension cannot be considered separately when examining the vitalization of Korea's national research system.

Figure 20

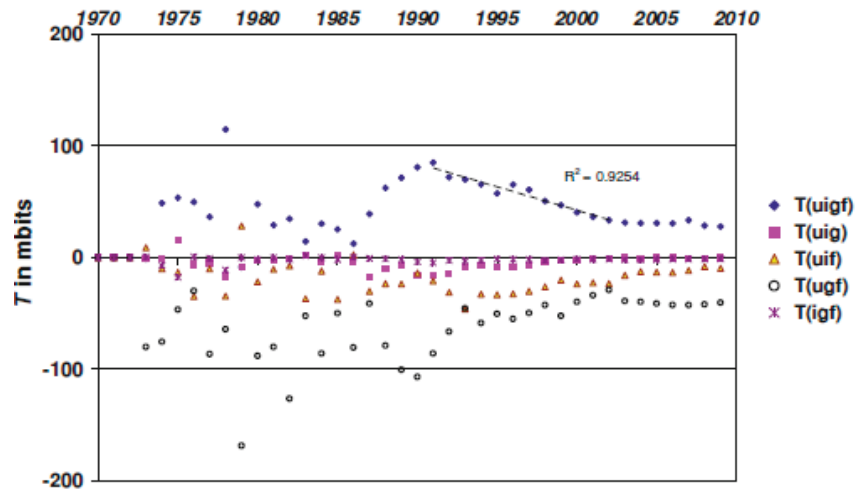
Mutual information in trilateral domestic TH relationship in Korea.



Note From Kwon et al. (2011).

Figure 21

Mutual information in three and four dimensions



Note. From Kwon et al. (2011).

In this study, I apply Shannon's entropy and Ledesdorff's mutual information indicators, First, to examine the dynamic of the synergy of local sectors in Thailand during 2006 - 2022. Second, compare the synergy dynamic when the United States and China are included as international partners to see if partnering with the two countries results in different synergies across local sectors. Third, examine those mentioned above in three different disciplines to see if distinct intellectual elements in each discipline lead to the different synergy among actors. The T values provide insights into the trend of collaborative synergy among local sectors in Thailand, considering both the inclusion and exclusion of international partners from the research system. In other words, the results indicate whether Thai local sectors exhibit stronger or weaker collaborations in both local and international settings. A greater dynamic can contribute to a more productive research environment, enhancing innovation and economic

development in the country. This analysis helps assess the successful translation of national policies in Thailand into real-world applications. I also examine how these trends manifest in different disciplines.

Finally, I utilize additional data from the database, specifically focusing on sources of funding, to explore potential correlations between funding origins from specific sectors and international collaboration. Liu et al. (2017) used multinomial logistic regression analysis to examine the role of government funding in fostering collaboration between knowledge-based sectors in China. Their findings indicate that Chinese government funds do not positively impact the likelihood of science-industry collaborations. Moreover, research collaboration with international partners is more likely when supported by regional rather than central government funding. In this study, I apply a similar method to determine whether funding from different local sources can predict the occurrence of international collaboration, Thai – U.S, and Thai – China collaborations. Variables used in this part of the analysis are:

Independent variables:

- U Fund: 1 if the source of funding is from university, and 0 otherwise
- G Fund: 1 if the source of funding is from government, and 0 otherwise
- I Fund: 1 if the source of funding is from industry, and 0 otherwise

Dependent variable:

- Int Collaboration: 1 if the publication is an international publication, and 0 otherwise
- Thai-U.S. Collaboration: 1 if the publication is a Thai – U.S. publication, and 0 otherwise
- Thai-China Collaboration: 1 if the publication is a Thai – China publication, and 0 otherwise

Qualitative Method: Semi-Structured Interview

While the quantitative section assists us in exploring the collaborative research activities, I want to go a step further by opening the black box and understanding the drivers or factors that convert input into output. In this project, I scrutinize policy and organizational elements that may impact scientific research efforts. Recognizing the direct contribution of individual scientists to scientific publications, I apply the concept of the cycle of credibility to explain the complex relationships between various components of scientific collaborations focusing on the connections between international and local collaborations. To do so, I must learn from the experiences of those who have participated in collaborative projects to explore how different types of credibility are acquired and exercised as well as how these practices influence scientific knowledge production.

Several studies have explored the relationship between different types of collaborations; however, few have undertaken qualitative inquiries to provide insights and elucidate observations. To address this gap, I conducted semi-structured interviews with individuals involved in scientific research collaborations. In the case study, the target participants are researchers and policymakers with experience in collaborative projects between local sectors in Thailand, as well as international collaborations between Thailand and the United States, and Thailand and China. The objectives are to uncover the organizational and social factors influencing both local and international research collaborations, and to offer policy recommendations to assist policymakers and researchers in fostering and maximizing the benefits of collaborative efforts, both locally and internationally.

Sample and Sampling The first step of the qualitative study is to identify the target informants. According to Katz and Martin (1997), collaborators are individuals responsible for

one or more major components of scientific projects, whose contributions are acknowledged in publications. While there is debate over whether to consider individual researchers, institutions, or both as collaborators, I argue that individuals and institutions are distinct yet interdependent agents. For instance, personal relationships can lead to scientific collaborations at the organizational level (Owusu-Nimo & Boshoff, 2017; Freeman et al., 2015), while organizational structures can influence management styles and individual decision-making (Shrum et al., 2007).

The credibility cycle concept enables multilevel analysis to understand scientific collaborations from both individual and institutional perspectives. Therefore, the interviews aim to investigate factors at both levels. Each informant represents themselves as an individual and as a member of their organization, providing a comprehensive view of the dynamics that drive research collaborations.

Prior to beginning the interview process, IRB approval was obtained. The research protocol was determined as “Exempt, under 45 CFR 46.104(d) category(ies) 2(ii) on April 4, 2022 (Appendix A).

Potential study participants will be recruited via personal and professional connections as well as expert recommendations. Some of them were selected from published sources such as websites and names on publications. Interview invitations, consent forms, and other communications will take place via email and other online communication tools (Appendix B). For Thai participants who preferred using Thai, consent forms were translated and certified for accuracy. For the sampling criteria, I focus on the heterogeneity of organizations, disciplines, and roles. I aim to include individuals from various positions, career stages, and organizations to capture diverse perspectives, as studies have shown that these factors influence perceptions and participation in scientific activities both directly and indirectly. According to Table 10, semi-

structured interviews were conducted with eighteen policymakers and scientists from different disciplines and sectors in Thailand and the U.S.

Table 10

Classification and the number of interviewees

	Domestic Collaboration	Thai – U.S. Collaboration	Thai – China Collaboration
1) Representatives from the Thai Government	1	4	
2) Representatives from Thai Universities	2	1	3
3) Representatives from Thai firms	2	1	
4) Representatives from the U.S.		3	
5) Representatives from China			1

SSK argues that to understand scientific knowledge production, I need to consider both cognitive and social aspects of scientific activities. Different disciplines have distinct structures, methodologies, problems, audiences, and social interactions (Bourdieu, 1999). Therefore, in this study, I take a closer look at three fields of study so I can compare social aspects such as organizational structure, and cognitive structures and components such as subjects of study, commitments, etc. The interviews are intended to elicit information about what actually occurred in the projects in which they were involved, as well as how scientific facts are generated and controversies are resolved, which may differ across disciplines.

Interview Questions and Sequences Before initiating the formal interview process, I conducted three pilot interviews to test and refine the interview questions. These pilot sessions also helped familiarize the interviewer with the nuances of discussions about scientific collaborations. In designing the research questions, I focused on the informants' actual practices and involvement in collaborative projects. Latour and Woolgar (1986) note that social dynamics are active during a scientific project but tend to dissipate once the project's goals are met and publications are completed. Consequently, the interview questions targeted specific projects to investigate social interactions and the influences of key factors on actions.

Drawing from Hessels et al. (2019), I used the Cycle of Credibility framework to analyze not only personal motivations and behaviors but also the informants' experiences throughout their research careers and the influence of their institutions. During the semi-structured, audio-recorded interviews, I solicited detailed experience narratives. Each interview lasted approximately 30 to 60 minutes.

Research questions for each informant are slightly different in order to produce a deeper understanding of a particular situation that occurred during the project they worked on. The research questions could be divided into themes, as shown in Table 11.

Table 11*Themes for Research Questions and Sample Questions*

Themes	Sample Questions
to describe the projects in which they are involved	<ul style="list-style-type: none">- Could you please tell me about the project we are talking about today?- Who were the key individuals or organizations in this project?- What are the problems or goals the projects are trying to solve or accomplish?- How was the project initiated?- Where did the funding come from?
To explore Individual and institutional factors	<ul style="list-style-type: none">- What was your strategy for selecting partners and projects?- What was it like to collaborate with partners from different industries or countries?- What are the challenges in working with them?- What are the advantages of working with them? (in terms of productivity, recognition, etc.)
To focus on Institutional factors	<ul style="list-style-type: none">- How was the project managed? (eg. levels of hierarchy, management styles, division of labor, etc.)

	<ul style="list-style-type: none"> - How were the project's costs and benefits assessed? - Why and how did your organization/company promote collaborations?
To focus on individual factors	<ul style="list-style-type: none"> - What did you expect from the collaborations, and did you get what you expected? (eg. funding, career progress, publications, etc.)
To explore the explanation for the quantitative data	<ul style="list-style-type: none"> - In the recent few years, has your organization engaged more or less in any form of research collaboration with Thailand? and in what way? - what are the reasons or the key factors that contribute to the increase/decrease of collaborative activities?

The interview processes

The interviews were conducted in two phases: the first (June-September 2022) and the second (May - June 2023). The reason for having two phases is so that I can review and reflect on the results of the first phase to see if there is anything I need to revise or focus on for the remaining interviews.

Before each interview, the researcher sent the informants the study information as well as a list of research questions. The researcher also asked them to consider a collaborative project they wanted to discuss and send some project information to the interviewer before the interview. At the start of each interview, the researcher asked if participants had any unanswered

questions and if they understood everything about the interview. All questions were answered before the interviews began.

Each interview is conducted in person in a location of the participants' choosing such as their offices, coffee shops, or over Zoom meetings. No one else but the interviewer will be present unless the participants would like someone else to be there. Thai informants are interviewed in Thai language. American and Chinese informants are interviewed in English. With their consent, a researcher recorded and took notes during the interview for accuracy. The records then were transcribed. The interview transcripts are translated into English if the interview was conducted in Thai.

Participants can opt out of answering certain questions or disclosing certain information provided during the interview to reduce the risks to themselves. Only the information they granted permission for is used in the study. Participants' names, positions, the names of organizations/companies, years of experience, and projects in which they have been involved are collected during the interview. However, they can choose between three levels of privacy when it comes to publicizing the data:

- **Tier I:** Tier I is complete anonymity, with just a basic description of their professions (eg. a researcher, a coordinator, and a policy maker) and broad categories of their organizations/companies (eg. a government research agency, a university, a private company) mentioned in the study.
- **Tier II:** the study specifies a wide category of their occupations as well as the name of their organization/company.
- **Tier III:** the study includes their names, positions, and the names of organizations/companies.

Qualitative Data Analysis For the analysis, Interview participants are assigned codes. For example, "P1 Eng I" represents participant number 1, who is from the engineering field and affiliated with industry, while "P2 Med U" represents participant number 2, who is from the medical field and affiliated with a university. This coding system allows for easy identification and categorization of interview participants based on their background and affiliation, facilitating analysis and interpretation of interview data. For participants who are willing to disclose their names and positions, I address the informants by their names. Otherwise, codes are used as identifiers.

A researcher created participant files for each participant which include their informed consent forms, their profiles and organizations'/companies' profiles that were provided by the participants or obtained from public sources, their contact information, transcripts, follow-up notes, and any important communication with the participants. All documents and transcriptions are stored at different places according to the approved IRB protocol. No one will be given access to your personal information.

In addition to the interviews, the researchers obtain additional information from policy documents and presentations, as well as news and announcements from related agencies. The data can be used as additional sources of information for the analysis.

The researcher analyzed the interview transcript and formulated thematic categories for analysis by integrating findings and perspectives learned from the literature review. By employing the Cycle of Credibility and Science, Technology, and Society (STS) perspectives as analytical frameworks, the researchers examined various facets across different collaborative setting to learn about the dynamics and connections between local and international collaborations.

Things to consider Ensuring the quality of qualitative study involves considering several key factors, including determining the extent of qualitative data required and deciding when to conclude interviews, a process known as saturation. Saunders et al. (2017) propose four approaches to validate saturation. Theoretical saturation occurs when no new codes or themes emerge from the data, indicating that the analysis has covered all relevant concepts, relying on coding or theme analysis to determine completeness. Inductive thematic saturation is achieved when the data comprehensively encompasses all constructions within a given theory, ensuring thorough coverage of the theoretical framework. A priori thematic saturation happens when the data is sufficient to illustrate a predetermined theory, focusing on collecting data that exemplifies pre-established theoretical categories. Data saturation is reached when no new information is generated during data collection, and there is no redundancy in the data collected, ensuring that all relevant information has been captured. By applying these approaches, I can ensure that the study is comprehensive, capturing all necessary information and covering all relevant themes and theories.

In addition to these deductive approaches, which rely on pre-identified codes, themes, or data, researchers may also consider employing an inductive approach. This method prioritizes the discovery of new codes or themes from the data, leading to the generation of novel theoretical insights. For qualitative studies adopting a biographical or narrative approach, researchers could concentrate on specific accounts provided by individual informants, employing methods such as interpretative phenomenological analysis (Adu, 2021). Ultimately, to ensure the quality of the qualitative research, it is imperative to identify the saturation point, where data collection can be concluded, and comprehensive insights have been obtained.

Furthermore, there are important considerations regarding analysis. Jentsch and Pilley (2003) discuss cultural differences as sources of bias in interview interpretation. Although the researcher understands both English and Thai and interprets the interview questions and transcripts herself, biases caused by cultural and linguistic differences should be avoided. Bias in the interview can arise from background characteristics (age, education, race, sex, etc.), psychological factors (perceptions, attitudes, expectations, motives, etc.), and behavioral factors (responses to questions, adequacy, and accuracy). Therefore, it is crucial to be mindful of these factors and incorporate personal perspectives thoughtfully in the interview analysis.

In this chapter, I have detailed the methodologies employed in the research, encompassing both quantitative and qualitative approaches. The aim is to illustrate the seamless integration of these methods to address the research inquiries comprehensively. As we progress, subsequent chapters will delve into the findings derived from these methodologies, expanding upon the frameworks and approaches elucidated here. In the next chapter, I will explore Thailand's national science system, focusing on specific details related to local and international collaborations, particularly with the United States and China.

Chapter 5

An Overview of Scientific Collaboration in Thailand

In this section, I present an overview of scientific collaboration in Thailand, based on insights gathered from the secondary research. This foundational information is crucial for the subsequent analysis. Thailand has been selected as the primary focus for studying the dynamics between its domestic collaborations and its international partnerships with the United States and China. This section covers the background of science and technology in Thailand, including factual data, evolving national policies, and political factors. Additionally, it explores elements that may influence Thailand's collaborations with its two key partner countries.

Science and Technology and Thailand's Path to High-Income Country

In economics, the term "convergence" refers to the phenomenon where less affluent countries experience faster growth rates compared to wealthier ones. Countries can be classified into two groups: "convergence successes" and "convergence nonsuccesses." Convergence successes comprise middle-income nations that either transition to high-income status or maintain an average annual growth rate exceeding 3 percent from 1960 to 2014, even if they do not achieve high-income status. Conversely, convergence nonsuccesses include countries with an average annual growth rate below 3 percent, making them unlikely to ascend to high-income status without significant changes (Lee, 2020). Historically, only a small fraction of middle-income countries has successfully elevated their economies to high-income status, with less than fifteen percent achieving this milestone by 2008 (Bandaogo, 2020).

Thailand has long been regarded as a convergence success story, boasting robust economic performance over several decades. However, the nation is currently grappling with a

growth slowdown and is at risk of falling into what is known as the middle-income trap—a scenario characterized by a deceleration in growth over a specific period. According to Bandaogo (2020), escaping this middle-income trap poses a formidable challenge for Thailand. He predicts that the country will witness a decline in human capital growth, a reduction in the growth rate of the working-age population to population ratio, and a decrease in the return on both private and public investment.

To address these challenges, the Thai government is promoting Thailand 4.0, an economic development model focused on fostering a value-based economy through innovation, technology, and creativity. As part of this initiative, the government is encouraging greater involvement of universities and the private sector in research and innovation. In 2019, the Ministry of Higher Education, Science, Research, and Innovation (MHESI) was established by merging four agencies: the Office of Higher Education Commission (OHEC) from the Ministry of Education, the Ministry of Science and Technology, and the Office of the National Research Council of Thailand (NRCT), aiming for a more seamless collaboration between sectors.

According to the Ministry of Higher Education, Science, Research and Innovation. (2021), the mission of MHESI is to serve as the primary agency driving Thailand's higher education, science, research, and innovation towards achieving global standards and enhancing sustainable competitive capacity by 2037. To accomplish this mission, the agency is focused on promoting human resource development in universities and advancing scientific and technological breakthroughs through collaborative efforts across sectors. MHESI has outlined four key strategies: 1) developing human resources and education to align with market demands and national needs; 2) strengthening research management and supporting initiatives that propel national progress and foster a conducive scientific ecosystem; 3) enhancing the economy and

quality of life through advancements in education, science, research, and innovation; and 4) reforming and managing these sectors for sustainable and balanced national development.

In alignment with the country's strategic goals, the Thai government is prioritizing the development of personnel in six key areas of advanced science and technology: biotechnology and the environment, metal technology and material science, electronics and computer technology, basic sciences, nanotechnology, and science and technology management. One approach to achieving this goal is by encouraging Thai students and scientists to pursue scholarships both domestically and internationally. Since the project's inception, phases 1 through 4 have resulted in a total of 5,336 scholarship recipients, with 4,969 receiving scholarships to study abroad and 367 receiving domestic scholarships. The government believes that increasing the number of experts and skilled personnel in these fields will enhance the country's competitiveness on the global stage (MHESI, 2022).

Research infrastructure is another aspect the Thai government is investing in to support this strategic initiative. MHESI is driving the establishment of Thailand's Regional Science Parks across the country's four regions. These parks are operated by key universities and regional university networks, currently involving 16 universities with plans to expand to 44. The designated science parks include the Northern Science Park (Chiang Mai University), Northeastern Science Park (Khon Kaen University), Lower Northeastern Science Park (Suranaree University of Technology), and Southern Thailand Science Park (Prince of Songkla University). These parks conduct diverse research activities, fostering innovations with significant economic and social impact, supporting startup initiatives, and driving business development.

Additionally, the Ministry spearheads initiatives to foster research and innovation collaboration between universities and industries to boost Thailand's competitive capacity. Notable programs include the Thailand Business Innovation Research (TBIR) and Innovation Fund, which support innovative business research, and the University-Industry Co-creation Platform, which facilitates collaboration between universities and industries to produce STEM graduates with the skills needed for the corporate sector.

Thai universities are tasked with multiple roles beyond teaching and conducting basic research. The Thai government categorizes universities into five distinct groups based on their strengths and preparedness: the World's Leading Research Development Group (16 universities), the Technology and Innovation Promotion Group (18 universities), the Local Community Development Group (41 universities), the Intellectual and Moral Development Group, and the Professional Personnel Production and Development Group (MHESI, 2022).

Thailand claims significant strengths, including high food security, a robust healthcare system, and abundant natural resources and cultural heritage. However, the nation grapples with challenges in enhancing educational quality and research capabilities. To address economic and social issues such as middle-income traps and low-value manufacturing, Thailand has introduced the BCG economic model. This model prioritizes bioeconomy, circular economy, and green economy initiatives, utilizing technologies like big data and digital platforms in agriculture and logistics, advancing vaccine and medicine industries, and promoting advanced therapeutic medicinal products such as CAR-T cells and gene therapy. Additionally, the model focuses on bolstering expertise in biopharma engineering and medicine, increasing investments in sustainable energy, and updating regulatory frameworks. Anchored in scientific, technological, and innovative knowledge, the model adopts the quadruple helix approach (MHESI, 2022, p.

53), emphasizing collaboration among government agencies, universities, industries and international partners. This initiative spans agriculture and food, health and medicine, energy, and materials, and biochemistry. Collaboration between government entities, academic institutions, and industry players serves as the linchpin of this initiative, with government agencies providing funding to nurture innovation ecosystems encompassing research and manufacturing.

Thailand's Scientific Collaboration

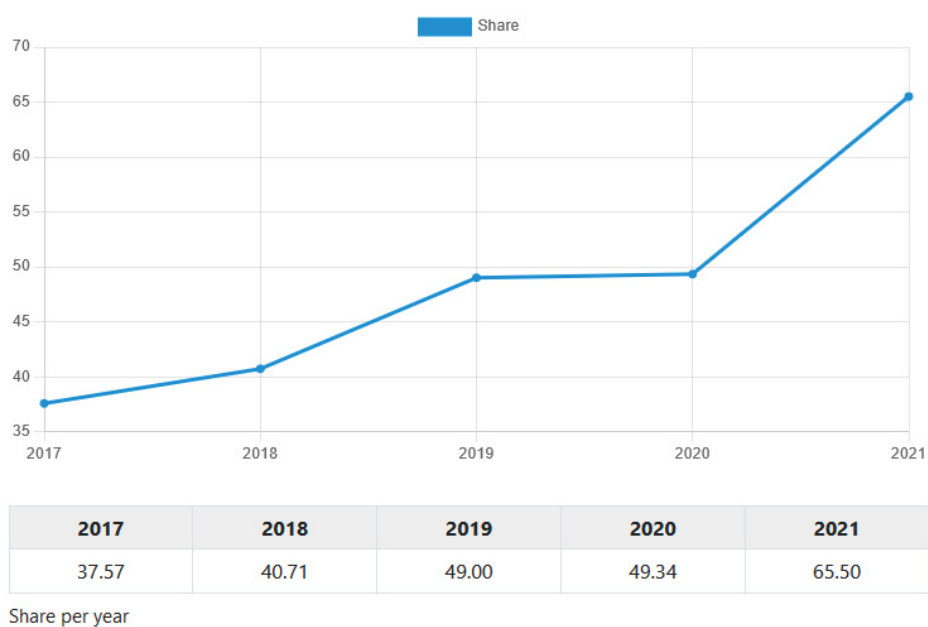
Thailand engages in extensive international scientific collaboration with various countries across the globe. Among its key partners is the United States, where collaborative efforts span healthcare, biotechnology, agriculture, and environmental science. Additionally, Thailand collaborates closely with China, focusing on infrastructure development, renewable energy, and information technology through joint research projects and academic exchanges. Japan is also a significant collaborator, with partnerships in advanced manufacturing, robotics, healthcare technology, and environmental conservation. Furthermore, Thailand participates in research initiatives with European Union countries under programs like Horizon 2020, covering diverse disciplines such as biomedicine, sustainable development, and social sciences. Moreover, collaboration within the ASEAN region is notable, with joint efforts addressing public health, agriculture, disaster management, and cultural preservation. These collaborations underscore Thailand's commitment to global scientific cooperation and knowledge sharing across continents and disciplines (Ministry of Higher Education, Science, Research and Innovation, 2022).

According to the Nature Index, which assesses research collaborations with Thailand, China secured the top position with 24.49% from December 1, 2021, to November 30, 2022, followed closely by the United States at 22.74%. During this period, Thailand published 268

scientific papers, placing it 40th globally, with a consistent increase in output shares (fractional count) over the last 5 years (figure 24). The top ten Thai institutes contributing to research publications are predominantly universities, with only two government agencies included. (Table 13)

Figure 22

Thailand's share output for the past 5 years



Note. Nature Index, December 1, 2021 to November 30, 2022

To enhance its competitiveness and promote sustainable economic development, Thailand can engage in various forms of international collaboration, including exchange programs, research partnerships, and talent mobility initiatives. One effective strategy is establishing representative agencies in key countries. Currently, MHESI operates three such agencies worldwide: in the United States (covering North and South America), Belgium

(representing the European Union), and China. For example, the Office of Science and Technology at the Royal Thai Embassy in Washington, D.C., is dedicated to initiating and fostering science and technology collaborations between Thailand and countries in the Americas. The agency's role is to represent the Ministry in seeking collaboration opportunities, creating activities and matching partners, pursuing MOUs for further collaborations, and providing support such as funding, information, and connections.

Table 12

Top 10 Institutions from Thailand by Share

Institution	Count	Share
1. Vidyasirimedhi Institute of Science and Technology (VISTEC)	31	17.05
2. Chulalongkorn University (CU)	102	11.98
3. Khon Kaen University	22	7.61
4. Center of Excellence for Innovation in Chemistry (PERCH-CIC)	6	3.73
5. Mahidol University (MU)	57	3.45
6. King Mongkut's University of Technology Thonburi (KMUTT)	10	3.37
7. Suranaree University of Technology (SUT)	74	3.11
8. Kasetsart University	18	2.90
9. National Science and Technology Development Agency (NSTDA)	7	2.13
10. Chiang Mai University (CMU)	22	1.93

Note. Nature Index, December 1, 2021 to November 30, 2022

Additionally, Thailand has been sending students abroad for higher education, enabling them to gain a world-class education, bring valuable knowledge back home, and expand their networks with professors and classmates. Many of these students maintain collaborations with their international peers after returning home.

The Thai government focuses not only on enhancing international collaborations but also on fostering synergy among local agencies. The new structure of MHESI aims to bolster academic autonomy and flexibility among university scholars while integrating higher education, national research, and innovation initiatives. These efforts align with the twenty-year national strategy and evolving government policies.

Developing nations like Thailand increasingly adopt the quadruple helix approach (MHESI, 2022, p. 53), recognized for its potential to drive economic development and bolster competitiveness. Science Parks, for instance, serve as vital platforms, fostering an innovative ecosystem where universities facilitate collaboration between the government and industry, with industry playing a pivotal role in research and development. Thailand Science Park (TSP) in Pathum Thani, near Bangkok, is overseen by the National Science and Technology Development Agency (NSTDA), a subsidiary of MHESI. Additionally, three regional science parks, each specializing in flagship projects like rice, livestock, and rubber technology, are strategically located in the northern, northeastern, and southern regions. Notably, NSTDA's flagship initiative, the Eastern Economic Corridor of Innovation (EECi), aims to establish itself as ASEAN's premier innovation hub. The Thai government has also instituted various programs to promote research and innovation within industries and small-scale enterprises, further bolstering collaboration between the government, universities, and industries.

The subsequent discussions focus on Thailand's relations with the United States and China. The selected pairs of international relationships for this study are as follows: Regarding annual co-authored publications, the United States emerges as Thailand's primary research partner, while the number of co-authored publications between Thailand and China exhibits the most rapid growth. Additionally, Thailand maintains a triangular relationship involving the

United States and China. The country enjoys robust and longstanding connections with both nations. However, given the tensions existing between the United States and China, Thailand exercises caution in avoiding over-reliance on either party.

Scientific Collaboration between Thailand and the United States

For close to two centuries, Thailand and the United States have maintained a military treaty alliance and forged economic partnerships. Following World War II, the Korean War, and the Vietnam War, their relations, especially in military and security aspects, have deepened. Thailand has provided the United States with access to crucial facilities like air bases and naval bases. Additionally, Thailand hosts annual Cobra Gold military exercises and various US military training programs (Chanlett-Avery et al., 2015).

In addition to military cooperation, Thailand and the United States engage in various other forms of collaboration. Leveraging Thailand's strategic location and its amicable relations with neighboring countries, the US supports Thailand's leadership in the Mekong region through initiatives like the Mekong-US Partnership (MUSP). This partnership aims to bolster cross-border economic ties and tackle emerging challenges in the region (U.S. Department of State, 2022b). Furthermore, Thailand stands as the United States' 25th largest export destination. Following Japan and China, the United States ranks as Thailand's third-largest trading partner. Moreover, the United States holds the position of Thailand's third-largest foreign investor, with a significant \$17.5 billion in foreign direct investment (FDI) (U.S. Department of State, 2022a).

Research cooperation between the two countries has been active for several decades. Thai agencies have worked with a number of U.S. research agencies such as the Centers for Disease Control and Prevention, The Armed Forces Research Institute of Medical Sciences, and the U.S. Agency for International Development (USAID). The collaborations cover a variety of topics

such as medical research and innovation, environment management, and energy management (U.S. Department of State, 2022a).

Following COVID, global health became one of the most important areas of collaboration between countries, including Thailand and the United States. Furthermore, the two countries are focusing on energy collaborations in order to develop energy resources and renewable energy innovation. The countries acknowledge the global risks posed by climate change and are committed to addressing environmental issues. The United States intends to make Thailand a regional hub for innovation and climate change leadership. A number of collaborative projects were undertaken to assist Thailand in increasing its capacity in critical energy supply chains, in order to support its Nationally Determined Contribution (NDC) and its goal of becoming carbon neutral by 2050 (U.S. Department of State, 2022b).

Based on various indicators such as centrality, the United States holds the position of the most significant country in global science, with European nations closely following suit (National Center for Science and Technology Evaluation, NCSTE, 2017). However, Edler and Boekholt's (2001) examination of U.S. strategic documents revealed a nuanced perspective. While the US government has made efforts to prioritize national science and research through institutional adaptations, such as appointing a new science adviser within the Department of State in 2000, it has not actively promoted international collaborations. This lack of emphasis on international partnerships may stem from the belief among some U.S. congress members that the country already leads the world in science and technology, thus negating the necessity of engaging in risky collaborations with international partners.

A report by the Subcommittee on International Science and Technology Coordination (ISTC) (2022) highlights several gaps in the United States' approach to scientific collaboration.

While the United States has excelled in investigator-driven collaboration, there are limitations, such as a narrow focus on specific issues that restrict opportunities. In contrast, many foreign governments are more inclined towards supporting larger-scale collaborations. Additionally, the United States must find a balance between mission-driven scientific activities and national security interests to prevent silos between development, security, and research priorities. The subcommittee recommends several measures to address these challenges. These include intensifying efforts to attract and retain STEM talent from other countries, particularly from lower and middle-income countries (LMICs), breaking down barriers between agencies, exploring additional mechanisms and opportunities for initiating international collaborations, and promoting the mobility of scientists and policymakers to enhance their understanding of international practices and networks. These initiatives aim to strengthen the United States' position in global science and foster fruitful international partnerships.

For decades, the United States has maintained its status as the global leader in international science and technology (S&T) investment, commanding over a quarter of the world's total investment. The gap between the United States and the second-highest spender was significant, with the U.S. investing more than double the amount. However, competition in this arena has intensified notably. In 2019, the United States contributed 27% (\$658 billion) of global S&T investment, but China made substantial strides by doubling its investment, reaching 22% (\$526 billion). This surge in Chinese investment raised concerns within the U.S. government, viewing it as a potential threat to the country's interests. They interpreted China's increased investment as a strategic move aimed at surpassing the United States in both civilian and military capabilities.

While the United States may still lead in terms of research impact globally, recent developments indicate a shifting landscape. In 2018, both the European Union and China joined the ranks of highly-cited countries and economies for science and engineering publications, signaling their growing influence in the field (ISTC, 2022). This trend underscores the evolving dynamics of global S&T investment and the need for strategic responses to maintain competitiveness.

In addition to facing challenges in establishing long-term membership in international scientific organizations/programs and initiating quick-win bilateral S&T initiatives for diplomatic purposes, the United States encounters difficulties in forming partnerships with lower and middle-income countries (LMICs) compared to high-income countries. This difficulty stems from the differing needs and readiness levels of potential LMIC partners. According to the ISTC report, addressing this issue requires the US government to adopt more flexible and longer-term approaches to support international scientific collaborations. Additionally, it recommends considering foreign policy interests and including nations that may not qualify for traditional development assistance in these efforts. Such measures can help bridge the gap and facilitate meaningful partnerships with LMICs, ensuring broader participation and mutual benefits in international scientific endeavors.

Scientific Collaboration between Thailand and China

China is another important partner for Thailand. However, the relationship differs markedly from that with the United States in terms of historical context, economic priorities, strategic interests, collaboration areas, and diplomatic approaches.

In 1978, China experienced a significant transformation under the leadership of Deng Xiaoping, a revolutionary figure and military commander. Despite the continued adherence to

centralized authority, Deng Xiaoping implemented sweeping changes in the Chinese economy, including agricultural and tax reforms, as well as substantial investments in science, technology, and military endeavors. These reforms, coupled with abundant cheap labor, led to a remarkable increase in Chinese exports over the past few decades. As a consequence of these reforms, economic competition between China and the United States has intensified significantly in recent years. China's emergence as a global economic powerhouse has positioned it as a formidable competitor to the United States in various sectors.

Between 2006 and 2016, the Chinese government substantially augmented its investment in research and development (R&D), nearly doubling it from 1.42% to 2.1% of the GDP. This increase in investment was accompanied by the implementation of favorable policies, resource provision, and the promotion of scientific mobility. Consequently, China witnessed a dramatic surge in the number of research publications during this period (ISTC, 2022). The transformation resulted in a remarkable 4.4-fold increase in collaborative publications, reaching 71,000 publications, which accounted for 18.6% of the global total. Furthermore, China experienced a notable rise in citation impact in 2015 (NCSTE, 2017). Leading academic institutions such as Peking University and Beijing Normal University emerged as key contributors to international collaborative publications. Collaborations with institutions like the French National Centre for Scientific Research (CNRS) and entities affiliated with the U.S. Department of Energy (DOE) were particularly prominent.

In terms of research fields, China exhibited robust activity in chemistry, physics, engineering, clinical medicine, and materials sciences, with a strong emphasis on both domestic and international collaborations. However, China's involvement in space science collaborations was comparatively less extensive when compared to its engagements in other research areas.

However, according to Feng (2020), there exists a debate regarding China's true influence on global research. Despite substantial investments in research and a significant uptick in publication numbers, a relatively small proportion of Chinese publications receive citations from other countries. The researcher conducted a bibliographic analysis and identified a phenomenon termed "capital discount" in China's research landscape. This phenomenon arises from an abundance of resources leading to a saturation effect and reduced motivation. Although the Chinese government allocates ample economic resources, the size of grants does not always translate into optimal research strategies, such as selecting journals with higher impact tiers. Conversely, social capital, including networks and opportunities for collaboration with international partners, is associated with more thoughtful selection of journal tiers. The researcher suggests that fostering international collaboration is imperative, as it has a positive impact on enhancing the effectiveness of China's research efforts.

According to an interview with the Chinese Ambassador to the United States, Qin Gang, conducted in 2021, the Chinese government took three specific measures to engage international partners: 1) sharing technologies that address the needs of partner countries and can be used to promote economic development in those countries; 2) establishing joint laboratories to conduct collaborative research in various fields; and 3) promoting young scientists through training classes and mobility opportunities (ISTC, 2022).

The collaboration between Thailand and China increased significantly after the implementation of the China-ASEAN Free Trade Agreement in 2010. As a result, China surpassed the United States as Thailand's largest trading partner. Thailand and China have signed several agreements relating to infrastructure development, environmental protection, and strategic cooperation.

Economic competition is not only a conflict between superpower countries; science and technology have become new areas in which countries are attempting to advance and gain leadership positions. Thailand's strategic partnerships with both the United States and China illustrate its commitment to leveraging these relationships for its development. Both partnerships offer unique advantages, positioning Thailand to benefit from diverse expertise and resources.

Thailand has indirectly profited from the tensions between China and the United States. For instance, the country has capitalized on exporting Chinese substitutes to the U.S. market and US substitutes to the Chinese market. Historically, Thailand tried to remain neutral, aligning its agenda with that of superpowers, leading to fragmented unity in various areas. However, recognizing the unsustainability of this approach, the Thai government acknowledges the necessity of mitigating future risks by fostering sustainable growth in the domestic market and enhancing competitiveness in the global arena. Moreover, Thailand may pivot towards issue-based diplomacy, enabling the nation to adopt diverse positions while prioritizing its needs and fostering unity. This strategic shift is seen as essential for navigating the complexities of international relations and safeguarding Thailand's interests (Puttasri & Wanlayangkul, 2022; Wongwaisiriwat et al., n.d.).

Triangular Relationship between Thailand, the United States, and China

Thailand, though small in comparison to many global powers, recognizes the significance of collaborations with more advanced nations, particularly in science and technology. Political and economic transformations in Thailand over recent decades have reshaped its relationship with the United States. Rather than seeking assistance, Thailand aims to showcase its readiness to engage in substantive collaborations with the United States, despite its size. This shift

underscores Thailand's commitment to fostering mutually beneficial partnerships and leveraging its strengths in the global arena.

Smaller countries often employ various strategies to establish connections with more developed counterparts. However, implementing these strategies typically demands significant investment, posing challenges for many developing nations (Connell et al., 2017). Fortunately, Thailand is positioned to adopt some of these strategies, including establishing a representative agency in the United States and facilitating exchange programs and visits. For instance, MHESI has arranged visits to Thailand for policymakers, researchers, and coordinators from esteemed entities such as the U.S. Department of State, NSF, and USGS. These programs provide an opportunity for guests to explore Thai scientific and research organizations, as well as universities, gaining insights into the country's capabilities and research interests, which may pave the way for future collaborations.

Fitzgerald et al. (2021) found that since 2000, scientific collaborations have become increasingly localized, with countries forming closer ties with others in their respective regions. This trend suggests that many nations and regions previously lacking in research capacity are becoming more self-reliant and less reliant on assistance from countries in other regions, particularly in the West. Furthermore, numerous initiatives and programs are underway to foster scientific and research collaborations within Asian regions (Varghese, 2022).

The trends discussed by Fitzgerald et al. (2021) are mirrored in the case study. While the United States may retain its dominance in international science and technology (S&T) investment, China has significantly bolstered its global presence by doubling its international investment and adopting more adaptable funding policies. China actively engages with low- and middle-income countries (LMICs), offering financing, loans, and fostering partnerships, while

also seeking collaborations with high-income nations. For a country like Thailand, positioned in the upper-middle-income bracket, securing financial support from China has become more viable than from the United States, facilitating the enhancement of its S&T capabilities (ISTC, 2022). Moreover, given their regional proximity and longstanding ties, Thailand and China share common challenges, notably poverty. Both nations acknowledge the pivotal role of science, technology, and international cooperation in driving economic and social advancement.

Thailand exhibits the highest number of co-authored articles with the United States, while the collaboration between Thailand and China demonstrates the highest compound annual growth rate. Analyzing the trend of co-authored articles between Thailand and these two countries across ten disciplines from 2006 to 2020, it is evident that the majority of collaborations between Thailand and the United States are concentrated in the field of medicine. Conversely, collaborations between Thailand and China have shown substantial growth across all disciplines during the same period.

In this chapter, I explored Thailand's scientific collaboration both locally and internationally, highlighting its strategies to advance its science and technology sectors. The next chapters discuss the findings derived from the quantitative and qualitative methodologies. The quantitative analysis provides a statistical overview of Thailand's scientific collaboration trends and triple helix relations of local sectors in Thailand, while the qualitative insights offer deeper understanding through interviews and case studies.

Chapter 6

Findings and Quantitative Analysis: Examining Collaborations Through Co-Authorship

This chapter presents the findings from quantitative and qualitative analyses which aim to address the research questions:

RQ1: What are the connections between local and international research collaborations, with a comparative analysis of Thailand, the United States, and China?

RQ2: How do social factors and strategic considerations influence the pursuit of scientific collaborations?

To address these research questions, I utilize co-authored publication data, mutual information analyses, and correlation analysis. These methodologies enable us to explore the patterns of research collaborations among local sectors in Thailand and between Thailand and foreign partners, including collaborations with the United States and China. Furthermore, I conducted qualitative interviews to gain insights and explanations regarding the relationships revealed in the quantitative analysis.

The quantitative analysis begins with an examination of co-authored publication data to identify trends and patterns in scientific collaborations. I analyze the volume and growth of these collaborations over time, focusing on both domestic partnerships within Thailand and international partnerships with the United States and China. Next, mutual information analysis is used to measure the amount of information shared between different entities in the research network. This helps us understand the strength and significance of collaborations and how information flows between local and international partners.

This chapter presents the quantitative findings and observations based on these methodologies. This quantitative analysis lays the foundation for a deeper understanding of the dynamics of scientific collaboration in Thailand and its interactions with key international partners. The chapter is organized into three essential components. Firstly, it presents data on Thailand's research publications, covering both local and international collaborations, with a specific focus on publication numbers and proportions. This section aims to offer a general overview and identify trends in Thailand's local and international collaborations, especially with the United States and China, within the chosen scientific disciplines.

The following section utilizes mutual information analysis to examine the dynamics of interactions among local sectors in Thailand within the context of both local and international research collaborations. The objective of this segment is to investigate the collaborative synergy between local sectors when engaged in research activities in various collaborative settings. The specific goal is to analyze the collaborative dynamics among universities, government, and industry, with the belief that tighter collaborations within these sectors contribute to fostering innovation and economic development in the country. Subsequently, I seek to understand the specific types of collaborative settings where these dynamics occur. Additionally, I delve into various disciplines to explore the influences of distinct cognitive factors that could affect the coordination between sectors.

Lastly, the section utilizes binary logistic regression analysis to determine if significant relationships exist between interactions among local sectors, the sources of local funding, and engagement with international partners. The objective is to explore potential correlations among these elements which could enhance the understanding of the collaborative landscape in Thailand and shed light on potential factors influencing these collaborations.

This multifaceted analysis will provide valuable insights into the particulars of collaborative activities, aiding policymakers, researchers, and stakeholders in optimizing strategies for fostering a robust research environment. Through this comprehensive exploration, I hope to contribute valuable knowledge that can inform future initiatives aimed at promoting innovation, scientific advancement, and effective collaboration between developed and developing countries.

Thailand's collaborative publication numbers and proportions

When examining the number of journal publications from Thailand from 2006 - 2022, it is evident that they have notably increased over time. The percentage of domestic collaborations varied between 50% and 60%, leading to 40% to 50% of international publications. During the study period. The proportion of co-authored publications between Thailand and other countries (except the United States and China) has remained steady at 30% (Figure 11 Chapter 4).

The number of Thai-U.S. and Thai-China co-authored publications has exhibited an increasing trend. While co-authored publications with the United States continue to surpass those with China, the proportion of publications between Thailand and the United States has been declining from 16% to 8% while those between Thailand and China have been increasing from 2% to 7% (Figure 23). I found that the proportion between Thailand and overall international partners, excluding the United States and China, has remained relatively stable. This suggests that, although the number of Thai-U.S. co-authored publications has consistently increased, the overall proportion has been impacted by the significant rise in the number of Thai-China co-authored publications. When examining the annual growth rate of Thai international publications with the United States and China from 2006 to 2022, it is evident that the annual

growth rate of Thai-China co-authored publications consistently surpass those between Thailand and the United States in almost every year (Fig. 24).

Figure 23

Percentage of Thai-U.S., Thai-China coauthored articles

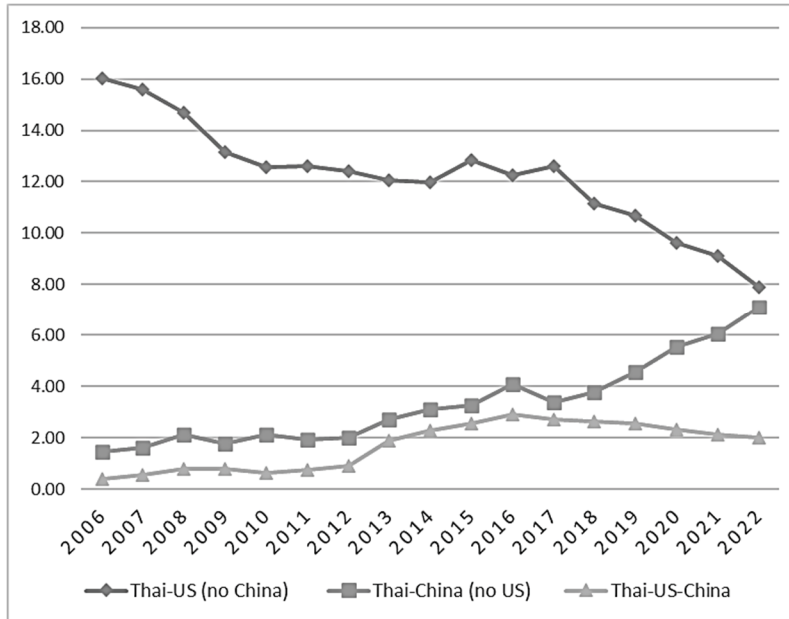
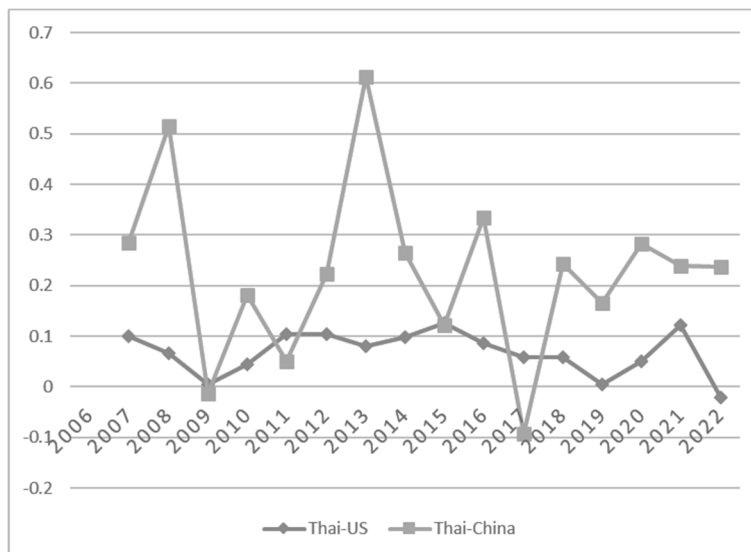


Figure 24

The annual growth rate of Thai international publications with the U.S. and China from 2006 - 2022



To examine the different cognitive and social elements of different disciplines, I examine the patterns of Thailand's domestic and international publications in three disciplines: medicine, agricultural and biological sciences, and engineering. According to Figure 14 in Chapter 4, the majority of publications in Medicine were produced locally. The number of Thai-U.S. coauthored publications has been increasing consistently while Thai-China coauthored publications made an evident uptrend after 2017 (Fig. 25). The proportions of international publications between Thailand and the United States have been consistent with a slight drop after 2019. The proportions of international publications between Thailand and China continuously increased (Fig. 26). Three other prominent countries engaged in co-authored publications with Thailand are the United Kingdom, Japan, and Australia. Although the number of co-authored publications with Thailand from these countries is increasing, the proportions have remained relatively stable throughout the observation period.

Figure 25

The number of Thai-US and Thai-China coauthored publications in medicine (2006 – 2022)

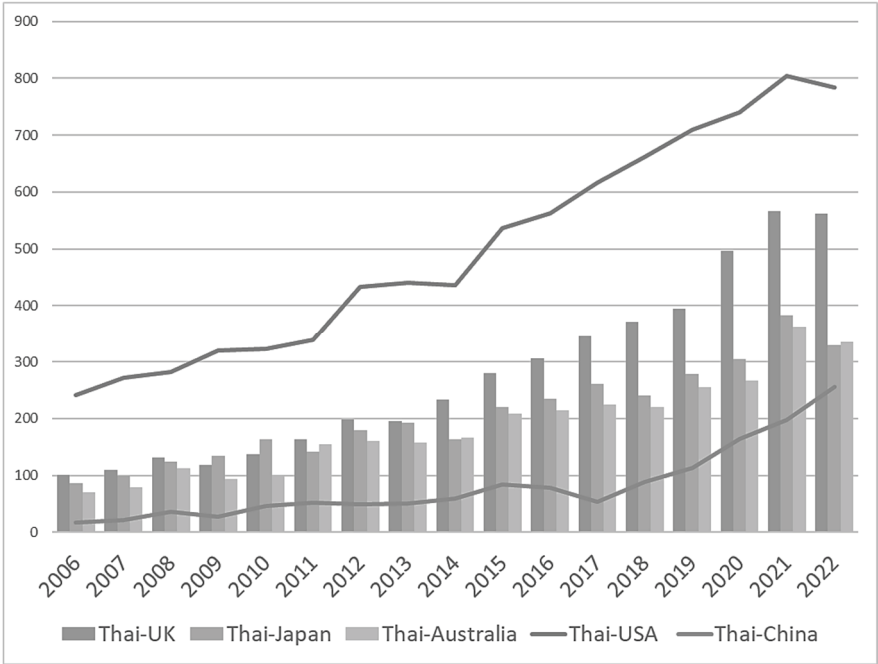
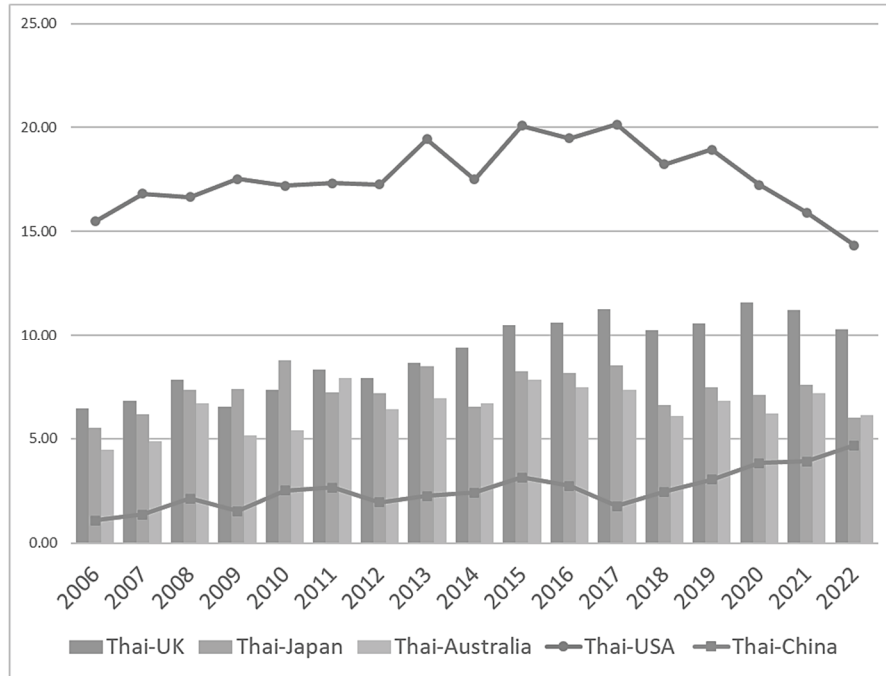


Figure 26

The proportion of Thai-U.S. and Thai-China coauthored publications in medicine (2006 – 2022)



According to Figure 27, both the number of Thai-U.S. and Thai-China co-authored publications in agricultural and biological sciences exhibit an upward trend. Similar to the field of medicine, Thailand also collaborates significantly with other notable countries, including Japan, the United Kingdom, and Australia. Co-authored publications between Thailand and Japan are at a comparable level to those between Thailand and the United States. However, in 2020, the number of Thai-China co-authored publications surpassed that of Thai-U.S. co-authored publications. The proportions of Thai-U.S. coauthored publications are steadily declining, whereas those between Thailand and China are steadily increasing (Fig. 28). The rising proportion of Thai-China co-authored publications has an impact on the proportion of Thai-Japan co-authored publications, causing it to trend downward. However, the proportions of Thai-UK and Thai-Australia co-authored publications remain stable.

Figure 27

The numbers of Thai-US and Thai-China coauthored publications in agricultural and biological sciences between 2006 – 2022

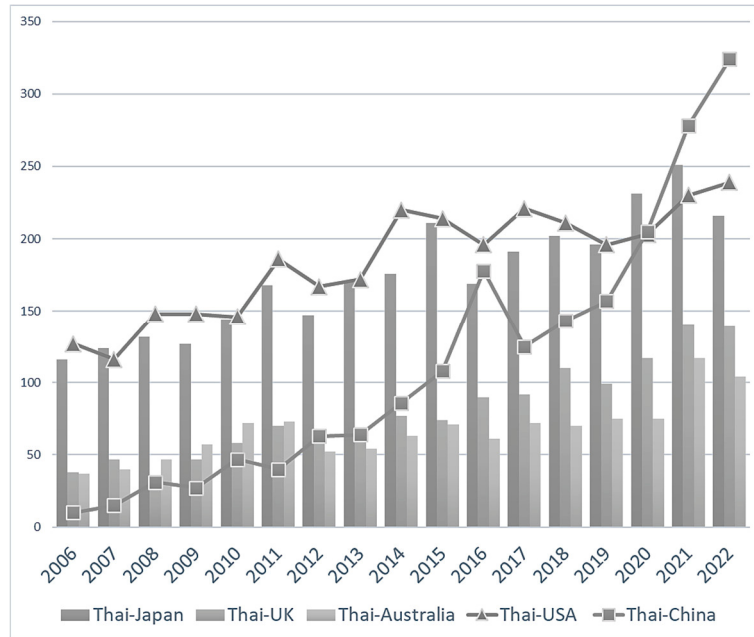


Figure 28

The proportion of Thai-US and Thai-China coauthored publications in agricultural and biological sciences between 2006 – 2022

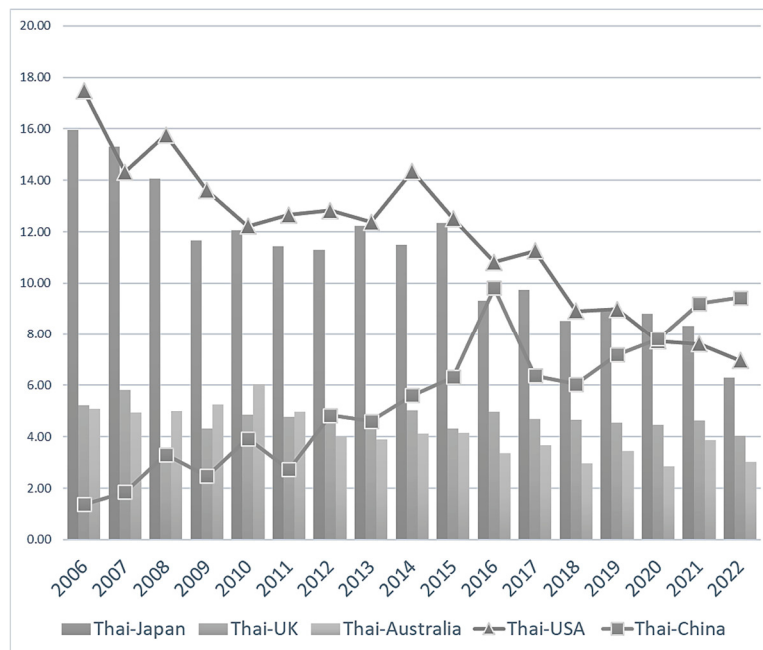
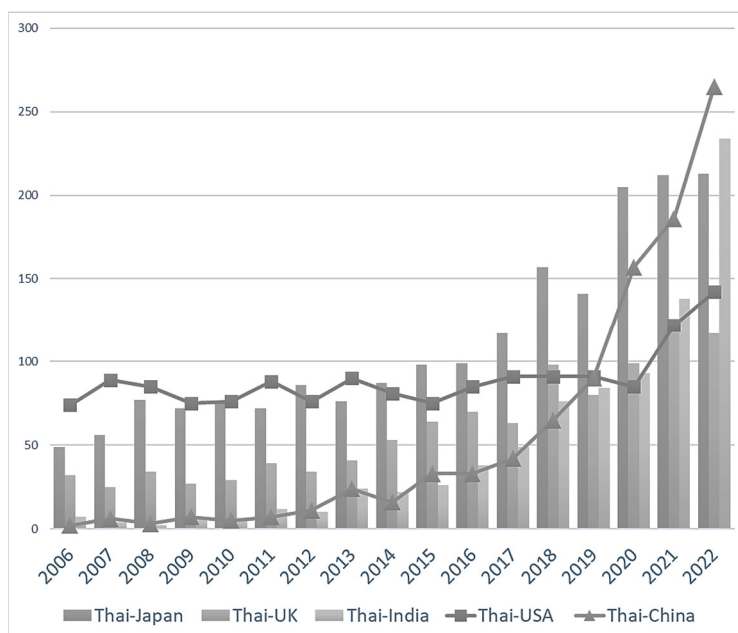


Figure 15 (Chapter 4) shows that local engineering publications have been falling in recent years, whereas international publications have increased. Notably, the number of Thai-U.S. co-authored publications in engineering remained constant from 2006 to 2020 and experienced a notable increase after 2020. Conversely, the number of Thai-China co-authored publications demonstrated a distinct upward trend since 2014 (Fig. 29). Consequently, there is a noticeable convergence in the proportions (Fig. 30). The proportions of co-authored publications between Thailand and the United States in Engineering are decreasing, while those between Thailand and China are consistently on the rise. In contrast to medicine and agricultural and biological science, the other three primary countries collaborating with Thailand are Japan, the United Kingdom, and India (instead of Australia). Interestingly, both the number and proportion of Thai-India co-authored publications are at the same level as Thai-China co-authored publications.

Figure 29

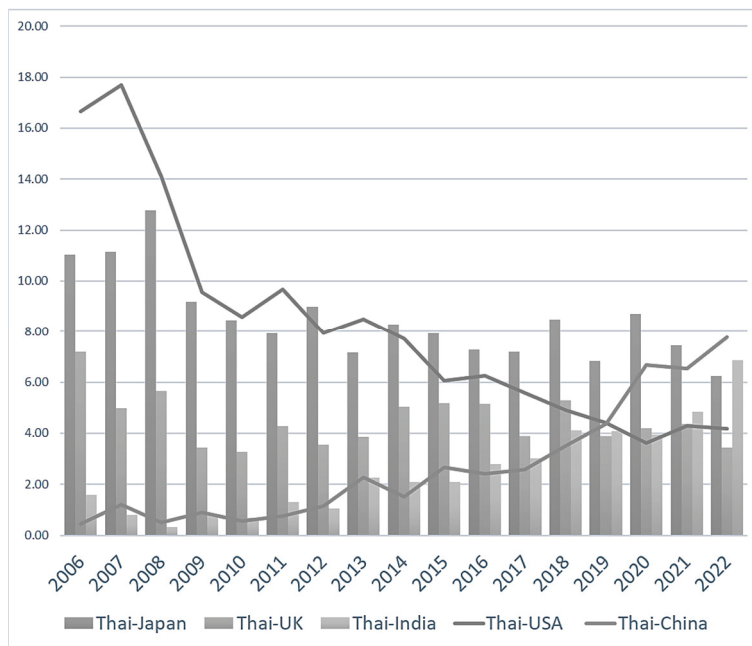
The number of Thai-US and Thai-China coauthored publications in engineering (2006 – 2022)



A few key observations emerge from this part of the data. First, collaboration between Thailand and the United States is notably higher than with any other country, particularly in the field of medicine. In other fields, such as agricultural and biological sciences and engineering, the trends are less pronounced. Second, the number and proportion of Thai-China co-authored publications exceed those of Thailand and the United States in agricultural and biological sciences and engineering. However, this trend is not observed in medicine. These observed trends highlight specific areas that require further focus in the later analysis.

Figure 30

The proportion of Thai-U.S. and Thai-China coauthored publications in engineering (2006 – 2022)



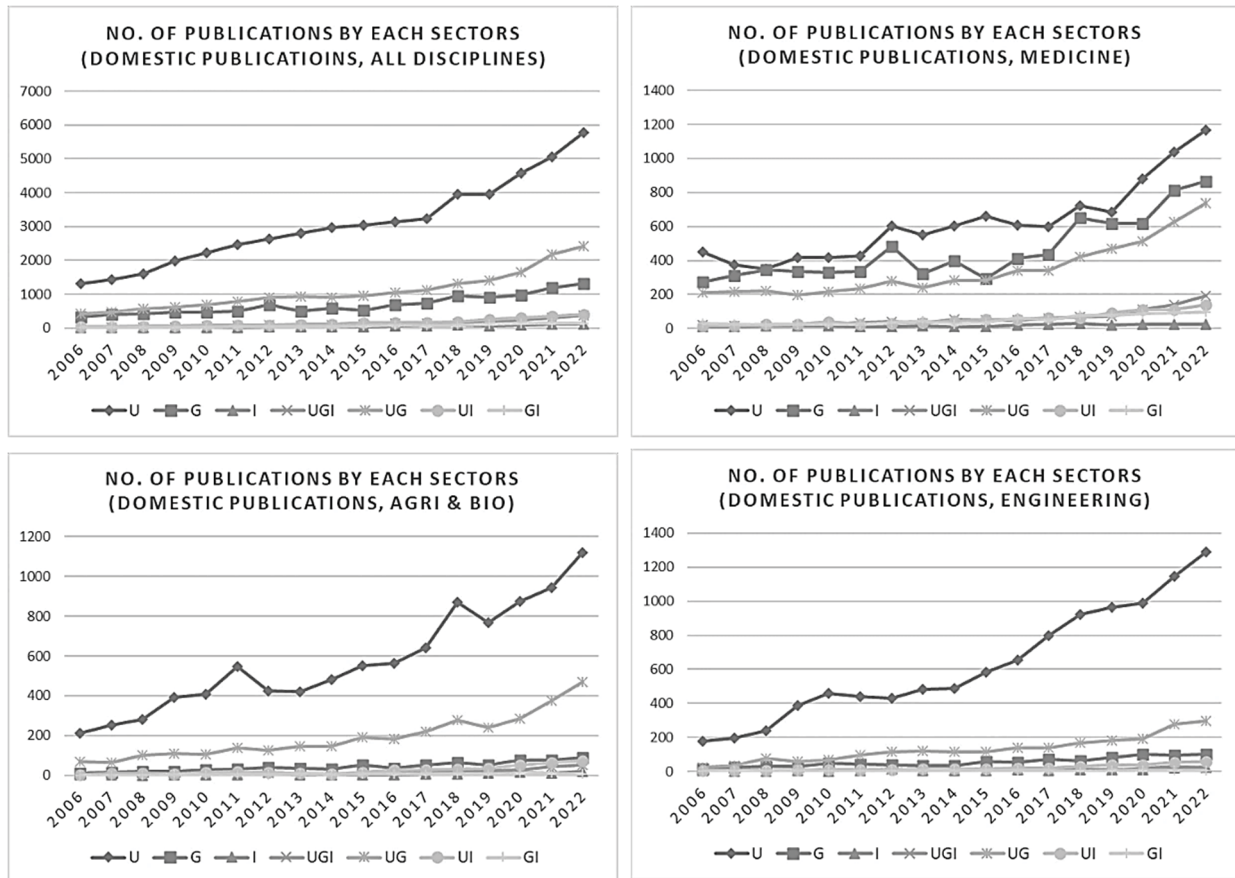
The collaborations between local sectors in Thailand in different collaborative settings

Then I classified Thai publications produced by various sectors as well as co-authored publications by different sectors. I use “U” for university, “G” for government agencies, and “I” for the private sector. Figure 33 shows the numbers of Thailand’s Local Publications in all disciplines, medicine, agricultural and biological sciences, and engineering. I discovered that university publications are the most prominent in all disciplines as well as in agricultural and biological sciences, and Engineering. However, governmental agencies and university-government collaborations also produce a significant number of medical publications. (Figure 31, top right).

Considering the proportion of publications produced by each local sector and the types of collaborations between local sectors at the local level in different disciplines, I found that while the university (U) remains the primary contributor to local research publications, the proportions have slightly declined in recent years. A similar observation applies to the government sector (G). Interestingly, the contribution by sole industry (I) may not change much over time, but collaborations between industry and other sectors show an uptrend, especially collaborations between university and industry (UI), and between university, government, and industry (UGI). This could suggest that the industry is becoming more actively involved in local research activities, particularly through collaborations with other sectors.

Figure 31

The numbers of Thailand's Local Publications in all disciplines (top, left), medicine (top, right), agricultural and biological sciences (bottom, left), and engineering (bottom, right).



Next, I compare local and international collaborations in different disciplines. In Figure 32, encompassing all disciplines, the comparison reveals the number of Thai domestic and international publications between Thailand and all other countries, the United States, and China. The data indicates that Thai universities are the primary contributors to both domestic and international publications. However, a distinct observation emerges when scrutinizing Thailand-

U.S. co-authored publications, highlighting the significant involvement of government entities in research (Figure 32, bottom left).

I also compare the proportions of publications across disciplines from various local sectors in Thailand, both with and without international partners. While university and government contributions slightly decline locally, they remain stable with international collaboration. Industry collaborations, particularly between universities and industry, and among universities, government, and industry, show an increasing trend locally and internationally.

Figure 32

The numbers of Thailand's domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in all disciplines

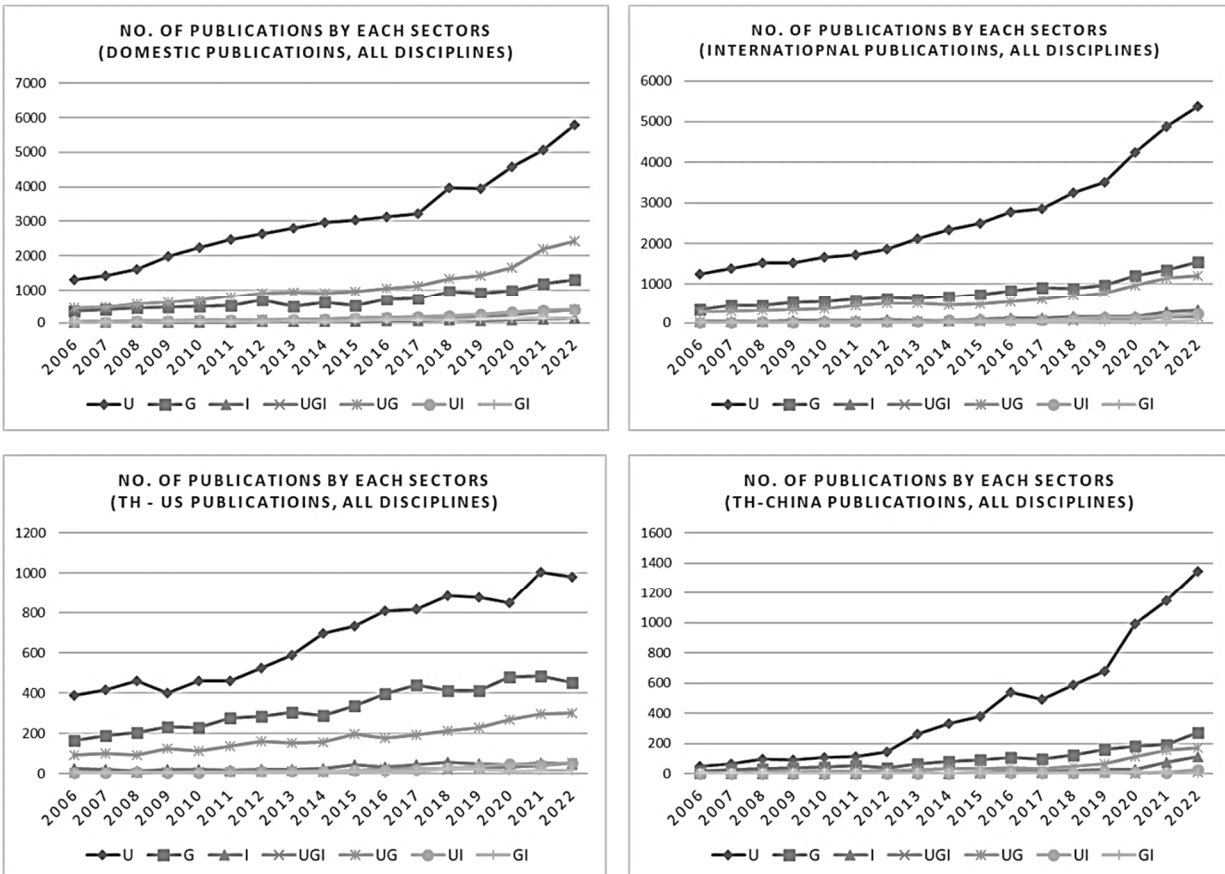


Figure 33 shows the number of Thai domestic and international publications in medicine. Surprisingly, while universities are the most important actors in publishing domestic and international publications as well as co-authored publications with China, Thai government agencies are the most important collaborators in publishing papers with the United States.

Figure 33

The numbers of Thailand's domestic publications (top, left), international publications (top, right), Thai-US publications (bottom, left), and Thai-China publications (bottom, right) in Medicine

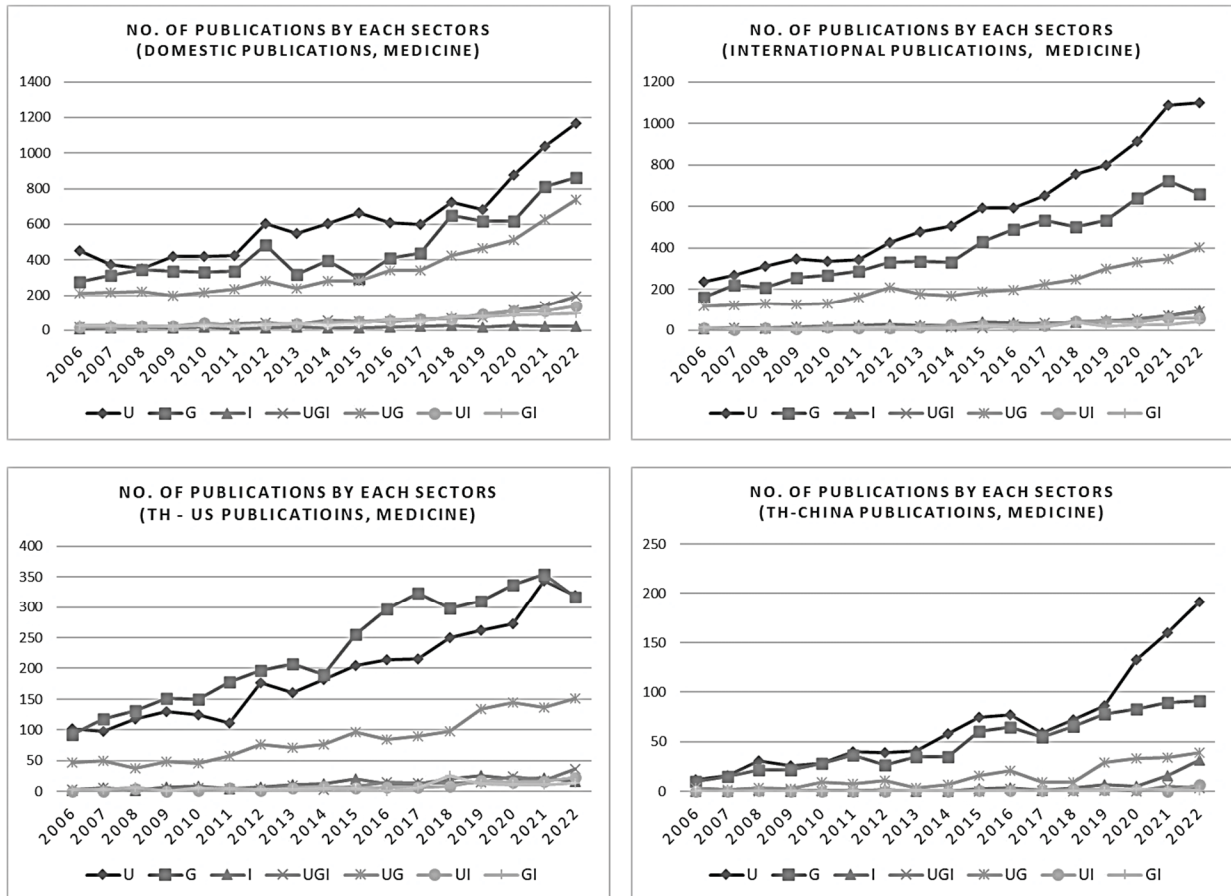


Figure 34 and Figure 35 show When examining the number of Thai domestic and international publications in agricultural and biological sciences, as well as engineering, it becomes clear that Thai universities are the most active contributors to both local and international research in these fields. Especially in Engineering, the number of publications from all other sectors, aside from universities, is notably small and presents very limited changes in recent years.

Figure 34

The numbers of Thailand's domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in agricultural and biological sciences

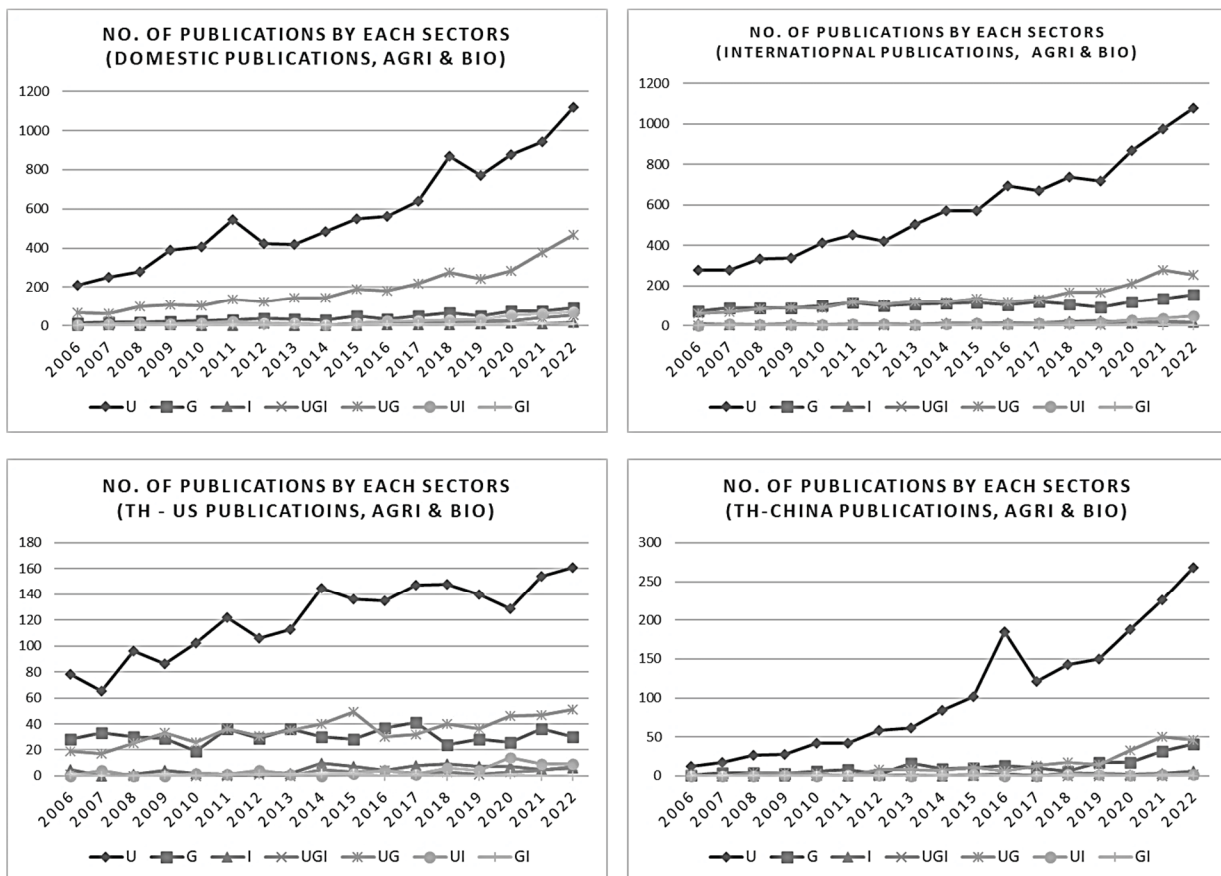
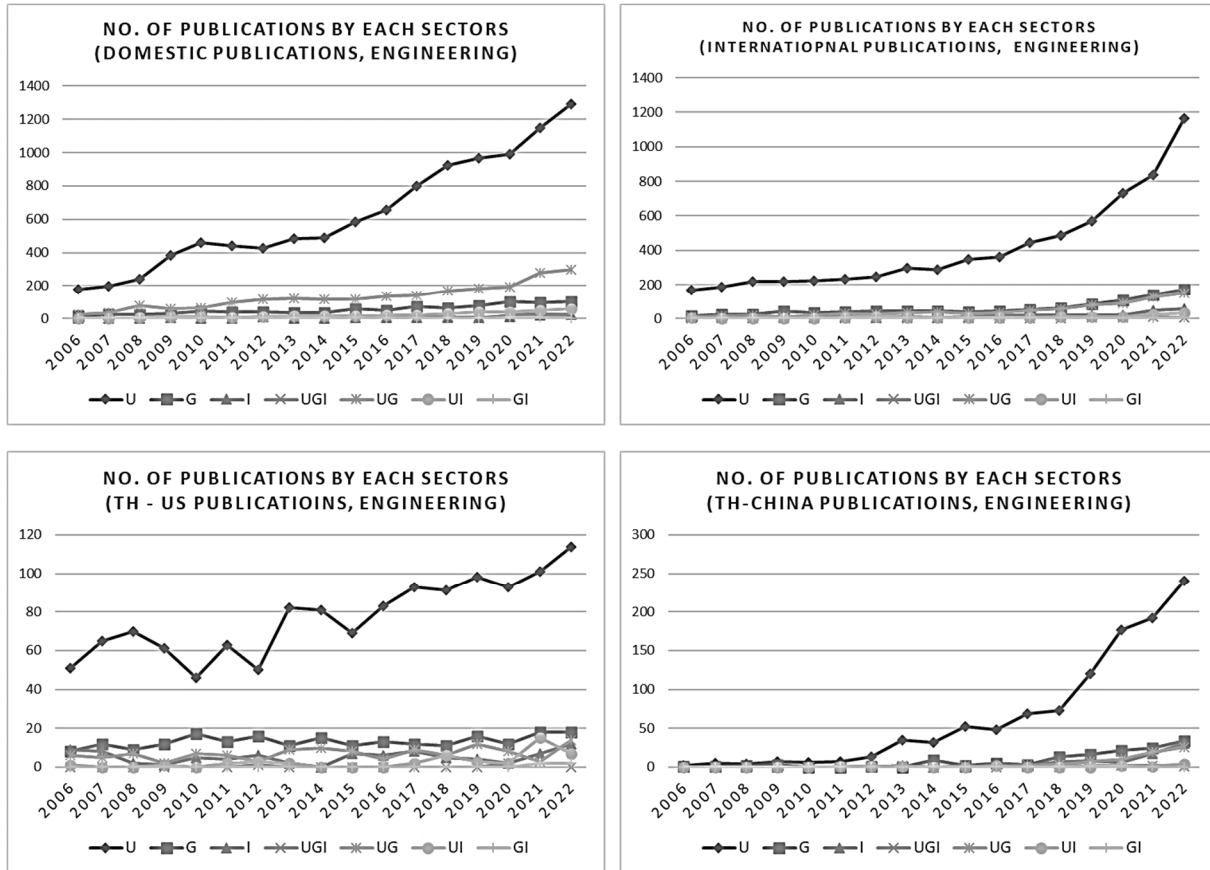


Figure 35

The numbers of Thailand's domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in engineering



In this section, I analyze the pattern of co-authored publications between local sectors in Thailand across various collaborative settings, both with and without foreign partners, using whole numbers and proportions of publications. Several key observations emerge. First, universities are the primary producers of research publications. Second, the government is more active in producing publications when collaborating with American partners than with Chinese partners. Third, in the medical field, the government shows a more active role compared to its

involvement in engineering and agricultural and biological sciences. In the next section, I employ mutual information analysis to further investigate collaboration patterns, aiming to derive deeper insights from the data, especially concerning the dynamics of collaboration between local sectors in different collaborative settings.

Co-authored publications on mutual information analysis. To explore the connections between local and international scientific collaborations, I begin by employing mutual information, a metric developed by Etzkowitz and Leydesdorff. This metric helps us quantify the synergy among interactions within various local sectors in Thailand and their trends during the period of study. In this study, I use mutual information to assess the relationships between universities, government entities, and industries in both two-dimensional and three-dimensional contexts. I also investigate how the synergy of their collaborations evolves over time. This methodology enables us to explore the interdependent relationships among these sectors, taking into account their individual contributions as well as the contributions stemming from collaborations with other sectors. Additionally, this metric facilitates comparisons across various scenarios, including scenarios with the inclusion or exclusion of international partners in the research ecosystem.

Figure 36 shows the mutual information of domestic collaborations among local sectors in Thailand across different disciplines, including all fields, medicine, agricultural and biological sciences, and engineering. The higher T values in two-dimension mutual information means the greater synergy of the interaction between two sectors. At the local level, collaborations between universities and governments (UG), as well as between government and industry (GI), exhibit significantly higher synergy compared to university-industry collaborations (UI), which display much lower synergy. Research collaborations in the field of medicine at the local level are

exceptionally vibrant when universities collaborate with government agencies. In all areas except medicine, the T values of university-industry (UI) interactions are below zero, indicating that university-industry collaborations have not gained synergy during the last decade. In other words, the university has contributed a significant number of research publications, and the co-authored publications between the university and industry represent a relatively small portion. As a result, the synergy between the university and industry appears to be low. In summary, collaborations between two local sectors in Thailand have generally maintained their level or experienced modest growth throughout the study period.

Figure 37 illustrates the three-dimensional T values within local sectors in Thailand, mirroring the findings of Ye et al.'s 2013 study. Their research suggests that globalization has gradually eroded local Triple Helix relationships in many countries since the mid-1990s. In contrast to two-dimensional mutual information, a higher T value in three-dimensional mutual information suggests weaker synergy in collaborations among the three sectors. In the context of Thailand, the three-dimensional T values among local sectors have shown a slight increase over time, indicating a gradual loss of synergy in local collaborations. Notably, the T value for the field of medicine surpasses those in all other disciplines (lowest synergy), highlighting that the majority of Thailand's research activities in medicine are concentrated within a single sector (either university or government) or involve collaborations between universities and government agencies, with limited engagement of other sectors or collaborative configurations.

Figure 36

The mutual information of domestic collaborations among local sectors in Thailand in all disciplines (top, left), Medicine (top, right), Agricultural and biological sciences (bottom, left), and Engineering (bottom, right).

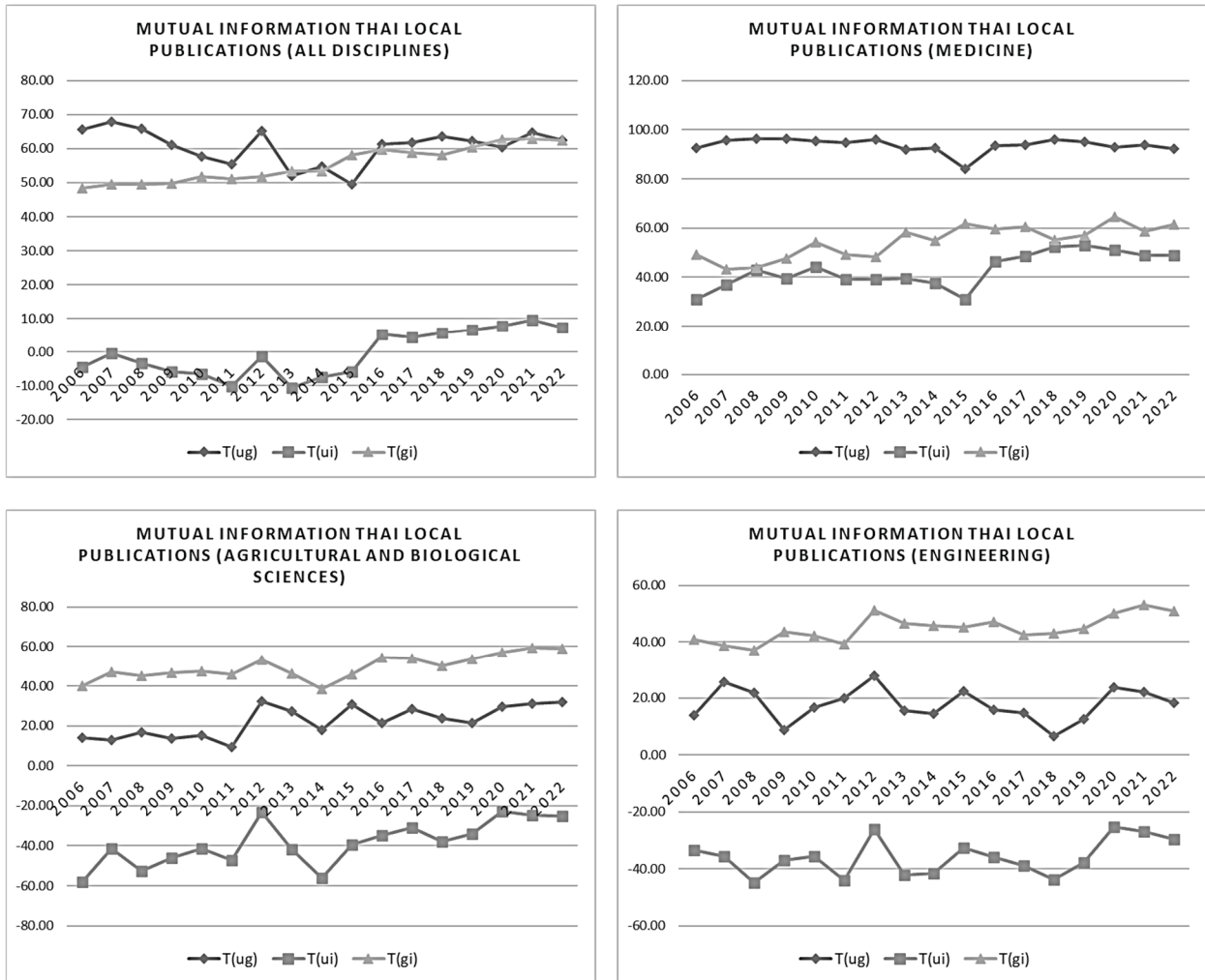
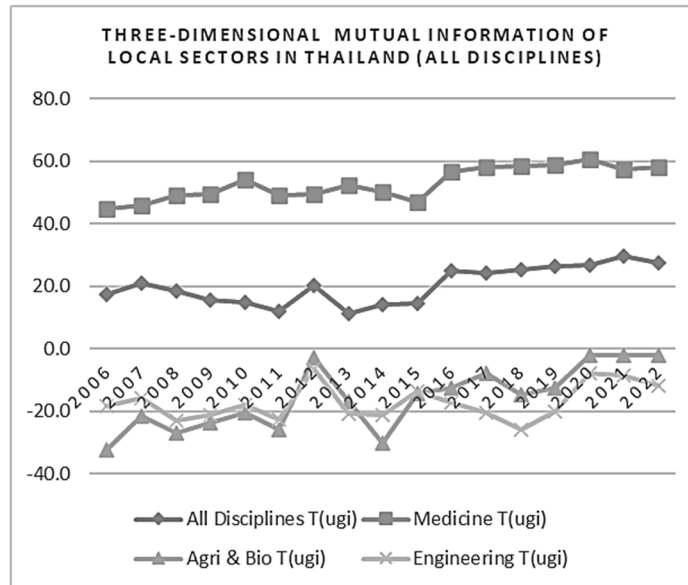


Figure 37

The three-dimensional mutual information of domestic collaborations in Thailand in all disciplines (top, left), Medicine (top, right), Agricultural and biological sciences (bottom, left), and Engineering (bottom, right)



Comparing mutual relations in local and international collaborations.

In addition to assessing the synergy of interactions among local sectors, several studies also investigate such interactions when incorporating international research into the national system. For instance, Kwon et al. (2011) reported that the inclusion of publications with foreign partners in the national research system led to greater synergy among Korean local sectors. To enhance the understanding of the subject matter, in this study, I examine the T values or the synergies of the collaborations between local sectors when foreign co-authored publications, as well as publications with the United States and China, were included in the analysis.

Figure 38 illustrates the comparison of two-dimensional mutual information within local and international configurations. The findings indicate that the two-dimensional synergy of collaborations between local sectors in both local and international collaborative settings are relatively similar, collaborative synergies between university-government (UG) and government-industry (GI) partnerships are more pronounced than those seen in university-industry (UI) collaboration. Similar to the local and international settings, when restricting the analysis to collaboration with American partners, the synergy of bilateral relationships between university-government (UG) remained steady, while those between university-industry (UI) and government-industry (GI) exhibited a slight increase. The difference is that the majority of Thai-US collaborations primarily center around interactions between universities and government entities (UG). However, when specifically examining collaborations between Thailand and China, the bilateral relationships between university-government (UG) exhibited a minor decrease in synergy, whereas those between government-industry (GI) and university-industry (UI) showed a slight improvement in synergy. In 2009, the systemness of cooperation between the university and the government was exceeded by government-industry partnerships.

The heightened synergy in collaboration between Thai universities and government agencies when engaging in research collaboration with the United States could indicate a distinct research landscape when Thailand collaborates with American partners. The analysis reveals a decoupling between the Thai government and industry when collaborating with the United States. This interesting observation will be discussed later in the chapter.

Figure 38

The mutual information between local sectors in Thailand was calculated using domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in all disciplines

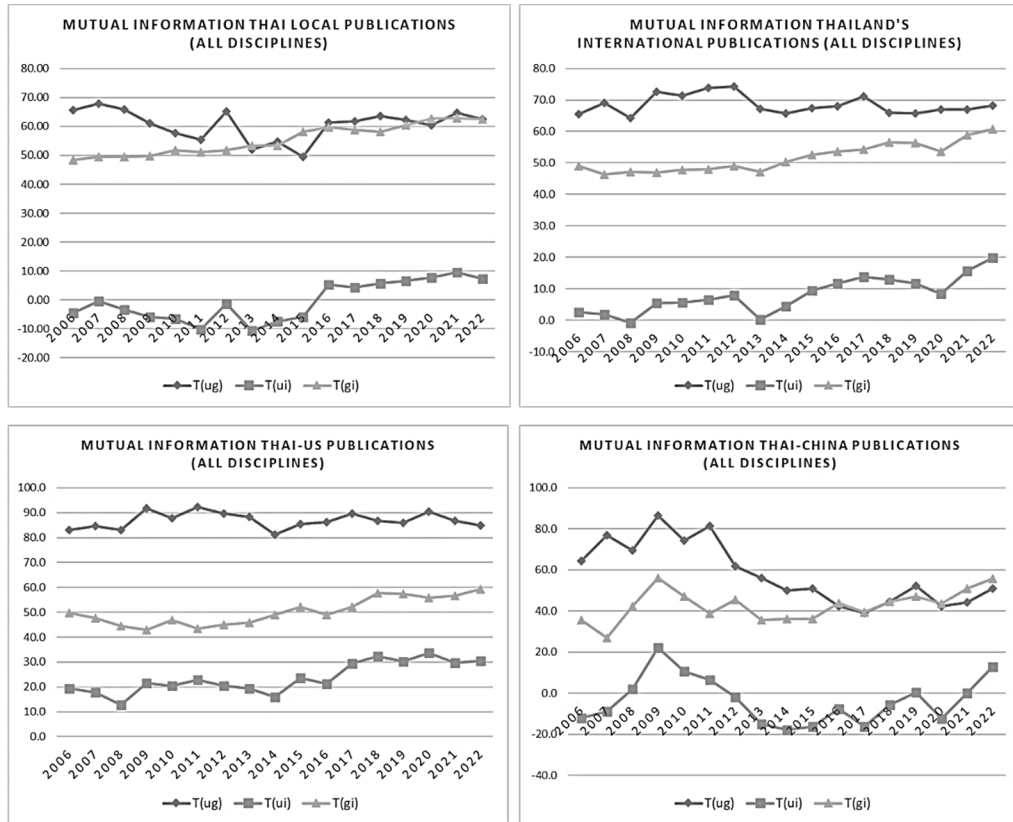


Figure 39 shows the three-dimensional synergy of the core sectors within the national system, with lower T values signifying a higher degree of integration. Notably, the trilateral mutual information among local sectors exhibits the lowest synergy in the configuration of Thai-U.S. collaborations (highest T values). This may be attributed to the fact that the majority of Thai-U.S. collaborations primarily involve contributions from the university-government

partnership. The synergy among local sectors is more robust within the local setting, followed by collaborations involving foreign partners. The synergy among local sectors in Thai-China collaborations is strongest, primarily because the synergies between university-government (UG) and government-industry (GI) are at the same level, while the synergy between university-industry (UI) is not much lower (Figure 38, bottom right).

Figure 39

Three-dimensional mutual information of local sectors in Thailand in different configurations (all disciplines)

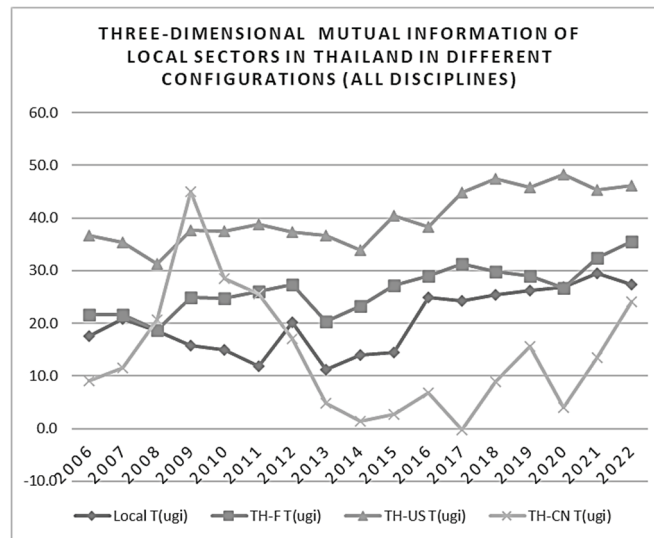
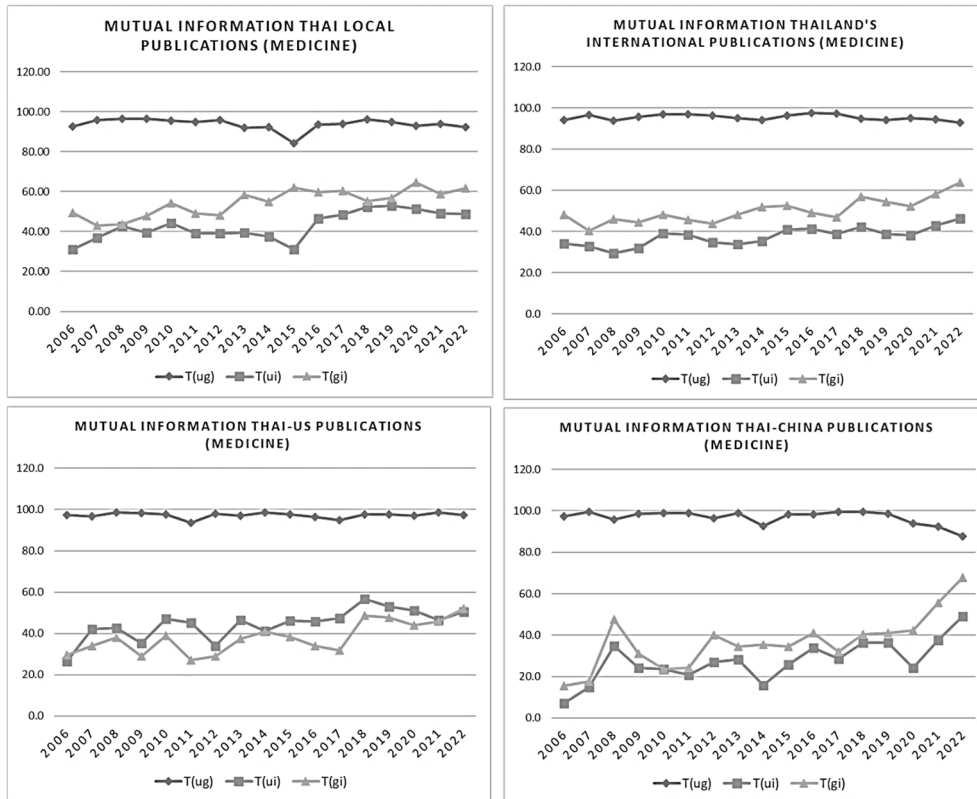


Figure 40

The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in Medicine



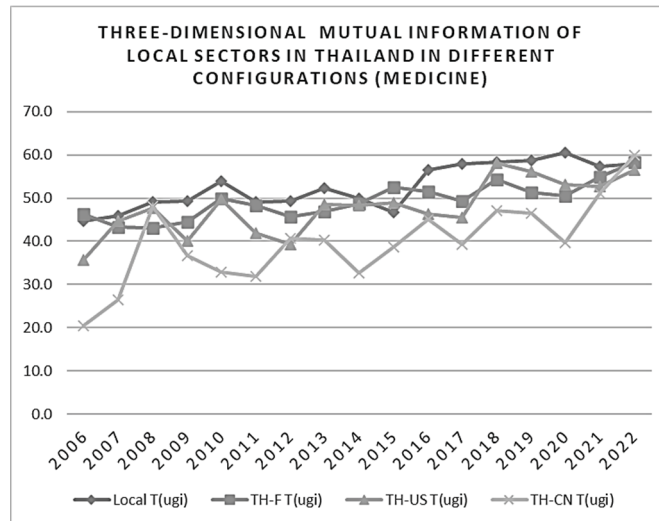
According to Figure 40, focusing on collaboration in medicine, the synergy of the interaction of the Thai local sector is similar when including and excluding international partners. In medicine, it is evident that the partnership between universities and government agencies (UG) played a pivotal role in collaborations, not only at the international and local levels but also in collaborations involving the United States and China. Nevertheless, in the

context of Thai-China collaborations, the synergies of government-industry (GI) and university-industry (UI) partnerships have exhibited rapid growth since 2020, nearly reaching parity with the university-government (UG) partnership.

Figure 41

Three-dimensional mutual information of local sectors in Thailand in different configurations

(Medicine)



The weakening three-dimensional relationships between local sectors in medicine can be observed in Figure 41 as the T values are increasing over the period of study. In the medical field, collaborations among local sectors in the national system are experiencing a decline in synergy over time, both at the local and international levels.

According to Figure 42, the bilateral relations among local sectors in Agricultural and Biological sciences have exhibited an increase in synergy at the local level. Nonetheless, these relationships seem to be losing synergy at the international level, with the exception being the partnerships between government and industry (UI), which have become stronger across all levels.

Figure 42

The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in agricultural and biological Sciences

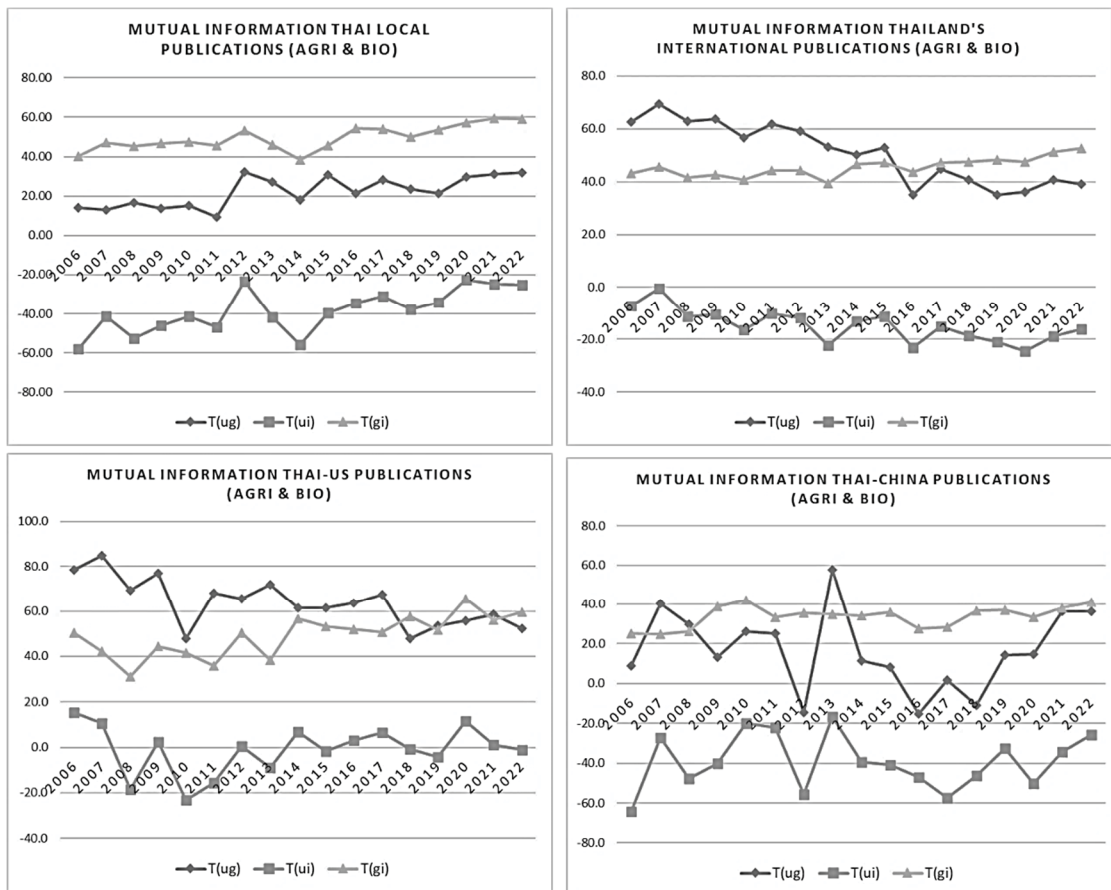
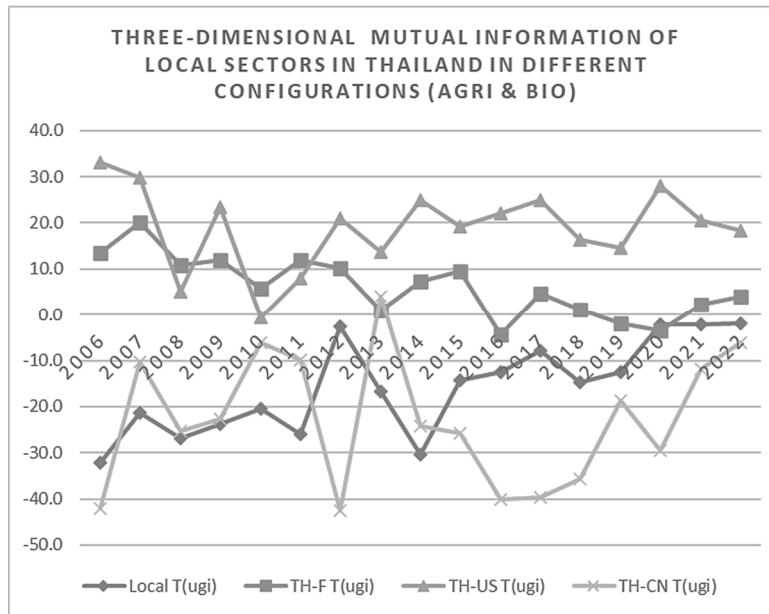


Figure 43

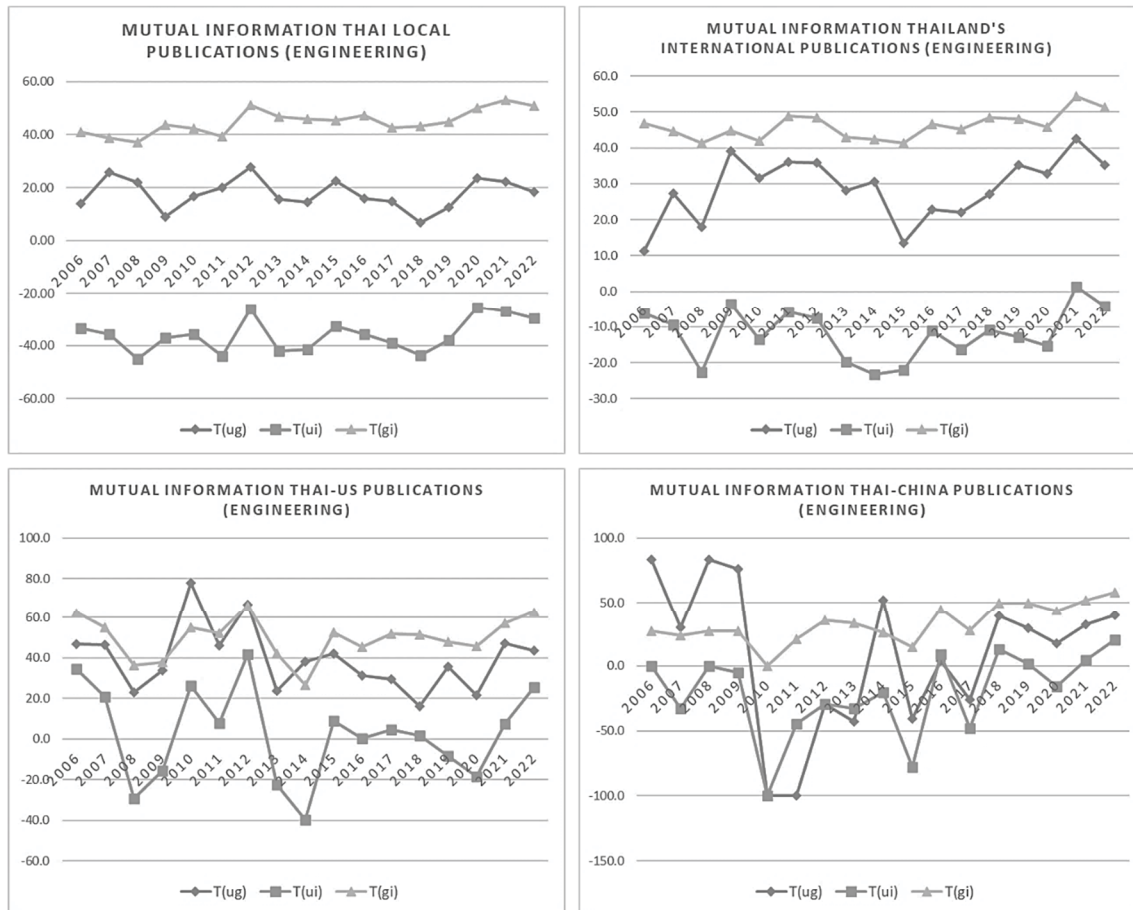
Three-dimensional mutual information of local sectors in Thailand in different configurations (agricultural and biological sciences)



As shown in Figure 43, when analyzing the three-dimensional mutual information of collaborations in agricultural and biological sciences, it becomes evident that the synergy among the local sectors became stronger when collaborating with foreign partners and remained stable when collaborating with the United States. There was a noticeable decrease in synergy at the local level and when including co-authored publications with China. This decline in collaborative synergy can be attributed to the substantial contribution of publications by universities, as indicated in Figure 34.

Figure 44

The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-U.S. publications (bottom, left), and Thai-China publications (bottom, right) in Engineering

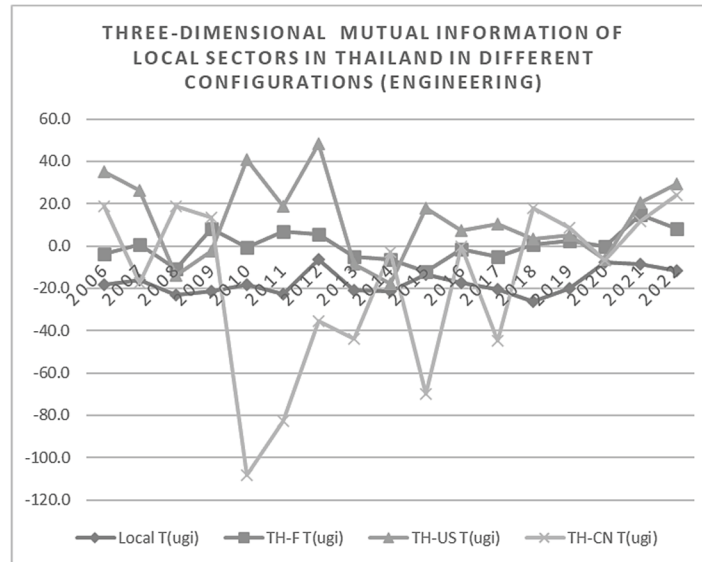


According to Figure 44, the bilateral relations among local sectors in Engineering have shown a consistent or slightly improved synergy at both the local and international levels. The synergy between government and industry (GI) stands out as notably stronger when compared to other partnership combinations.

Figure 45

Three-dimensional mutual information of local sectors in Thailand in different configurations

(Engineering)



The three-dimensional mutual information of local sectors at both the local and international levels are at the same level and remained steady during the study period (Figure 45).

In this section, I explore the interactions among Thai local sectors across various collaborative settings, including domestic collaborations in Thailand, collaborations between Thailand and foreign countries, collaborations between Thailand and the United States, and collaborations between Thailand and China. I observe diversity in collaboration patterns across different settings and disciplines. According to the Triple Helix concept, higher synergy between sectors leads to increased knowledge sharing and innovation. Therefore, the ideal condition is to

have more synergy in collaborations between local sectors, aligning with Thailand's national policy. However, in practice, I observe distinct collaboration patterns at both national and disciplinary levels, as elaborated above.

I utilize a variety of tools and metrics to illustrate the patterns of sectoral interactions. Employing metrics such as the total number of publications, publication proportions, and Leydesdorff's mutual information, I gain insights into the dynamics of collaboration. Through the examination of numbers and proportions, I can discern trends in different types of publications produced by specific sectors and the types of collaborations between local and international partners.

To observe the evolving dynamics of interactions between sectors across different collaborative landscapes, I computed mutual information or T values, considering the inclusion and exclusion of foreign countries, specifically the United States and China, from the research landscape. The analysis reveals that although local sectors are increasingly involved in research collaborations, this synergy is not consistently reflected at the national level, as indicated by weaker trilateral mutual information values across all disciplines. In a globalized society, collaboration with foreign countries has become a common practice. University, government, and industry actively engage in international collaborations, often without collaborating with other local sectors.

Our research revealed that universities are the primary contributors to scientific publications in Thailand. However, there are notable exceptions. For instance, in the field of medicine, government plays a more significant role in research, both locally and internationally. Moreover, distinct patterns emerge when Thailand collaborates with the United States and China. The Thai government assumes a more crucial role in collaboration with the United States, while the industry appears more active in collaboration with China. The observed patterns will be explored in greater depth in the integrative analysis chapters, where I will combine findings from the qualitative methods to provide insight and explanations.

In the next section, I discovered that the dataset holds potential for further exploration, which could yield additional insights. I employ correlation analysis to investigate the relationships between types of local collaboration, source of funding, and international collaborations. The objective is to determine if specific types of collaboration within local sectors or sources of funding are correlated with the likelihood of partnering with international counterparts.

The relations between funding sources and international collaboration using binary logistic regression

The collected data enables us to extend the analysis further. I chose to conduct a multivariate logistic regression analysis to examine whether the likelihood of engaging with

foreign partners was associated with a particular source of local funding, utilizing the funding data provided by the data source. The analysis uncovered an interesting resource that supports findings from other parts of the study.

First, I filtered only the publications that included funding data. This step was necessary because it was unclear whether the absence of funding information is due to a lack of funding support for the program or simply because the funding information was not reported. Then, I categorized the funding sources of each publication (sources from U, G, and/or I) as predictor variables, with the dependent variable indicating whether the publications were local, Thai - U.S., or Thai – China Collaborations (1 for international collaborative publications, 0 for local collaborative publications). Table 13 demonstrates the table used for the analysis.

Table 13

Examples of the predictive variables (types of local funding sources) and dependent variables indicating whether the publications were local or international.

U Fund	G Fund	I Fund	Thai – U.S. Collaborations
1	0	0	1
1	0	0	0
1	1	0	0
1	0	1	1
1	1	1	0

Given the categorical nature of the dependent variable (whether a publication is internationally co-authored), this study employs a multinomial logistic regression model, which is suitable for analyzing dichotomous or categorical dependent variables. The beta coefficients (β) derived from the model indicate the change in the odd ratio ($\text{Exp}(\text{B})$) of the dependent variable occurring with a one-unit increase in the predictor variable. For instance, if the beta coefficient for a variable like government funding is significant and positive, it suggests that this variable enhances the likelihood of collaborations with international partners.

The likelihood of engaging with international partners based on different sources of local funding:

Table 14

The Likelihood of International Collaboration and Various Funding Sources

	International publication		Thai – U.S. Publication		Thai – China Publication	
	β	$\text{Exp}(\text{B})$	β	$\text{Exp}(\text{B})$	β	$\text{Exp}(\text{B})$
University as a funder	-0.12	0.78	-0.39	0.46	-0.13	0.76
Government as a funder	0.84	1.18	Not significant	Not significant	0.28	1.75
Industry as a funder	0.26	1.67	0.47	2.57	Not significant	Not significant

Note. All have $p < .0001$.

Table 14 reveals that when a university is the funding source, the odds of having international partners decrease by 22%. Conversely, government funding increases the odds of

international collaboration by 18%, while industry funding significantly boosts the likelihood, with a 67% increase in the odds of having international partners,

When examining the correlation between funding sources and the odds of collaboration with the United States, university funding is associated with a 54% reduction in the likelihood of a publication is a Thai – U.S. coauthored publication. In contrast, industry funding is linked to 2.57 times higher odds of Thai – U.S. collaboration. However, the correlation with government funding is not significant.

When examining the likelihood of engaging with partners from China based on different sources of local funding, I found that university funding is associated with a 24% reduction in the odds of having Chinese partners. In contrast, government funding is associated with a 75% increase in the odds of Thai – China collaboration. However, industry funding does not show a significant correlation with the likelihood of having Chinese partners.

The results from the multinomial logistic regression analysis might appear to contradict the previous findings. In this section, I observed that university funding decreases the likelihood of engaging with international partners, whether from the United States or China, while funding from industry is associated with higher odds of engaging with foreign and American partners. To explain these contradictory results, I consider several factors.

First, Grassano et al. (2016) examined publications in cancer research and found that most researchers do not acknowledge funding sources if they are from their employer organizations. In contrast, researchers who receive external funding are more likely to explicitly acknowledge their funders in the publication metadata. Second, Bianchi (2024) found that Scopus provides the smallest number of articles with funding information compared to Web of Science and PubMed. This suggests that the funding data available from Scopus may not present a complete picture of the funding landscape. Although I cannot determine whether the funding is from external or internal mechanisms in the study, applying Grassano et al.'s (2016) findings could provide some clarity.

Universities are the primary sector collaborating with foreign partners; therefore, external funding from universities may not be essential for fostering international collaborations, as these partnerships are typically part of the universities' annual plans and formal budgets. Conversely, funding from the private sector can be a significant driver for Thailand to engage in collaborative projects with foreign partners, as the most valuable resource private companies can offer is financial support. In contrast, universities and government agencies possess other types of resources, such as research personnel and databases, which may not require external funding to facilitate international collaborations. Many collaborative projects managed by universities and government agencies are identified in formal agreements such as MOUs or national strategic plans.

Observation from the quantitative analysis

The quantitative analysis highlights several observations and assumptions that need further examination and discussion. These include distinct patterns within various collaborative configurations and across different disciplines, and so on.

The trends of Thailand-US and Thailand-China collaborations. While the number of co-authored publications between Thailand and the United States, as well as between Thailand and China, has been consistently increasing each year, the proportions reveal a different story. The proportion of co-authored publications between Thailand and the United States has been declining while those between Thailand and China have been increasing through the study period. The proportions are almost at the same level in 2022. Besides the policy and support from the Chinese government in publishing research publications with other countries, what other factors might contribute to the increased level of collaboration between researchers from Thailand and China, and how do these factors operate at both the individual and sectoral levels?

The strong collaborative ties between Thailand and the United States in medical science. When examining the data from different disciplines, the findings indicate that the proportions of collaborations between Thailand and the United States have been decreasing across all disciplines, including agricultural and biological sciences, as well as engineering. Starting from 2019 to 2020, the proportions of publications between Thailand and China have

surpassed those between Thailand and the United States. However, in the field of medicine, the proportions of collaborations between Thailand and the United States are experiencing a slight decrease, yet they remain significantly higher than those between Thailand and China. It is imperative to delve into the underlying factors driving the evolving patterns of cooperation between Thailand, the United States, and China. Additionally, there is a need to investigate the determinants contributing to the strong collaborative ties between Thailand and the United States in the field of medical science, particularly in contrast to the fields of agricultural and biological sciences and engineering.

The role of government agencies in collaborating with the United States. When examining various collaborative configurations, including local, international, Thailand-US, and Thailand-China collaborations, across all disciplines, the most notable observation is the university's exceptional productivity in publishing research papers. A noticeable trend emerges in the co-publications between Thailand and the United States, where Thai government agencies play a significant role as contributors, following Thai universities as primary contributors. Especially in the field of medicine, Thai government agencies have generated a higher number of co-authored publications with the United States compared to Thai universities. This observation could suggest that engaging with the US necessitates more official relationships, which could take place through governmental institutions.

Synergies of the interactions of local sectors in all disciplines. When comparing the three-dimensional synergy of interactions among local sectors in Thailand, both including and excluding foreign partners, the findings reveal that Thailand-US collaboration exhibits the weakest synergy, whereas Thailand-China collaboration demonstrates the strongest synergy among the local sectors' interactions. The lower synergy observed in Thailand-US collaborations can be attributed to the prominent roles played by universities and government, with limited involvement of the private sector when engaging with the United States. Conversely, Thai private sectors play a more significant role when collaborating with China compared to their involvement in collaborations with the United States. This assumption needs further investigation to better understand the factors that contribute to greater engagement of Thai private sectors in collaborations with China.

Weak synergy of local interactions and the role of government agencies in medical research. When I examine the trend through the lens of the Triple Helix framework using mutual information analysis with domestic publication data, I discover that agricultural and biological sciences, as well as engineering, exhibit a stronger synergy in three-dimensional interactions among the three local sectors in Thailand. On the contrary, in the field of medicine which has the weakest three-dimensional synergy, local collaborations are predominantly centered around the partnerships between universities and government (UG). I also observed distinct patterns in the field of medical sciences when analyzing the number of publications

produced by local sectors in Thailand. Specifically, I found that universities are the primary contributors to domestic research publications. However, in the field of medical science, government agencies and collaborations between universities and government entities are highly productive and have nearly reached the level of output seen by universities in terms of publishing publications. This could imply that medical science is an important field that could have a significant impact on the Thai population. Consequently, private companies may have limited involvement or insufficient support for conducting medical research in Thailand. Moreover, the three-dimensional synergies among Thai local sectors in the field of medical science remain consistent whether foreign partners are included or excluded. This suggests that foreign partners have little to no influence on shaping the engagement of local sectors in this domain.

Weak collaborations between Thai universities and industries. The collaborations between universities and industry (UI) appear to have a minimal impact when considering the number of publications across all disciplines. Furthermore, the weak two-dimensional synergy between universities and industry is also evident across all disciplines, including the three selected ones. Nevertheless, the collaborative synergy between the two sectors demonstrates an upward trend in most collaborative settings, indicating increased active collaboration over time.

University-government cooperation and international collaborations. The collaboration between universities and government entities is also the most crucial contributor to

publishing research papers with foreign partners, both with the United States and China.

Although this trend aligns with several previous studies, it is intriguing to understand the specific reasons behind this trend in this case study.

Growing synergy in the collaboration between government agencies and industry.

Our findings reveal a growing synergy in the collaboration between government agencies and industry (GI), despite the relatively smaller number of such collaborations compared to other forms of partnership, both at the local and international levels.

Strong cooperation among local sectors in agricultural and biological sciences and engineering. While local sectors in Thailand are losing collaborative synergy within the national system due to the effect of globalization as argued by Ye et al. (2013), the research findings indicate that the three-dimensional synergies of local interactions in agricultural and biological sciences, as well as engineering, remain stable whether I include or exclude co-authored publications with international partners. This observation requires further exploration through the qualitative interview.

The application of the Triple Helix model and the analysis of quantitative data from this study can offer several key benefits for Science, Technology, and Society (STS) scholars in many ways.

First, it deepens our understanding of the case study context. By applying the Triple Helix model, which highlights the interactions between universities, industry, and government, the analysis offers a structured framework to examine how these sectors collaboratively shape the production of scientific knowledge and innovation, particularly in Thailand's collaborations with the U.S. and China. The data reveals how social forces, such as government policies and industry interests, influence the direction of scientific research. Additionally, the study explores external factors, such as the power and political status of partner countries, and how these dynamics shape collaborative efforts.

One of the core interests in STS is the politics of knowledge—who controls it, how it is produced, and who benefits from it. The Triple Helix model enables me to explore how power is distributed across universities, industry, and government, and how this power dynamic shapes Thailand's scientific agenda. It also allows for an examination of how international collaborations with the U.S. and China influence Thailand's scientific and technological trajectory, offering insight into global power relations in science. This sheds light on how a smaller nation like Thailand navigates the pressures of geopolitics, sparking rich discussions on scientific autonomy and dependence within this global context.

The findings offer practical insights for science policy, particularly regarding how Thailand can enhance its innovation capacity to overcome the middle-income trap. For example,

how do government policies that emphasize collaboration with universities shape the types of knowledge that are produced? Are there social equity concerns regarding which sectors of society benefit from these collaborations?

In the next chapter, I present the findings from qualitative interviews conducted with Thai, American, and Chinese researchers and policymakers who have been engaged in both local collaborations in Thailand and international collaborations between Thailand, the United States, and China. These interviews provided valuable insights that complement the quantitative study, helping to answer the research questions. I will explore how these personal experiences and perspectives enhance the understanding of the dynamics and implications of these scientific collaborations.

Chapter 7

Qualitative Interviews: The Cycle of Credibility Driving Scientific Collaboration

Qualitative interviews were employed to delve into the implicit factors that might influence scientific collaborations. I used a semi-structured interview format, which allowed us to customize questions according to the distinct roles of each group. This flexibility enabled us to address various aspects of their involvement. For instance, I could explore their general experiences and challenges, while simultaneously delving into specific topics from which I sought insights.

This section is divided into two segments. The first part provides essential demographic information regarding the interviewed participants. The second section entails the presentation of the interview results. The findings have been structured and categorized into various themes for clarity and organization.

Part I. Demographics

Table 15 provides the demographics of the interviewees. The participants are predominately male (11 out of 18). Despite the efforts to have an equal number of participants from three disciplines (medicine, agricultural and biological sciences, and engineering), I ended up with a higher number of participants from the engineering field (7 from 18) and two from chemistry. Nonetheless, this is not a cause for concern, as each participant has the potential to provide valuable information and insights that can significantly enhance the study. The majority of interviewees come from academia, with only four individuals representing the private sector. This is probably because researchers from the private sector tend to be more cautious about sharing information concerning their work, as they aim to avoid disclosing sensitive business

secrets. In contrast, participants from academia and government sectors are generally more inclined to offer assistance and share insights. In terms of forms of collaborations, nine of the participants have been involved in Thai-U.S. collaborative projects, five have engaged in local collaborations, and four possess experience with Thai-China collaborations. Although researchers involved in Thailand-US collaborations may appear to be overrepresented among the interviewees, it's worth noting that many of them also have experience working with other local sectors. As a result, they were able to provide valuable insights and share their experiences beyond their involvement with American partnership.

Part II. Qualitative interview results

To examine the qualitative interviews, I carried out a four-stage qualitative analysis process following the approach outlined by Bryman and Gibbs (Bryman, 2001). Initially, I carefully reviewed the interview transcriptions to identify significant themes and specific instances or phenomena that need to be highlighted. Then, I revisited the material, selecting particular quotes and assigning corresponding codes to the text. In the third step, I proceeded to delineate the themes associated with the marked quotes, and if necessary, I supplemented or modified the existing themes and codes. The last step entails interpreting the data and establishing interconnections between codes and themes. This process allows us to relate the findings to existing literature and answer the research questions.

Table 15*Demographics of the interview participants*

	Number of Participants	Percentage of Participants
<u>Gender</u>		
Male	11	61.1%
Female	7	38.9%
<u>Areas of study</u>		
Engineering	7	38.9%
Agricultural and Biological Science	5	27.8%
Medicine	4	22.2%
Chemistry	2	11.1%
<u>Sectors</u>		
University	8	44.4%
Government	6	33.3%
Industry	4	22.2%
<u>Types of Collaboration</u>		
Local collaborations	5	27.8%
Thai-US collaboration	9	50.0%
Thai-China collaboration	4	22.2%

The study aims to explore the relationships between local and international research collaborations. For instance, it investigates how international collaboration enhances the research capacity of the local research community and whether local networks among researchers lead to

establishing new connections with international research partners. Several themes emerged from the interviews, providing insights into the dynamics and factors impacting scientific collaboration at both local and international levels. In this section, I discuss each theme and analyze how these insights help us answer the research questions.

The Significance of Collaborative Networks Among Researchers in a Nation's Advancement in Science and Technology

One recurring theme from the interviews is the critical role of relationship networks among scholars. These networks are consistently emphasized for their critical impact on various aspects of scientific collaboration and research advancement. All interviewees emphasized the importance of scientific collaborations, highlighting their essential role in the dynamic landscape of research. As P3 Med G, a head of a government research agency, stated from a big picture perspective, the interconnectedness of all disciplines necessitates cooperation, as no single institute can possess all the requisite expertise. When diverse fields merge, collaboration becomes indispensable, and it extends beyond national borders, involving agencies both within and outside their country. According to P7 Mat G, a female mid-career researcher in material science at a government agency, research collaborative networks take place on various scales, involving both local and international organizations. Such collaborative endeavors allow researchers or countries to leverage their expertise while complementing it with the specialized knowledge of others. For the interviewee, research collaborative activities and network connections coincide.

“Actually, it’s not just international partners. They [the agency] encourage any form of research collaborative network. Our researchers work with both local and international organizations... We are trying to create a research network

with various agencies. Even with in the Ministry, we constantly discuss the potential to collaborate across agencies.” - P7 Mat G

The more people you know, the more opportunities you have to discuss and explore potential future collaborations.

One of the remarkable aspects of scientific collaborations, as highlighted in P7 Mat G, is the ability to combine different areas of expertise. This fusion not only fosters more extensive collaborations but also sparks creativity. Engaging in discussions with experts from diverse backgrounds can lead to the development of new ideas and approaches that might not have emerged in isolation. Moreover, these collaborations can bridge gaps in knowledge and technology. They enable research teams to acquire new technologies or techniques that were previously unexplored. Each partner brings specific competencies to the table, and by working together, they can address a broader spectrum of challenges. This synergy often leads to a richer and more comprehensive understanding of complex scientific problems.

“When we collaborate with researchers from different groups, people from diverse backgrounds can contribute more connections. We can combine our expertise with others' knowledge in different areas. This often leads to new collaborations. Sometimes, we gain new ideas through discussions with others. Furthermore, partnerships help us fill gaps in our capabilities. We may acquire new technology or techniques that we have been seeking or have never considered. Since we specialize in specific areas, we tend to focus on those. Working with people from diverse backgrounds who have expertise in different areas is incredibly valuable.” - P7 Mat G

Addressing the necessity for research collaborations, P8 Bio G, a senior biologist actively engaged in global initiatives related to environmental and animal issues, highlights key areas requiring attention in the ongoing trend of scientific partnerships. The most demanding issues currently revolve around human health, biodiversity loss, and the global warming crisis. These critical concerns are poised to become a new worldwide trend, driving the proliferation of collaborative efforts.

“The UN Environment Programme (UNEP) has coined the term "triple planetary crisis," referring to the interconnected crises of climate change, biodiversity loss, and waste and pollution. Under this term, all the crises are considered together. To solve climate change issues, you can't focus on just one thing. It's similar to curing cancer: while we destroy dangerous cells, other problems can develop. We have to think holistically, and collaborations are crucial in this regard.” - P8 Bio G

In numerous countries, a common approach to enhance research collaboration involves increasing the number of researchers in specific fields. P10 Mat U is a female researcher in material science at a prestigious university in Thailand. She recently participated in a researcher exchange program facilitated by a Chinese government agency. She posited that there exists a direct correlation between the volume of citations and the size of the research workforce. Countries or institutions with a larger number of researchers tend to produce a greater number of research papers. An example of this phenomenon can be seen in China, which boasts a substantial population of scientists and engineers. This extensive pool of talent contributes significantly to the substantial output of publications, encompassing both international and domestic arenas.

“So, I believe that because the number of scientists and researchers in China is increasing rapidly, as are collaborations, they grow very fast both quantitatively and qualitatively. Being more active in collaborating with other countries is not the most important factor. It’s the number of people.”

The commitment to advancing scientific collaborations is an integral part of Thailand's national policy, recognizing that collaboration with other nations holds the key to stimulating innovative ideas and expanding the country's engagement across diverse fields (P5 Bio G). In numerous Thai organizations, international scientific collaboration has evolved into an essential component, with its significance reflected in Key Performance Indicators (KPIs) (P6 Eng U).

“We won't advance in our careers if we don't make an effort to have research projects. One of KPI at my university is international outlook. The long-term objective is to elevate our university to a global level. So, if we can have co-authors from other countries, we can increase our impact and number of citations. As a result, our university will rank higher. So, I have to seek collaborative projects.” – P6 Eng U

P6 Eng U is a young female researcher and associate professor in space engineering who has recently been appointed to a leadership position in the curriculum development office at a university in Thailand. Several times during the interview, she discussed her dedicated efforts to advance in her career and gain recognition from her peers. While expressing a personal passion for space science research, she emphasized that her endeavors to participate in collaborative projects, especially with foreign partners, also serve the dual purpose of advancing her academic and research career. On the other hand, P10 Mat U, being more senior, places a greater emphasis on acquiring knowledge and pursuing personal interests through involvement in research

collaborations. A primary objective behind these international partnerships is the pursuit of fundamental research and the publication of findings, as this is the predominant form of international collaboration (P10 Mat U).

“It was not about meeting KPIs at all. It was all about my own interest. I really wanted to know about the materials they were working on.” – P10 Mat U

The need for acquiring knowledge from other countries is supported by P1 Eng I, a male engineer at a private company. Although Thailand has significant scientific and technological assets, there are several knowledge gaps that may be filled by learning from other countries (P1 Eng I). To harness its capabilities fully, the nation must also proactively showcase its strengths to the international community through collaborative activities (P7 Mat G). Furthermore, given the scale of many global concerns that transcend national boundaries, such as animal conservation and pandemics, it is evident that cooperation and information exchange among different countries are essential (P8 Bio G and P15 Med U).

“But I do think there will be a lot more international engagement. Because of these issues, obviously, they are across borders. I think the pandemic has pretty much changed people's perceptions on wildlife diseases.” - P15 Med U

P15 Med U, a senior researcher in biology and a director of a regional center at a U.S. research agency spanning biology, geography, geology, and hydrology, expressed his insight. He noted that global pandemics, like SARS and the H1N1 virus, have underscored the realization that certain challenges cannot be confined or effectively addressed at a local level alone. To confront such issues and ensure global safety, collaborative efforts involving multiple countries are imperative. Consequently, his agency actively promotes international collaborations and

capacity-building initiatives in various countries. Establishing international research networks is deemed crucial in addressing global threats effectively.

However, there are significant financial costs associated with participating in international scientific cooperation. Budget constraints can pose a significant challenge for a developing country such as Thailand. In the absence of adequate funding, collaborations may be initiated but could fall short of yielding concrete results. As highlighted by P2 Med U,

"Without a budget, we can explore avenues like online communication, offering or receiving advice, and co-authoring papers. However, with a budget, we can nurture more substantial collaborative efforts. Therefore, financial resources play a pivotal role in international scientific collaborations."

To pursue sustainable development, collaborations with foreign partners should take on more substantial and meaningful forms. As exemplified by P4 Bio G, a government scientist specializing in epidemic viruses in animals, Thailand's previous approach involved merely providing data to foreign researchers, resulting in limited knowledge transfer to Thai researchers. It's imperative to shift the paradigm of collaboration. P4 Bio G suggests that for Thailand to fully leverage these partnerships, the focus should be on practical applications and the acquisition of essential know-how from their counterparts.

"They want us to collect and test samples to look for diseases. But we negotiated with them. We told them that just by collecting and testing the samples, Thailand gained almost nothing from the project... So, when I saw the opportunity (to collaborate with foreign countries), my goal was to have

not only publications but also applications that we could use in Thailand.

Secondly, we would use only Thai researchers because I know that Thai researchers can research on our own.” – P4 Bio G

This shift in approach will empower Thailand to become self-reliant, reducing the need for external assistance and enabling independent action (P9 Eng U).

Many international organizations recognize the needs of developing countries and have made it their mission to assist them in building their capacity. An example is the partnership between the U.S. Geological Survey and Mahidol University in establishing the Thailand National Health Center, facilitated through the World Organization of Animal Health. The primary aim of such collaborations is to facilitate the transfer of skills and knowledge from more advanced agencies to their partner institutions (P15 Bio G).

International scientific collaborations could serve purposes beyond the generation of new knowledge. For instance, the scientific collaborations in the field of livestock between Thailand and China aim to establish trust with the Chinese government by demonstrating Thailand's commitment to rigorous research, ultimately ensuring disease-free livestock zones. Inviting Chinese researchers to participate in livestock research allows Thailand to showcase its expertise and commitment to transparency. Such research collaborations play a pivotal role in promoting meat exports from Thailand to China (P4 Bio G).

Participants cited several constraints that pose challenges to international collaborations. The foremost is the geographical distance between partner countries. Since much basic research takes place within laboratory settings, researchers must collaborate and have close interactions in these facilities. This necessitates travel, time and budget for traveling must be carefully

considered (P2 Med U, P7 Mat G, and P10 Mat U). Due to the challenges, international collaborations can significantly benefit from official support, as underscored in P8 Bio G: “[h]owever, the JCM we signed on that day created another push for collaborations. Government support or facilitation makes collaboration persist longer and go more smoothly.” Such support can manifest in various forms. the establishment of the National Nanotechnology Center in Thailand through collaboration between NANOTEC (Thailand) and Shanghai University (P11 Mat U). This center serves as a platform for promoting sustained communication and interaction between Thai and Chinese researchers. Another example is the involvement of an official authority, such as the Thai Embassy in Washington D.C., serving as the principal representative of Thai researchers and students in the United States. This entity can coordinate training programs with U.S. research organizations, including NASA (P13 Eng I), enhancing the overall effectiveness and efficiency of collaborative efforts.

International scientific collaboration has demonstrated several benefits in enhancing Thailand's science and technology capacities. However, to overcome the middle-income trap, it is imperative to address existing gaps in self-sufficiency and strengthen the local research system. Several interview participants have highlighted this concern. In the pursuit of sustainable development, it is crucial for countries like Thailand to recognize the significance of local scientific collaborations. Thailand possesses notable scientific and technological strengths, yet it often finds itself dependent on advanced nations for critical resources, advanced tools, and specialized knowledge.

“Thailand is well-known for its healthcare system. But did you know that the majority of our raw materials are imported from other countries? We never

have the actual technology to make our own medicine. We rely on materials and technology from other countries.” (P2 Med U)

The key to development lies in diminishing dependence on external resources and fostering self-reliance. By promoting and nurturing domestic collaborations, Thailand can enhance its internal expertise and innovation.

Based on insights from the interviews, research collaborations hold significant importance for the informants, impacting both cognitive and social aspects. The concept of the credibility cycle enables an examination of how researchers acquire what they need through source conversion in collaborative activities and how the sources lead to future collaborative endeavors. As highlighted earlier, I observed that network relationships play a significant role in providing opportunities for researchers to participate in the cycle of credibility source conversion. To comprehend the dynamics of scientific collaborations, I questioned the informants on how their research initiatives got started and how they were managed. I discovered that network interactions among researchers play a substantial impact on scientific collaboration. When seeking to initiate collaborations, researchers typically turn to individuals they are acquainted with, such as college friends and former colleagues (P3 Med G, P4 Bio G, and P8 Bio G). Additionally, some collaborative projects were driven by the altruistic motive of helping friends in need, as described in P9 Eng U. Formal relations could turn into friendship if they have established a strong working relationship. Notably, one informant expressed a preference for collaborating with individuals they have familiarity with rather than someone whom he knew through formal networks, particularly in the early stages of a project. Trust and the flexibility that stems from familiarity play pivotal roles in facilitating smoother collaborations (P2 Med U and P10 Mat U). P2 Med U said,

“In my opinion, compared with informal collaborations, we are friends, and we work together. I believe we can accomplish far more through casual collaboration. In my perspective, if we get to know one other well and trust each other, we can do more work together.”

Moreover, researchers can discern the networks of those people they are already acquainted with, which enables them to expand their connections through their existing relationships of their peers. Individuals with extensive networks can serve as central hubs for forging new connections, as emphasized in P6 Eng U.

Many collaborations might start with formal approaches. For instance, one can proactively approach target researchers or organizations upon identifying common interests and compelling reasons to work together (P1 Eng I and P3 Med G). Some organizations allocate resources to create opportunities for their employees to broaden their connections, typically through official exchange or visit programs, or participation in professional conferences (P2 Med U and P15 Bio G). For example, P7 Mat G could initiate a fruitful collaboration between a Thai researcher and her Chinese counterpart when she attended a conference organized by her agency. During the conference, several Chinese researchers and professors were invited to present their work and explore collaborative possibilities with Thai scientists. Another mechanism frequently employed by organizations to facilitate international collaborations is the establishment of branches or offices in their target countries. For example, the Office of Science and Technology at the Thai Embassy in Washington D.C., a part of the Ministry of Higher Education, Science, Research, and Innovation (MHESI), was set up in the United States to enhance engagement with U.S. agencies. This entails attending events, hosting gatherings, and organizing activities that contribute to the expansion of connections and partnerships.

While human connections undeniably play a substantial role in building relational networks, we also discern the profound impact of the cognitive aspects of science. When a researcher seeks a collaborator, their selection is often guided by the expertise and experiences of that are relevant to the project (P7 Mat G, P8 Bio G). Furthermore, it is noteworthy that most individuals within one's network tend to specialize in the same areas, as they have undergone similar training, worked on analogous projects, attended the same conferences, and been part of the same professional communities (P10 Mat U, P11 Mat U, and P17 Bio I).

Both informal and formal connections are invaluable assets as they open doors to new opportunities. For instance, when a researcher from Prince of Songkla University (PSU) established a connection with a professor from the University of Utah, they became eligible to apply for a US-ASIAN research grant, which requires collaborations between American and Asian entities (P2 Med U). Likewise, P10 Mat U gained eligibility to apply for a grant from a Chinese local government due to her collaboration with a Chinese professor at Fudan University. These connections often lead to further connections, introducing individuals to new contacts and expanding their professional networks (P2 Med U and P7 Mat G).

Relational networks are dynamic and can be both cultivated and gradually fade away over time, particularly when researchers become less active within the research community due to factors such as age and career changes (P2 Med U and P6 Eng U). The interviews revealed that researchers recognize the necessity of exerting effort to maintain their networks. Some make deliberate attempts to continuously collaborate with their partners (P7 Mat G). Others explore various forms of collaboration, such as online-based programs, when physical collaboration is not feasible (P2 Med U). Additionally, some researchers actively participate in professional events to sustain their visibility within their fields (P12 Eng I). These relational networks can

prove advantageous both at the organizational and professional levels, as they remain with individuals even when they move from one agency to another or change their job titles.

The most crucial consideration in collaboration is meeting the requirements of all participating partners. Understanding the needs of all parties involved and identifying the common areas where collaboration is feasible holds great importance (P1 Eng I and P7 Mat G). Based on the insights from the interviews, the initial step for researchers typically involves identifying the essential resources and the individuals or organizations that possess them, to locate potential collaborative partners (P11 Mat U).

“The keyword is EMI shielding...This is the keyword we want to solve. Both teams have been trying to work on this topic for the past few years. And we found that from our talking, from discussions during workshops... we found that our partner at NANOTEC has developed some materials, especially at Dr. S.’s lab. She has developed very interesting beads in her lab that could be used to combine with Dr. F. Team to develop a new material for EMI shielding applications. So this is the problem that we want to solve. That’s the main content of the collaborative projects we are working on with the Thai partner.”

- P11 Mat U

Simultaneously, researchers must also assess the resources they can contribute and explore the opportunities aligned with the resources at their disposal, as highlighted in P4 Bio G.

Recognizing the significance of collaborations, the Thai government is actively promoting research collaborations both within and across sectors, as highlighted in P7 Mat G.

Notably, government agencies are supporting research collaborations with universities in order to develop a larger pool of research people.

“That’s one of our KPIs. We need to develop next-generation researchers. We have tools and data available. So, we want to let the students use our resources to gain experiences and develop skills.” (P7 Mat G)

Some participants acknowledge the importance of commercialization as part of the national sustainable development strategy. They stress that for Thailand to achieve success in this endeavor, there's a need for stronger connections among local sectors. Participants shared their experiences on the benefits they have gained or anticipated when engaging in cross-sector collaborations. For instance, universities collaborate with government agencies and private companies to secure grants and gain access to expert knowledge and advanced tools (P9 Eng U, P10 Mat U). The government seeks to bolster its future workforce through collaborations with universities (P7 Mat G), while private companies aim to enhance their reputation and credibility by partnering with government agencies (P12 Eng I) as well as to acquire new ideas for commercialization by collaborating with universities (P9 Eng U). The recognition of the need for collaboration among various sectors has led to an evolving dynamic of network relationships within the national system. This trend is clearly evident in the interviews.

The roles, impacts, and evolving dynamics of network relationships within local sectors in Thailand.

Another theme identified in the interviews is the role of network relationships in shaping the dynamics of interactions among local sectors in Thailand. Simultaneously, the findings

indicate that the Triple Helix model also influences the formation and development of connections between researchers.

The interviews highlight the conventional role of universities, wherein faculty members are entrusted with the dual responsibilities of teaching and research (P2 Med U and P9 Eng U). Nonetheless, it is evident that universities are undergoing significant transformations. For example, the Thai government has embraced the Technology Readiness Level (TRL) framework, originally developed by NASA, for assessing the research capacity of research organizations and managing research grants for universities. This shift implies that universities are now expected to go beyond their traditional roles of teaching and conducting basic research; they are also encouraged to explore practical applications for their research. While some universities continue to prioritize basic research, which is seen as a fundamental goal of academia for knowledge production, others are increasingly directing their efforts toward research with commercial potential, making them more technology-focused. This shift encourages universities to enhance their research capacity and collaboration with other sectors becomes essential. This evolving trend is exemplified by P2 Med U, a professor who also holds the position of President of the Research and Development Office (RDO) at a Thai university. In his role, he actively engages with local private sectors and government entities to advance the university's research capacity, aligning with the objectives of his position.

The informant (P2 Med U) highlights the evolving societal dynamics that necessitate changes in university roles. According to P2 Med U, dwindling college enrollment rates, along with the realization that research is a kind of education, drive the need for universities to widen their focus to include not only traditional research but also applied research.

“Universities must change in a variety of ways. Initially, the university's role was to develop students. The number of college students is currently declining. The importance of research grew. Research is a form of lifelong education. Research leads to a higher standard of living.” – P2 Med U

Furthermore, universities are encouraged to foster increased collaboration with various sectors. This transformation also implies a need for universities to adapt their management practices in order to keep pace with other sectors, particularly private enterprises. P6 Eng U offers an illustrative case of this new university role, emphasizing the importance of engagement with the private sector and international partners.

“There is a Thai millionaire who wants to invest in a Chinese [space] startup. But before doing that they want to prove the concept. They want to make sure that the technology can be used in Thailand. They need to try using the technology in Thailand. The easiest way is to go through universities. So, there are many projects like this coming to Thai universities.” – P6 Eng U

Under the national system that aimed to replicate the Triple Helix model, government agencies are also required to adjust their roles and responsibilities. Based on the interviews, the government's multifaceted responsibilities include formulating policies, advancing science, fostering official programs for scientific collaborations, and undertaking and executing large-scale research endeavors to address the nation's critical issues.

Governmental agencies play a fundamental role in shaping the course of national research by formulating and executing policies. P6 Eng U highlights the significance of aligning research

focus with government priorities, as it can facilitate easier access to support from the government.

“Actually, it is understandable. Same as in Thailand. The government would like us to focus on specific areas because these are current opportunities or challenges. It’s easier to find support on the focused areas. Pandemics, agriculture, and catastrophe protection are critical for many countries. So, it is easier to find research funding.” - P6 Eng U

This, in turn, encourages scientists to direct their research efforts toward areas that receive governmental attention and available resources. Consequently, these critical areas for Thailand encompass pandemics, agriculture, disaster preparedness and response, as well as remote sensing and space engineering, reflecting the pressing challenges the nation faces

Furthermore, one of the government's essential roles is nurturing the next generation of researchers. Numerous government agencies have incorporated this mission into their employees' KPIs. Government research agencies, equipped with cutting-edge tools and comprehensive data resources, hold a pivotal role in cultivating the future science workforce. They actively promote collaborative efforts between universities and research institutions, creating opportunities for college students to access advanced equipment and technologies not typically available in university laboratories (P9 Eng U). This hands-on experience empowers students to develop essential skills, ensuring their preparedness for future roles in the field (P7 Mat G).

In addition to their capacity to undertake large-scale research initiatives, government research agencies also play a vital role in connecting and supporting other sectors. P2 Med U underscores this role of government by emphasizing his team’s efforts to establish a network that

links his university with private enterprises and government bodies. The objective is to elevate university research to a commercialization stage. This endeavor relies on government support in the form of legal guidance, subsidies, and financial assistance, underscoring the significance of such support in fostering innovation and economic growth.

“So, my team and I are trying to build this kind of system. For example, if a researcher wants to conduct rubber research, we can connect them with the Rubber Authority of Thailand, make suggestions, and provide maker space. We can connect them with private companies and producers if they want to scale up their research.” – P2 Med U

Scientific collaborations are significant in the modern scientific landscape. However, forging connections with agencies from diverse sectors and countries can be a formidable task, making government support indispensable. Government agencies often serve as catalysts for international collaborations, organizing events or activities such as official visits to Thailand for U.S. researchers, as exemplified in P2 Med U and P3 Med G. Similarly, local collaborative programs are frequently initiated following innovation exhibition events arranged by national research agencies, as demonstrated in P12 Eng I. These government-led initiatives help facilitate cross-border and cross-sector collaborations, promoting the exchange of knowledge and expertise in the scientific community.

In the middle of this evolving environment, there exists a divergence of perspectives among government researchers. Some steadfastly uphold their primary mission, which is conducting research aimed at addressing the nation's challenges, as emphasized by P3 Med G. Conversely, some researchers advocate for increased engagement with other sectors and the promotion of researcher commercialization, recognizing these as avenues to fully harness and

derive tangible benefits from scientific research, as highlighted in P4 Bio G. This diversity of viewpoints reflects the multifaceted roles and evolving priorities within the field of government-sponsored research.

In contemporary science, where research collaborations among diverse stakeholders have become crucial, the networking of researchers has emerged as a valuable asset. Within this context, I have demonstrated in this section that researchers recognize the imperative to establish connections with individuals across various sectors. Furthermore, governments play a vital role in both initiating and sustaining network relationships among researchers and agencies. The evolving landscape also influences how industry researchers engage with others. According to an interview with a researcher representing one of Thailand's largest companies (P1 Eng I), while the private sector is increasingly engaging with universities and government institutions, the primary objective remains profit-driven. When seeking collaborations with universities, the focus is on uncovering new market ideas, identifying novel challenges that can lead to the development of new products, and exploring innovative approaches to problem-solving, often through interactions with young students. This underscores the pragmatic orientation of private sector involvement in research and innovation.

“Publication is not my goal. My goal was to test the market. Getting fresh ideas from college students... like new problems we need to solve, new approaches to do things... Publication, to me, was just a byproduct.” - P1 Eng I

The involvement of private companies proves to be indispensable, particularly when research advances to the commercialization stages (P2 Med U). This is especially critical in fields such as chemical engineering, which require complex, advanced machinery and facilities that are typically available only within industrial settings. As highlighted in P9 Eng U, "Without

a private company, we can't expand our project from research to pilot, to commercialization." Moreover, as P11 Mat U points out, certain types of research are geared toward addressing the challenges that society faces, underscoring the significance of transferring knowledge and technology from university or governmental laboratories to industries. A pertinent example is the collaboration between NANOTEC and Shanghai University, which aims to develop new materials for use in electronic products with Electromagnetic Interference (EMI) shielding, necessitating the participation of industry partners for further development and practical applications. This highlights the pivotal role of private sector engagement in translating research into real-world solutions.

The ways in which the private sector engages in scientific research can be quite diverse. As exemplified by P9 Eng U, private companies are not limited to mere collaboration with universities; some companies have taken it a step further by establishing joint laboratories. For instance, Siam Cement Group (SCG) has founded a joint lab within the Department of Engineering at Chulalongkorn University. This joint lab serves as a platform for sustained collaboration between the company and the university department, resulting in numerous co-authored publications and fostering ongoing research partnerships. This underscores the multifaceted nature of private sector involvement in scientific research.

As scientific challenges grow in complexity, researchers from different sectors have realized the potential of sharing resources and expertise to accomplish their goals (P1 Eng I). This collective approach thrives on shared interests, goals, and the availability of resources, resulting in a collaborative environment that propels scientific research and innovation forward (P3 Med G). Recognizing the imperative of sustainable development, the Thai government actively fosters collaborative model similar to the triple helix relationship (P2 Med U).

Fascinatingly, the demarcations between sectors do not impede cross-sector collaborations. As mentioned by P9 Eng U, as long as shared objectives align, their expertise augments project outcomes, and sufficient resources are available, their organization can collaborate with entities across diverse sectors.

The preceding section presents findings from interviews that shed light on the evolving perspectives of research collaborations between countries and sectors. Research collaborations are acknowledged as crucial factors for advancing science and technology, particularly for developing nations like Thailand, which seek to acquire knowledge and knowhows from more advanced counterparts. Collaborations among various sectors have become more prevalent and are actively encouraged as they present opportunities for resource exchange. Researchers are actively seeking connections, with some collaborations occurring organically and others being facilitated through government support. The subsequent section delves deeper into the exchange of resources within these collaborations, providing additional evidence for why network relationships are considered essential assets. From the interviews, informants detailed a set of credibility sources that are crucial for their time and resources. The discussed resources align well with the cycle of credibility model.

Expertise. When asking about exchanged resources in scientific collaborations, the aspect most frequently cited in the interviews is the credibility derived from expertise and knowhows. The primary driving force for both local and international scientific collaborations is to secure access to the necessary skilled professionals, as well as to reciprocate these resources for other forms of credibility.

Expertise and skilled professionals stand out as a crucial factor in establishing credibility, attracting researchers seeking collaborative opportunities. From the standpoint of a foreign

research collaborator, a country's preparedness in terms of facilities and highly skilled researchers is a quality that makes it their preferred choice for collaboration, as it facilitates progress in their development projects.

“From my perspective, Thailand has good diagnostic laboratories, well-qualified scientists and support staff, and financial support. Thus, I think Thailand was at a stage of development in which our expertise could be useful to help Thailand reach the next level of capacity.” (P15 Bio G)

For these causes, the Thai government invests considerable effort in nurturing its scientific workforce by providing support for students and researchers to pursue studies and training abroad. The skills and experiences they acquire in foreign countries can ultimately make them valuable human resources for the nation (P4 Bio G). This approach not only enables self-reliance in terms of the workforce but also augments the pool of researchers, thereby expanding opportunities for future collaborations (P7 Mat G).

“We expanded our collaborative activities by hosting a workshop to recruit new members to our network. We have been working more with international partners recently.” - P7 Mat G

Thailand's preparedness, characterized by a proficient workforce and expertise, enables the nation to actively cultivate and broaden the network of relationships among researchers, facilitating ongoing knowledge exchanges. Conversely, the connections forged among researchers not only present opportunities to acquire expertise from partners but also serve as a source of credibility, aiding researchers in establishing new networks.

Advanced tools and equipment. According to P5 Bio G and P15 Bio G, one of the paramount motivations driving Thai researchers to seek collaboration with international partners is the necessity to acquire specific chemical substances and advanced tools that may not be readily available in Thailand, often constrained by budget limitations or legal restrictions. For instance, fields like space science demand cutting-edge tools and facilities, the expense of which can be too expensive for a small country like Thailand. NASA is an aspirational agency for Thai space engineers, providing access to cutting-edge equipment and resources (P13 Eng I).

Since Thailand is prepared for collaboration at equal levels, in some collaborative areas, Thai researchers can shift their focus toward learning from their foreign counterparts instead of tools and financial support. It becomes more convenient to attract experts from other countries, as they do not have to make significant investments (P8 Bio G).

Similar to collaborations across nations, accessing and sharing resources is the main reason for collaborations across sectors. For instance, as P9 Eng U mentioned, his engineering department's frequent collaboration is with National Science and Technology Development Agency (NSTDA), a Thai national laboratory well-equipped with tools and experienced personnel. Some scholars emphasize resource sharing in addition to resource access. As an example, P1 Eng I's company possessed several high-performance computers, advanced software, and data resources that were significantly underutilized. The primary incentive for their company to launch collaborative projects with universities was to share these resources instead of allowing them to remain unused. Furthermore, he also offered guidance on utilizing these tools and addressing specific problems he had expertise in.

According to P9 Eng U, equipment and personnel are extremely valuable assets that attract collaborative partners. Even if you graduated from or work at a reputable institute, lacking the essential tools and skilled individuals can make it difficult to attract partners.

Research Funding. Credibility sources often center around financial resources, which are highly essential for collaborative activities. These collaborations can be cost-intensive, primarily due to factors like travel and living expenses, as highlighted in P2 Med U. The limited budget, a common challenge for scientists in Thailand, can hinder their work. In seeking financial support from external sources, researchers may need to fulfill various requirements from grant providers and stakeholders, as indicated in P4 Bio G.

“So, we wrote a proposal to request a budget. We said... “okay we are going to do what you asked for but we are going to do something else too.” They said ‘okay’ after a number of meetings”. - P4 Bio G.

The quote from P4 Bio G emphasizes that the primary focus is on fulfilling the requirements of the grant provider, followed by meeting the expectations of other partners. Nonetheless, the attainment of this agreement is not a straightforward process, as indicated by the interviewee, who mentioned the necessity of engaging in multiple discussions to reach a consensus.

As highlighted by P9 Eng U, financial resources also equate to influence. He articulated, "With adequate financial resources, we can engage in collaborations more equally." Monetary strength substantially boosts an organization's credibility, rendering it an appealing partner for collaborative ventures.

While budget constraints may not affect some organizations, accessing grants and financial support remains a coveted opportunity. For instance, P1 Eng I is eager to assist universities by offering access to their corporation's advanced tools and data. Moreover, if collaborative projects with universities can lead to research grants, he anticipates utilizing these funds to maintain or upgrade the tools within his labs.

It's noteworthy that while some informants acknowledge financial limitations as impediments (P3 Med G and P4 Bio G), others claim to be in favorable positions due to their substantial budgets (P9 Eng U). These insights suggest that disparities in resource availability, particularly financial resources, persist among Thai agencies.

“And the key to the success of the collaboration is that we are not expecting anything back from utilizing our resources or our partners. We don't expect anything in terms of personal, financial, or reputational gain. At CRA, we can do everything. This attracts other partners; this makes other agencies want to work with us.” - P3 Med G

As the leader of a prestigious research center and hospital, backed by the Thai Royal family, The interview highlights that this agency is endowed with ample financial resources and autonomy, setting it apart from others. Consequently, researchers within this agency can devote more attention to knowledge and discovery, reaping the fruits of their collaborative endeavors.

Data. Collaborative efforts yield access to valuable data for research purposes. The interviews, particularly those with experts in Medical, Agricultural, and Biological Sciences, emphasize that data represents Thailand's most abundant resource. Thailand boasts rich

biodiversity, rare animals, plants, and emerging diseases, situating the country on the frontline against potential pandemics and environmental challenges (P4 Bio G and P8 Bio G).

“Thailand is located in Southeast Asia, a region rich in biodiversity. We have many types of bats like... Lyle's flying fox and many other types.” – P4 Bio G

Researchers worldwide are drawn to Thailand by the wealth of natural data. For example, USAID collaborates with Thai universities and government research agencies, focusing on viruses in animals that could transfer to humans and may cause global pandemics. The objectives are to understand the viruses and implement measures to curtail their dissemination. This critical data and information concerning animal-origin pathogens are only accessible and investigable through the collaborative synergy between Thailand and the US. One partner contributes the knowledge and tools, while the other supplies the essential data and local workforce (P4 Bio G).

The need for specific data for research also occurs in engineering fields. Developing tools to address specific issues requires data from the source. NASA, despite possessing global land and water data and advanced tools, can enhance the accuracy and utility of this data by integrating it with ground data and insights into local human activities through international collaborations with local research agencies like the Asian Disaster Preparedness Center (ADPC) (P13 Eng I).

“For data, we mostly used public data. We didn’t have a problem accessing data we needed from NASA. We also needed some data from Thailand. We didn’t have any problems as well because ADPC provided us with everything we requested.” - P13 Eng I

Consequently, the exchange of various sources of credibility to access or generate data constitutes a pivotal aspect of scientific collaborations.

Arguments. Among the key outcomes of research endeavors, publications often stand out as significant achievements. However, given Thailand's commitment to advancing its economic development, the government is actively promoting the prioritization of applied research and research commercialization within the Thai research community. For instance, collaboration between the private sector and universities offers the private sector the advantage of gaining innovative ideas and market data from young college students, potentially fueling their business innovations (P1 Eng I). Even for researchers within some government agencies, the primary emphasis lies in the real-world application of research findings rather than publication, as highlighted in P4 Bio G.

“For government agencies, the most important aspect is probably the application of research findings, not publication. But we want to pull the work to apply and make it available to the general public.”

However, not all researchers agree with the notion that commercialization and immediate applications should be the sole purposes of scientific research. As indicated by P3 Med G, knowledge derived from basic research holds substantial importance for advancing the frontiers of science, serving as the foundation for future investigations.

“However, finding real-world applications for research isn't the only priority for the scientific enterprise. Actually, strong intellectual foundations are required for academic advancement in all disciplines. Therefore, it's impossible to push some research... no..., actually...most of the research to the production process. It is not necessary. Some research can

be used to lay the groundwork for future research.” - P3 Med G
Even research leading to conceptual arguments can have significant value. Furthermore, it's unrealistic to anticipate commercialized outcomes from every research endeavor, and not all scientists can be expected to prioritize practical applications. As a high-ranking official at a Thai national research agency, he is satisfied with having even just a few out of every hundred research projects at his agency result in tangible real-world applications.

Publications. Publications is reported as the common expected outcome in most collaborative activities. Universities put priority on publications because the number of publications and citations helps increase the universities' global rank and visibility (P6 Eng U). Many universities put publication as the key KPIs for its employees (P7 Mat G). For instance, the researcher needs to be the first author or a corresponding author to meet the KPI requirement (P9 Eng U).

However, in many interviews, publications are not all they want. For instance, P18 Med U engaged in a collaborative project with a Thai university. She said the requirement from her research partner was to spend time at the lab and teach their research team. Although, the project and the final publication could be done through online interactions but what is also important is knowledge transfer. Similar to what P2 Med U said:

“We've been concentrating so much on publication. Is it advantageous to us?

It is, indeed. However, it is not sustainable because we have not developed any know-how or knowledge for the country.” P2 Med U

P2 Med U suggested that Thailand needs to pay more attention to translational research which leads to benefits to humans. He brought up an example from Utah, United States. Utah

State invests greatly in a center that focuses on seizure treatment and medicine. The center also collaborates with private companies in analyzing and testing drugs. The center provides service up to FDA submission and product commercialization. P8 Bio G agrees with this saying that being a researcher with high impact factors but never coming up with any practical applications is like you didn't contribute to any community. P4 Bio G put his priority on capacity building. For him, having his name on publications is useless if his team and he did not learn anything from the collaborative projects.

While some informants insist that science should do more than just produce knowledge and pay more attention to tangible contributions to society, some informants argue the significance of publications. To pursue academic advancement in all disciplines, they need publications as an intellectual foundation. For P3 Med G, applicants are also important. However, this mission should be responsible by a different entity, not the researchers.

Recognitions. Recognition yields multiple advantages, including elevating an organization's standing in rankings and enhancing its visibility, which, as indicated in P6 Eng U, can bolster opportunities for securing funding and attracting collaborative partners. Furthermore, recognition is not limited to facilitating collaborations with external agencies; it also plays a pivotal role in enabling research efforts to garner acceptance from higher-level authorities and receive stronger support from their own organizations.

"I've observed a number of changes recently, particularly in the attitudes of high-ranking officials. It's evident that requesting resources and support has become much easier, particularly after we can show that the knowledge from our research can be effectively applied in real-world contexts." - P6 Eng U.

While the primary objective of scientific research is the generation of knowledge, it's essential to acknowledge that, particularly for the general public, the most visible outcome is often the reputation derived from research rather than intellectual content. Consequently, some high-level policymakers place greater emphasis on tangible returns such as higher ranks on particular ranking and higher factor impact numbers. As complained by P5 Bio G, "This made me feel sorry for government agencies whose decisions are based on politics rather than intellectual grounds. We tried to argue against their decisions with reasons, but they didn't listen."

The next section focuses on the dynamics and influences that shape the practice of credibility conversion among researchers within the network. By examining how credibility is built, shared, and transferred, I gain a deeper understanding of the mechanisms that facilitate successful collaboration. Through this analysis, I aim to uncover the critical elements that drive the conversion of credibility into tangible research outcomes.

Sources of credibility conversion between researchers in the network. The credibility cycle concept elucidates the process by which scientists acquire and bolster their credibility through research activities. This project specifically delves into the dynamics of how sources of credibility undergo transformation through interactions among researchers engaged in collaborative projects. A key motivator prompting researchers to invest time and effort in collaborative research is the pursuit of necessary resources through reciprocal exchanges.

The primary motivation is to pursue what they need to accomplish their organizational goals. The exchanges of credibility sources manifest in diverse ways. As exemplified by P1 Eng I, when a private company provides university students with access to high-performance computers and guidance, it anticipates that the students may come up with new knowledge and

generate innovative ideas that can be applied to their business. Similarly, private companies extend research grants to universities, seeking involvement in research initiatives and the opportunity to leverage the project's results for their own benefit. By offering financial support, the private sector became a more appealing research partner than government institutions in some contexts. For instance, P10 Mat U stated “Now, Thai universities and companies are collaborating a lot more. First, the companies possibly benefit from the new knowledge produced from research. For universities, instead of getting funding from government agencies... We require funds to pay our students and cover research-related expenses. Every lab must make an investment. So, universities can have additional financial resources.”

Although public goods are the primary tasks for government and universities, numerous collaborative research initiatives between Thai universities and the government are driven by a synergistic exchange of resources and goals. Thai universities often require access to advanced tools and equipment owned by their government counterparts, while government researchers seize the opportunity to publish research papers, fulfilling their KPIs. This mutual cooperation facilitates the attainment of both parties' objectives. These exchanges are made after careful consideration. Collaborations are initiated for various reasons, such as an abundance of resources to be shared across agencies (P1 Eng I and P4 Bio G), a necessity to obtain required resources (P4 Bio G), and the importance of maintaining long-term relationships among researchers (P4 Bio G). Some collaborative efforts focus on ensuring substantial returns, where partnering agencies must possess the necessary resources and guarantee expected outcomes (P9 Eng U). Some young researchers are willing to invest everything to have the opportunity to work with prestigious organizations, considering it a valuable and rewarding experience (P13 Eng I).

Publications do not only show knowledge production, it can be a tool to gain trust. P12 Eng I, a CEO and a researcher at a private company posited that his company gain trust from current and potential clients and collaborators by getting quality certificates or engineering certificates, as well as academic publications as well.

“The most crucial thing for engineering companies is to gain client trust.

There are numerous ways to demonstrate the high quality of our products and services. For example, getting quality certificates such as ISO or engineering certifications. Another way is through academic publications. That’s why I also pay attention to publications. So, I tried to publish journal articles and attend academic conferences.” – P12 Eng I

The next theme I found in the interviews is that the demarcation between sectors or nations is not a significant barrier in today's interconnected society. Collaborative research, whether at local or international levels, exhibits various distinct characteristics. Yet, the interviews with participants reveal that they do not perceive these two types of collaborations as entirely distinct activities, particularly when focusing on credibility source conversions. As anticipated, the findings revealed that a majority of interview participants emphasized the positive correlation between local and international scientific collaboration. The most frequently cited reason for this was the recognition that scientific knowledge in the contemporary world knows no geographical boundaries (as noted in P2 Med U, P7 Mat G, P8 Bio G, P11 Mat U, and P15 Bio G). Knowledge derived from both basic and applied sciences in foreign countries can be immensely beneficial within a domestic context. Numerous scientific and technological research endeavors are geared towards addressing global challenges and problems faced by humanity,

with their outcomes holding the potential to impact human lives worldwide (P11 Mat U). As P1 Eng I mentioned,

“My company is a petrochemistry-related company. There would be some problems related to petrochemistry which are also problems in other countries. They are common issues.”

The demarcation between local and international collaboration is not only blurred but engaging with foreign partners also leads to an expansion of knowledge for local researchers and agencies, as highlighted by P7 Mat G. Several international collaborative projects have been initiated to facilitate the learning process for Thai researchers, enabling them to transfer acquired knowledge back to their homeland. For instance, the OIE Twinning project between USGS and Mahidol University aims to assess the needs and develop a plan for training and capacity building for Thai researchers focusing on wildlife disease surveillance (P15 Bio G). Even when capacity building is not the primary goal of a project, Thai scientists are aware that they must seize the opportunity to absorb as much knowledge as possible and subsequently apply it back in their home country. P6 Eng U, a Thai researcher who collaborated with Chinese Space agencies, said “Our responsibility was to go to China and learn from them. Now, we are building TSC-1 and TSC-2. We are doing it ourselves.” Indeed, some international collaborative projects help enhance research capacity in developing countries, indirectly yielding benefits for local collaborations, as highlighted in P14 Med U, P17 Bio I, and P18 Med U. Furthermore, in order to compete for very competitive international funding, local Thai agencies may need to collaborate to build research teams with the necessary expertise and research capacity.

“We had to look at what resources we had, then we created the projects according to what we had. What we can do, what we cannot do. Mahidol

University had a professor who had a degree in Math Modeling. He can develop models to predict how a pandemic will spread. I knew him so we decided to work together in the area that we could work on.” - P4 Bio G

According to the quotation, the researcher expressed a desire to seek a grant from a U.S. organization. Recognizing the necessity of meeting the funder's requirements, the researcher acknowledged the need to recruit additional experts into the team to enhance the likelihood of securing the grant. This instance illustrates how collaborating with foreign partners indirectly fosters local collaborations and contributes to capacity development.

To support this argument, P2 Med U contends that collaborating with foreign partners doesn't inherently result in a depletion of resources available for local partnerships. Local collaborations can, in fact, reap benefits from international projects. Thailand faces challenges in maximizing the benefits of research collaborations due to limitations in knowledge and research management. These are the specific areas that Thailand should concentrate on improving. Thailand must improve this in order to maximize the benefits of all research activities.

However, contrasting perspectives regarding local and international collaborations also emerge. Due to the significant emphasis placed by Thai agencies on metrics like the number of publications and impact factors, some scientists focus primarily on publishing and reaping rewards, as stated in P2 Med U. Certain researchers, particularly younger ones seeking to establish their reputations, prioritize international collaborations because they have the potential to yield higher-impact publications (P8 Bio G and P10 Mat U).

“Collaboration with more developed countries is a no-brainer... But if you are younger, you may need to grab all the opportunities you can find. Depends on

what strategy you want to use. Giver or taker. Some are takers so they focus on international collaborations.” - P8 Bio G

This aligns with the proposal made by Kwiek (2020). The researcher suggests examining the distinctions between "internationalists" and "locals," particularly focusing on their objectives when participating in research collaborative activities.

In addition to possessing the required resources for exchange, trust stands as one of the most pivotal elements in ensuring the success of collaborations. Despite the modern technology that facilitates long-distance collaborative work, face-to-face interactions remain indispensable. A number of collaborative projects could not take place until possible partners could meet in person (P2 Med U). In certain cases, grants necessitate the residency of researchers at host organizations to ensure optimal project outcomes and lay the groundwork for future collaborations (P10 Mat U).

P15 Bio G, a researcher from a government agricultural agency, pointed out that in certain instances, exchange arrangements were not always straightforward, especially when it came to sensitive research areas like diseases with international partners. Due to concerns that disease-related information could potentially be misused as a bioweapon, thereby affecting national security, government agencies in Thailand sometimes display caution or reluctance in engaging in international collaborations.

In such cases, according to P5 Bio G, U.S. agencies have found indirect approaches necessary, initially providing funding to focus on enhancing the capacity and infrastructure that the Thai agency required. Later stages of the project focused on personal development and

delivering results from research projects. Through this phased approach, the Thai agency eventually engaged in collaborative research with the U.S. agency.

What I feel is that the U.S. is smart enough to recognize that Thailand may not disclose everything, such as all the details about diseases. So, they provide support by funding the establishment of facilities, research buildings, and labs. Many of these projects are multi-phase initiatives. The initial phases focus on building and upgrading infrastructure—establishing and renovating facilities. We gladly accept their financial help, and suddenly, we have new buildings and state-of-the-art labs. The next phase shifts towards personnel development, where research takes center stage. In this phase, they not only train our staff but also expect access to research results and direct involvement of their personnel in the projects. - P5 Bio G

Countries, regardless of their level of advancement, utilize strategies to attain their objectives. To identify suitable strategies, one crucial factor to consider is the negotiation power possessed by each involved party. Negotiations within scientific collaborations are a component of the interactions among the involved actors. Those who possess essential resources, such as natural resources or specific expertise required for the projects, often hold significant negotiation power. Nevertheless, the interviews reveal that partners who provide financial support typically wield the greatest influence. The priority for researchers is to meet the requirements of their funders (P4 Bio G).

Inequality between research partners from developing and developed countries emerged as a topic of discussion in the interviews. In some instances, partners may have equal roles during research projects, but when it comes to writing publications, the majority of the

responsibility often falls on the side with more experience, such as the American researchers. Thai researchers frequently find themselves listed as co-authors. As mentioned by P5 Bio G, "Thai researchers are frequently listed after American counterparts because we have less experience writing and submitting articles in international publications. A language barrier is also a factor." Some factors stem from Thai culture and social norms, particularly the difficulty in saying no or expressing their specific needs directly (P5 Bio G). In contrast, informants with experience working with Chinese partners (P7 Mat G and P10 Mat U) do not encounter this type of inequality when collaborating. However, according to P6 Eng U, despite reporting unequal power dynamics with her Chinese supervisor, she believes the strong seniority system prevalent in Asian countries is the reason.

The inequality between Thailand and more advanced countries has seen some resolution in certain cases. According to P3 Med G and P8 Bio G, Thailand's economic status and research capacity have shown improvement over the years. This progress has translated into increased resources, including financial strength, which has in turn bolstered Thailand's negotiation power and ability to hold its ground when necessary and avoid engaging in the semi-colonial model or parachute research with more advanced countries (Costello, 2000).

“But Thailand is not in that position anymore. We can protect our benefits. In the past, we were unable to say no when we received requests for samples from larger nations. We used to send monkey brains to other nations upon request. Now, we have more negotiating power... Today, we feel the need to protect our rights. We don't need to do everything they ask. We can negotiate, so we learn from them or get tools or money from them.” – P8 Bio G

In addition to negotiations between partners from different countries, researchers frequently encounter the need to persuade or negotiate with decision-makers within their own agencies to obtain the necessary resources and organizational approval for their projects. However, according to many participants, if researchers have conducted preliminary research and can verify the necessity of the collaborative project with specific partners, decision-makers are more likely to endorse their proposals (P2 Med U and P3 Med G). However, it's crucial that the proposed project aligns with the broader thematic focus of their agency (P10 Mat U).

Researchers employ various approaches when considering research collaborations. A prominent theme discerned in the interviews is that collaborations are regarded as investments in which researchers must evaluate and substantiate their investments as they rely on resources to carry out their work. They must weigh what they stand to lose and gain, assess whether it's worth the effort, and determine if they can achieve their goals before making a decision (P5 Bio G). During the interviews, all participants consistently discussed both their contributions to collaborations and the benefits they expected to receive in return (P6 Eng U, P8 Bio G, and P14 Med U). Moreover, a higher allocation of resources often results in a greater return on their efforts (P8 Bio G).

Table 16 displays coding for emergent and structured themes, including the six sources of credibility and the relationship network. I quantified the frequency of appearances of these sources of credibility in the interviews, reflecting the perceived importance attributed by the participants to each item. It was observed that staff, equipment, and publications are mentioned more frequently in the interviews, suggesting that these two sources of credibility play a significant role in Thailand's scientific collaborations. Interestingly, almost all participants

emphasized the importance of the relationship network among researchers in collaborative activities.

Table 16

Plot themes and their frequencies emerged during the interview coding process.

Interviewees	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Staff and equipment	x			x	x		x	x	x				x	x	x			x	10
Data	x		x					x					x	x					5
Arguments	x		x	x									x						4
Publications	x	x	x	x		x	x	x	x			x						x	10
Money	x	x	x	x					x					x				x	7
Recognitions				x	x	x													3
Relationship networks	x	x	x	x		x	x	x	x	x	x	x		x			x	x	14

In the previous and this chapters, I discussed the key observations derived from both quantitative data and qualitative interviews. The next chapter will present an integrative analysis, where I synthesize findings from both methodologies and previous research to gain a comprehensive understanding of scientific collaboration at both local and international levels. This analysis will help us answer the research questions related to the connections between these two types of collaboration and the drivers influencing their dynamics.

Chapter 8

Integrated Analysis: Credibility Cycles Driving Triple Helix Relations

This study's main objective is to explore the dynamics and relationships within the collaborative landscape of local and international research partnerships, particularly between developing and developed countries. To achieve this, I conducted an extensive analysis using both primary and secondary data, employing a blend of qualitative and quantitative methodologies. Quantitative data were derived from co-authored publication records spanning from 2006 to 2022, while qualitative insights were gathered through interviews with 18 researchers from diverse collaborative settings conducted between the summer of 2022 and 2023. The research questions are:

1. What are the connections between local and international research collaborations, with a comparative analysis of Thailand, the United States, and China?
2. How do social factors and strategic considerations influence the pursuit of scientific collaborations?

To address the first research question, I analyze the co-authored publication trends between Thailand and both the United States and China. Additionally, I employ mutual information analysis, developed within the Triple Helix framework, to comprehend how the involvement of international partners impacts the interaction of local sectors within Thailand's collaborative network.

In order to investigate the relationship between international and local scientific collaboration, I analyze these relationships across various collaborative landscapes and

disciplines. I first examine scientific collaborations within Thailand and between Thailand and foreign partners using descriptive statistics and the mutual information model. Subsequently, I explore three selected areas of study, specifically focusing on collaborations between Thailand and the United States and China. This comparative approach allows us to draw parallels between the case studies and to evaluate collaborative settings across different disciplines.

In this chapter, I provide an integrative analysis using findings from quantitative methods, qualitative interviews, and background research, focusing on significant observations that could help us answer the research questions. First, I examine the different patterns found in collaborations between Thailand and the United States and Thailand and China. Then, I discuss the varied patterns I observed among the three subject areas.

International Research Collaboration between Thailand and Its Two Allies

Although scientific collaborations between Thailand and many countries worldwide are consistently on the rise, the focus is on the United States and China, given their prominence as collaborative partners. According to the Thailand International Cooperation Agency (TICA) (2022), Thailand has established national-level Memoranda of Understanding (MOUs) in science and technology with 12 countries, including Germany, the United States, France, China, the European Economic Union, Japan, Canada, South Korea, Hungary, Australia, Turkey, and Sweden. Among Thailand's top 10 collaborators, the United States leads in the number of co-authored publications. However, from 2016 to 2022, the Average Annual Growth Rate (AAGR) of Thai-US co-authored publications is relatively low at 6.81%, with Japan exhibiting the lowest AAGR at 6.60%. India stands out with the highest AAGR of co-authored publications at 22.99%, followed closely by China at 22.82%, which also contributes a significantly larger number of publications than India. In this section, I discuss the findings related to the collaborations

between Thailand and its two main partner countries, the United States and China, drawing on data from both quantitative and qualitative studies.

According to the quantitative results, I identified several similarities and differences in the collaborations between Thailand and its two main partner countries, the United States and China. The observations include the historical relationships between these countries, which influence the forms of collaboration and expectations from each partner, the rate of increasing collaborations between Thailand and these two nations, and the role of local sectors when engaging with American and Chinese partners.

First is the distinct historical relationship between Thailand and the two countries, which influences the form of relations and expectations from its partners. Thailand is the United States' oldest ally in Asia, sharing a longstanding relationship across various domains. The ties between Thailand and the United States are characterized by strong diplomatic and military support and activities. Given the United States' global leadership in science and technology, it is regarded as Thailand's most significant partner in this dimension. Many interview participants highlighted that the primary reason for Thailand to engage in collaboration with the United States is the desire to learn from its superior advancements in science and technology. This consensus is widely acknowledged among the interviewees. For example, during an interview with P5 Bio G, a researcher and research project coordinator at a Thai government agency, when asked about her interest in collaborating with American agencies, she expressed,

"The United States has exceptional technology. They are currently undergoing a significant scientific revolution and achieve considerably more." - P5 Bio G

While Thailand's collaboration with the United States represents a north-south partnership characterized by dependent relations, the collaboration between Thailand and China is considered a south-south research collaboration which is more equal. The relationship between the two Asian countries began much later due to several wars and political conflicts. In 2025, Thailand and China will mark the 50th anniversary of the establishment of diplomatic relations, nearly 150 years after establishing relations with the United States. However, despite the delayed official relationship, Thailand and China are geographically close and share a rich history, cultural, and economic ties. The Chinese minority has migrated to Thailand since the 13th century, creating strong connections between the people of both nations. While several countries such as Cambodia, Laos, and Sri Lanka have come under the direct and indirect control of China, Thailand has adeptly maintained a balance of power and preserved its status as an equal friend to China. This achievement is attributed to Thailand's astute diplomatic strategy, economic resilience, and robust ties with the United States (Skaggs, et al., 2023). This type of dynamic is also reflected in the relationship between Thai and Chinese researchers. For instance, P11 Mat U, a Chinese researcher has expressed the way he treats his Thai research partners:

“At our center, we treat our partners as friends. We talk to each other through our workshops, throughout our conferences, throughout our platforms. The scientists will finally figure out the interests of the two sides. So actually, no one has more power. It’s a very equal and friendly discussion.” - P11 Mat U

Several memoranda of understanding (MOUs) on science and technology have been established between government agencies and universities in Thailand and China. Numerous research collaborations and innovation partnerships have been initiated under the Belt and Road

Initiative (BRI) which is a global infrastructure development project initiated by the Chinese government in 2013.

The distinct evolution of these countries and their relationships leads to the second observation: the differing rates of increase in collaboration between Thailand and the United States and China. While collaboration between Thailand and both countries is increasing, they are doing so at different rates. The number of co-authored publications between Thailand and the United States has been steadily growing over time, with a slight dip in 2022. The annual growth rate has consistently remained around 6 - 10% from 2006 to 2022. The United States continues to be a crucial partner in scientific research for Thailand, as evidenced by the consistently high number of Thai-U.S. co-publications across all years and disciplines. In contrast, the proportion of Thai-U.S. collaborations has been affected by the substantial increase in collaborations between Thailand and China. While the quantity of collaborations between Thailand and the United States continues to rise, the surge in Thai-China collaborations has shifted the balance, indicating a dynamic shift in Thailand's international research partnerships. The quantity of collaborative publications between Thailand and China has been on the rise over time, particularly showing an evident upward trend after 2012. The annual growth rate, though fluctuating significantly from year to year within a broad range, generally falls between 20% and higher which exceeds the annual growth rate of co-publications between Thailand and the United States.

Another similarity and difference I found is the level of engagement across different local sectors. Similar to trends observed in many countries, universities play a pivotal role as the primary contributor to research publications between Thailand and the United States and Thailand and China. However, the roles of the government and industry sectors differ when

engaging with American and Chinese partners. The examination of the quantity and synergy in research collaborations reveals a limited involvement of Thai industry in the collaborative landscape of Thailand's research, especially with the United States. Despite various initiatives and financial support from the government, establishing robust Triple Helix relations requires Thailand to focus on creating an innovative ecosystem that seamlessly connects basic research with commercialization. This approach aims to attract increased participation and investment from the private sector in research activities, especially with international partners. However, the private sector must go beyond mere considerations of costs and benefits, as emphasized by P2 Med U, a university researcher who also leads the university's Research and Development Office.

“Yes, Thailand does not prioritize translational research. We don't care about the utility of our research; we only care about publication. In my opinion, it's easy to do but it doesn't benefit our country as much as we want...Moreover, most entrepreneurs in Thailand don't understand innovative ecosystems. They may know about cost control and market mechanisms. But they don't understand much about innovations. We need to develop our ecosystem. This is what we need to do in Thailand.” - P2 Med U

Hence, for Thailand to maximize the benefits of learning from more advanced foreign nations, it must also delve deeper into its local science and technology infrastructure. This local system should be capable of effectively translating research-derived knowledge into tangible outcomes that benefit the country.

In China, universities and government entities lead the way in collaborative efforts, mirroring the dynamic seen between Thailand and the United States. Universities are the most

active participants in partnerships with China, followed closely by government institutions. Because of their geographical proximity, the sharing of facilities occurs more seamlessly and frequently. For instance, the Chinese government established the Chinese Academy of Sciences Innovation Cooperation Centre in Bangkok, fostering increased collaboration between Chinese researchers and their Thai counterparts from government agencies and universities (Chik, 2022). Establishing joint laboratories is a strategy employed by the Chinese government to enhance research relationships with Thailand across various domains including material science, as noted by P11 Mat U:

“In 2018, we could establish an innovation joint lab which is the National Nanotechnology of Thailand. In this way, the scientists from the two sides could talk more frequently together. Then when they find an opportunity to collaborate or to apply for grants, they can work together more easily.” - P11 Mat U

However, a key difference is that the industry sector is more actively engaged in the national research system when it comes to research collaboration with China. According to Figure 38 (Chapter 4), when Thailand collaborates with Chinese partners, the T values of collaboration between government and industry (GI) are very close to those between universities and government (UG). On the other hand, when working with American partners, T values of collaboration between universities and government (UG) are much stronger. Moreover, I found that the need to include the Thai private sector in research collaboration is recognized not only by Thai stakeholders but also by Chinese partners. As P11 Mat U, a Chinese researcher, suggests, his university's interest in collaborating with National Science and Technology Development

Agency (NSTDA) stems from the organization's goals and mechanisms to integrate the private sector into the research landscape.

“Especially the Nano Technology Center of Thailand [a sub-organization under NSTDA], which the Thai government is trying to promote to transfer technology to industry. This has a big advantage and is a key development strategy. That’s why we are interested in working together. We have accumulated expertise in commercialization and industrialization of technology and materials.” - P11 Mat U

The question here is whether perceptions of Thailand's research capacities and the dynamics of scientific collaboration with other countries influence how Thai researchers leverage knowledge from both local and international collaborations as well as the decision-making processes when participating in specific collaborative projects and how they establish network relations between researchers.

The literature suggests that enhancing local research capacity through collaboration within local sectors is vital for sustainable economic development. Governments of many countries try to extend scientific activities to all local sectors, fostering collaboration among government, academic, and industry entities to address pressing challenges and advance scientific knowledge. Despite progress in Thailand, there are still many challenges including the limited engagement of the Thai industry in research collaborations and the imperative to prioritize translational research and innovation ecosystems.

A significant observation found is the heightened two-dimensional collaboration between Thai universities and government agencies (Tug) when engaging with American partners. In the

examination of two- and three-dimensional synergies within local sectors in Thailand across various collaborative landscapes, I discovered that the two-dimensional synergy of local sectors does not vary significantly in domestic, international, Thai-US, and Thai-China collaborative settings, with the exception of a stronger collaboration between Thai universities and the government in the Thai-US partnership. This indicates that the involvement of international partners in Thailand's research landscape does not significantly alter the level of collaboration among Thai local sectors with a few exceptions. Furthermore, the three-dimensional synergy of local Thai sectors weakened across all collaborative settings, with the weakest observed in collaborations between Thailand and the United States and the strongest with China.

In Figure 32, which illustrates the total number of publications by sector, I observed that the number of Thailand-U.S. publications produced by the government and government-university collaborations is higher than in other collaborative settings. This trend is also evident in Figure 38, which displays two-dimensional mutual information. Here, the $T(ug)$ values are significantly higher than the $T(gi)$ and $T(ui)$ values in the Thailand-U.S. collaboration, compared to other settings. This indicates that Thai-U.S. collaborations are predominantly government-sponsored. This assumption is further validated by interview data, as all participants involved in Thai-U.S. research collaborations reported that their projects were initiated and funded by government budgets.

While the collaborations between Thailand and the United States predominantly revolve around research activities involving Thai universities and the government, the dynamic is different in Thai-China collaborations. In the case of Thai-China partnerships, the synergy between government and industry (Tgi) is nearly as significant as the synergy between universities and the government (Tug), particularly in domestic collaborations. This suggests that

Thai private companies exhibit more active involvement in research collaborations between Thailand and China, leading to a higher level of three-dimensional Triple Helix synergy. The observation aligns with what I found in the interviews. Even though I have a greater number of interview participants with experience in collaborating with American partners compared to Chinese partners, it is noteworthy that none of them have experience involving the private sector. The projects discussed in the interviews primarily revolve around universities and government agencies' research activities. Conversely, interviewees who have experience working with Chinese partners reported engaging with the private sector at various points in their collaborations. For instance, P11 Mat U, a senior researcher from Shanghai University, indicated that they are interested in collaborating with Thailand's NANOTEC because they perceive that the Thai government encourages collaborative research involving the private sector, which aligns with one of their goals.

“And our center is very interested in working with industry. So, that common interests are a very strong motive for our joint collaboration. Especially the Nano Technology Center of Thailand which the Thai government is trying to push... to transfer technology to industry. This has a big advantage.” - P11 Mat U

The U.S. and China are engaged in significant geopolitical competition, with Thailand becoming a focal point due to its strategic location in Southeast Asia. Both nations recognize Thailand's importance, but their approaches to collaboration differ, influencing how Thai researchers and institutions engage with them. According to P15 Bio G, an American researcher, the U.S. views Thailand as a less developed partner in need of support. Consequently, U.S.-Thailand collaborations often emphasize assistance and capacity building, aiming to strengthen

local institutions and enhance expertise through training and technical support. This relationship can create a dynamic where Thailand is seen as the recipient of resources and expertise. In contrast, China approaches its collaboration with Thailand as a mutual partnership, framing itself as a friend and equal. China emphasizes shared interests and a common development vision, employing funding as a strategic tool to build partnerships. Interviewees noted that Chinese financial support comes with fewer restrictions and a more flexible process, allowing Thai researchers to initiate smaller projects with greater autonomy. This streamlined approach makes China an appealing partner for Thai institutions. The differing strategies of the U.S. and China in engaging with other countries influence how Thailand decides to interact with both nations. This impacts the topics of focus and the strategies Thailand adopts when collaborating with the U.S. and China.

In addition to analyzing Thailand's international research collaborations with two countries in general, I also explore variations across three fields of study: medicine, agricultural and biological science, and engineering. The objective is to explore co-authored publications both in the aggregate and within these specific disciplines to uncover potential variations and delve into possible explanations for the observed diversity in collaborative patterns. As noted by Turner (2000), disciplines exhibit a wide range of differences encompassing organizational structures and intellectual aspects. These disparities manifest in institutional structures, problem-solving approaches, tools employed, training methodologies, markets, products, division of labor, and sources of funding, among other factors. Various lenses can be applied to examine these differences, as demonstrated by Yan (2014), who observed unique connectivity patterns and knowledge pathways within different disciplines. The connectivity of disciplines may be shaped by commonality in language and adherence to shared laws that are formulated based on

empirical evidence. The three disciplines under the study showcase diverse natures and characteristics, encompassing the interaction between researchers and knowledge or technology, functions, involved stakeholders, and patterns of discovery, innovation, and diffusion (Etzkowitz and Leydesdorff, 1995).

Scientific Collaborations in Medicine

I selected research in medicine because it is the most crucial research area for Thailand. Thailand not only has the highest collaboration in medicine with the United States and China but also with almost every other country. Medical science revolves around the practice of healing, which involves documenting cases, interventions, and their outcomes (Gillett, 2006). It relies on experimental explorations and measurements to understand human functions, natural phenomena, and objects. Gillett (2006) delves into the link between social, political, and economic power and the concept of Truth in medicine, which refers to scientific discourses controlled by specific authorities like universities, the military, and hospitals.

In interviews with participants in the medical domain, several conclusions have emerged regarding medical science in Thailand. Firstly, medical science significantly impacts individuals' lives, directly influencing health, well-being, and overall quality of life for Thai populations. Additionally, the field is marked by intense competition, driving the pursuit of advancements, breakthroughs, and innovations. Research in medical science spans both short-term and long-term perspectives, with some discoveries leading to immediate applications and benefits, while others contribute to foundational knowledge over extended periods. Moreover, the landscape of medical science varies across countries, with certain nations excelling more prominently in specific subfields. Even within Thailand, research and advancements may be concentrated in regions with robust infrastructures and resources.

Both local and international research activities in medicine remain robust during the study period compared to the other two disciplines, reflecting the Thai government's commitment to investing in medical science and positioning Thailand as a medical hub. According to the Ministry of Higher Education, Science, Research, and Innovation (2021), the focused medical areas include drug and vaccine development, as well as advanced therapy medical products. Similar to all other disciplines, universities are the primary contributors to research publications in medical science. When I consider the two-dimensional mutual information, I observed more active government involvement in medical research activities, particularly in collaborative projects with universities (Fig. 40). This engagement is driven by the government's dual objective of resource sharing with universities and the cultivation of a skilled workforce in the medical science field. As depicted in Figure 40, universities, government entities, and collaborative efforts between these two sectors play a substantial role in Thai medical research activities both locally and internationally. Universities, in particular, require access to advanced tools, data, and expertise from professionals, leading to extensive collaboration, notably with government agencies and hospitals. Additionally, according to P3 Med G, a prominent leader at a distinguished government hospital in Thailand, several Thai hospitals were founded and supported by both the Thai government and the royal family. Thai hospitals and governmental medical research agencies have substantial funding, allowing them to invest in research activities.

While medical research is primarily conducted by universities and governmental agencies, there is pressure to expand collaboration to other sectors, especially the private sector. According to P2 Med U, the Thai government is striving to position Thailand as a medical hub in the region, necessitating an improvement in commercialization capacity. The informant

highlighted the need for Thailand to move beyond focusing solely on producing publications and to develop an innovation ecosystem that facilitates advancements in medical research, including testing, FDA approval, and market production. However, the Triple Helix effect is progressing slowly in Thailand, and the government needs to transform more rapidly to manage expectations from society and other sectors. Consequently, Thailand currently relies on other countries for commercial production to meet market demands.

“Thailand is well-known for its healthcare system. But did you know that the majority of our raw materials are imported from other countries? We never have the actual technology to make our own medicine. We rely on materials and technology from other countries. Unfortunately, the know-how was never developed here.” - P2 Med U

P2 Med U's opinion is reflected in the two- and three-dimensional mutual information of collaborations among local sectors. According to Figure 40 - 41, the collaboration between the university and government (Tug) shows the strongest synergy in two-dimensional mutual information between UG, resulting in the weakest three-dimensional mutual information or weak Triple Helix relations among UGI. In Thailand, research collaboration in medicine is primarily led by universities and government entities, with limited industry involvement. Despite medical science being prominent, P2 Med U argues that the national system inadequately promotes innovation. Thai agencies generate globally recognized medical knowledge but struggle to apply it in the real world.

According to Figure 41, I observed the highest three-dimensional mutual information values (Tugi), indicating the lowest synergy, in the interactions among local sectors (both including and excluding international partners) in the medical field, compared to the T values in

other disciplines. Furthermore, the T values in all types of collaboration exhibit identical patterns in medicine. The patterns also appear different in other disciplines. This could imply that in medical science, collaborative research activities are predominantly led by specific sectors, universities, and government, with Thai private companies playing a lesser role. Even including international partners, there is no impact on the dynamic of the local sector's interaction. Government entities play a crucial role in both local and international medical research, as they are predominantly responsible for most research activities. This is reflected in the Triple Helix relations, where the T value among local sectors is notably lower in medicine.

As mentioned earlier, the declining proportions of co-authored publications between Thailand and the United States do not reflect reduced collaboration between the two countries but rather the impact of the significantly increasing number of co-authored publications between Thailand and China. I observed a slower growth rate and smaller proportions of co-authored publications between Thailand and the United States in several fields, including agricultural and biological sciences and engineering. However, in the field of medicine, there is a robust and consistent presence of Thai-U.S. collaboration. According to Figure 25-26, the number and proportions of Thai-U.S. co-authored publications in medicine are still significantly higher than those of Thai-China co-authored publications.

The robust collaborations in medical research between Thailand and the United States can be attributed to their longstanding relationship that spans over a century. The majority of established collaborations focus on military and medicine. One notable collaboration involves the United States Agency for International Development (USAID), the Armed Forces Research Institute of Medical Sciences (AFRIMS), and the U.S. Centers for Disease Control (CDC) working in conjunction with the Thai government (U.S. Agency for International Development,

2022). This collaboration aims to protect the health of American, Thai, and international communities through advancements in medical research and innovation (U.S. Department of State, 2022b). The historical ties between the two nations can account for the observation that, although universities play a crucial role in both local and international research collaborations in medicine, Thai government agencies have prominently emerged as the primary contributors to co-authored publications with the United States over the observed period (Fig. 33).

A similar trend is generally observed, but specific differences emerge when analyzing co-authored publications between Thailand and China. According to Liang et al. (2023), among ASEAN countries, Thailand ranks as the second most significant research partner in medicine for China, following Singapore. The quantity of co-authored publications between Thailand and China experienced a gradual increase starting in 2006, with a significant leap occurring after 2017, particularly in co-authored publications involving Chinese and Thai universities. The rise in co-authored publications can also be attributed to the effects of the Belt and Road Initiative.

The collaboration between Thai local sectors shows little difference when Chinese partners are integrated into the landscape, with Thai government agencies and universities actively engaging in joint projects with China. Notably, there has been a stronger synergy between universities and industry (UI) and government and industry (GI) after 2020, suggesting that Thai private companies are increasingly involved in collaborations with China, possibly due to the commercialization opportunities these projects offer (P11 Mat U and P6 Eng U). A key factor promoting these collaborations is the positive perception between Thai and Chinese researchers, who view each other as equals and friends, fostering long-term partnerships (P7 Mat G and P10 Mat U). In contrast, a comparison of medical science collaborations reveals that while the rise in Thai-China co-authored publications has impacted various fields, it has not affected

Thai-U.S. collaborations in medicine, which remain strong. This enduring partnership, rooted in over a century of ties focusing on military and medical research, results in significantly more Thai-U.S. co-authored medical publications. Much of this collaboration occurs under sustainable intergovernmental initiatives. Despite the growth in university and government collaborations, overall three-dimensional synergy—combining local and international partnerships—has declined over time. To provide a clearer understanding of research collaboration in the field of medicine in Thailand, I present detailed insights from relevant interviews below.

Case study in medicine: strong field but it is time to change. P2 Med U serves as both a professor in the herbal medicine department at Prince of Songkla University (PSU) and the President of the Research and Development Office (RDO). His dual roles underscore the necessity for the evolution of medical science in Thailand. In addition to teaching and research responsibilities, he is required to collaborate with other sectors to fulfill the mission mandated by the university and the government. The initiative, known as the Andaman Municipal Corridor Development Project, aims to establish the southern region of Thailand as a medical hub within the region.

“I have two main roles. I work as a researcher at the Faculty of Pharmaceutical Sciences and I did a lot of research. I work as an assistant to the President of RDO, I’m responsible for creating partnerships between universities. Of course, PSU has excellent personnel with diverse expertise. But we are not good at everything. And now MHESI classifies universities into different TRLs. Some universities have to focus on working with local and regional partners. PSU also needs to work more with local agencies and communities.” - P2 Med U

P2 Med U suggests that to overcome the middle-income trap, Thailand needs to prioritize research commercialization. He underscores that this is the key to ensuring the country truly benefits from research efforts. Consequently, collaborations between universities and industry are essential, as they facilitate the translation of research into commercially viable products. Although the commercialization of research has become a priority for the Thai government and researchers, the synergy between university and industry interactions has not significantly developed over the years (Fig. 40). He believes the main problem is the absence of genuine connections between sectors, with no one truly understanding the entire ecosystem that connects all the pieces together.

P2 Med U is not only accountable for local collaborations but also international ones. He actively sought collaborative opportunities through his connections with friends and professors. However, he faced challenges, such as having different interests or instances where his professors became inactive in research pursuits. The Thai government also played a role in facilitating connections between P2 Med U's research team and partners from American universities. This support was extended through various programs, including visiting programs. With the newly established relationship, the universities could explore additional collaborative activities.

Regarding the relationship between local and international collaborations, he does not perceive them as having conflicting relations. Both types of collaborations can be beneficial to each other. The challenge for Thailand lies in knowledge management. The country faces difficulties in connecting and utilizing the knowledge produced from both types of efforts.

“When we look at our innovative value chain, we realize what we are missing. We need the agencies that help us upscale our research. We have no idea what to do with our research. But we have a problem in that we don't have a proper

platform that allows us to work easily. Our government pays no attention to this issue. Producing knowledge in Thailand or knowledge that will be accepted globally has become extremely difficult. As a result, our researchers are solely concerned with publishing and reaping rewards.” - P2 Med U

While the current co-authored citation data and researchers' direct experiences may not comprehensively depict the diverse collaborative landscape of Thailand's medical science, the Thai government, spearheaded by the Thailand Center of Excellence for Life Sciences (TCELS), is actively engaged in incorporating private sectors into Thai life science and innovation endeavors, both domestically and internationally. Notably, Thailand is emerging as a significant clinical trial hub, with TCELS playing a pivotal role in facilitating connections among researchers, clinical trial laboratories, and regulatory bodies such as the Thai FDA. TCELS aims to bolster this capacity, ensuring that Thai researchers and innovators can autonomously conduct trials within the country, thereby reducing dependence on foreign investment (Chau, 2023).

In conclusion, the case study in medicine sheds light on the strengths and challenges facing Thailand's medical science landscape. These insights underscore the need for research commercialization as a mechanism to overcome the middle-income trap, emphasizing the necessity for genuine connections between other sectors and industries. While Thailand demonstrates success in promoting both local and international collaborations, the key challenge lies in effectively harnessing and exchanging knowledge across sectors for optimal outcomes. The ongoing efforts by the Thai government to integrate private sectors into life science and innovation initiatives represent a proactive approach towards enhancing the country's scientific endeavors and reducing reliance on foreign investment.

Scientific Collaborations in Agricultural and Biological Sciences

Agricultural and biological sciences are characterized by data rooted in nature. Certain countries, particularly those in the southern regions, possess abundant data in this domain, such as rare species, certain diseases, and viruses in tropical animals like bats. Research in these fields could result in the development of pesticides, fertilizers, and commercial applications in biotechnology, genomics, and pharmaceuticals. Additionally, some research areas prioritize environmental protection and address ecological issues. One notable characteristic of agricultural and biological sciences is their focus on studying natural ecosystems, biodiversity, and the interactions between organisms and their environments. These sciences are closely intertwined with nature, and phenomena such as animal migration and disease spread transcend geopolitical boundaries. Given the interconnected nature of these sciences, collaboration between nations is essential. This necessity for cooperation may serve as a catalyst for scientists to rise above political conflicts and work together towards shared objectives.

Thailand emerged as a prominent center for research in agricultural and biological sciences, distinguished by its global recognition as a major exporter of agricultural products like rice, sugar, and rubber. The country strategically integrates the promotion of sustainable development into its national policies, reflecting a longstanding commitment to agricultural research predating the implementation of economic development plans. A notable effort in this regard is Thailand's active participation in advancing its bioeconomy, which encompasses agriculture, biotechnology, and food for future initiatives (Fielding & Aung, 2018). Despite agricultural research investment, averaging below 1 percent relative to agricultural GDP, these efforts play a crucial role in bolstering production and fostering agricultural development (Suphannachart, 2019).

Moreover, Thailand's diverse natural resources and tropical ecosystem serve as compelling factors attracting research in this field. This biodiversity richness consistently emerges as a key point during interviews when questioned about why Thailand is an appealing research partner for numerous countries. The diverse ecological landscape of Thailand not only provides a fertile ground for scientific exploration but also positions the country as a desirable collaborator for research endeavors in agricultural and biological sciences for many countries.

In Thailand, top-down management is governed by the government, with key agencies such as the National Science and Technology Development Agency (NSTDA) and its subnational research centers—BIOTEC, MTEC, NANOTEC, and NECTEC—serving as a crucial link between academic research requirements and innovation in the industry. Numerous pilot plants operate through collaborations between the private and public sectors, exemplified by the Agricultural Research Development Agency (ARDA) under the Ministry of Agriculture. Many research programs are administered and situated within leading universities across Thailand. The well-established research network between universities and the government facilitates biotech companies in scaling up their research endeavors before commercializing their innovations (Thailand Board of Investment (BOI), November 14).

Research in agricultural and biological sciences at the local level has consistently increased over the study period. Universities have been the primary producers of local publications in this field (Fig. 34). When examining sectoral levels, it is observed that although there are a small number of publications produced by the industry, those co-authored by the Thai government and industry (Tgi) exhibit the strongest synergy. On the other hand, publications co-authored by universities and industry (Tui) show the weakest synergy (Fig.42). The data aligns with the findings in Suphannachart (2019). According to the study, in 2015, there was a

significant increase in the proportion of expenses allocated to Thai private-sector agricultural research. This rise is primarily attributed to heightened awareness within the private sector about the importance of research and development for enhancing competitiveness. While private sectors contribute minimally in terms of quantity to agricultural and biological science research in Thailand, a significant portion of their research activities involve collaborations with government agencies. The increase is also influenced by government policies supporting the infusion of technology into the agricultural sector and fostering greater private-sector participation.

The three-dimensional interactions among local sectors (Tugi) exhibit heightened synergy when engaged in international collaborations. However, there is no observable change when considering collaborations exclusively with partners from the United States or China. Collaboration with these two countries does not lead to increased engagement among Thai local sectors in this particular area of research, as there is little change in both two- and three-dimensional mutual information for both Thailand-U.S. and Thailand-China collaborations (Fig. 42-43).

Consistent with the general observation, the university is at the forefront of international collaborations. When examining the interactions between local sectors in different collaborative settings, I found that the university and government exhibit greater synergy when engaging with foreign and American partners (Fig. 42). The necessity for support and supervision from the Thai government in this domain stems from various factors, some of which may be linked to national resources and security concerns. For example, according to P5 Bio G, the majority of collaborative projects with the United States are facilitated through Thai government agencies.

“I also had projects with the United States too. They mostly collaborate with the agencies that work on the Biological Threat Reduction Program with the Defense Threat Reduction Agency (DTRA). They aim to keep viruses from spreading across the border. DTRA is an agency under the Thai military.” - P5

Bio G

Furthermore, agricultural and biological sciences are intertwined with global issues that necessitate collaboration from multiple countries. Such collaborations often involve governments as representatives; hence, many initiatives are initiated by government agencies or take place under intergovernmental frameworks. P15 Bio G, an American researcher and the leader of a USGS, shared his story about the initial encounter with his long-term partner in Thailand.

“I was invited to participate in a One Health workshop that was funded by USAID as part of the PREVENT program, the emerging pandemic threat prevention program. It was hosted in Bangkok, so I had the opportunity to meet various folks working in wildlife health in Thailand, including Dr Pontheop.” - P15 Bio G

The two-dimensional synergy analysis indicates that, uniquely in collaboration with the United States, the synergy between local universities and government is stronger than government-industry collaboration. A contributing factor to the substantial involvement of the Thai government and universities is that many collaborations between Thailand and the U.S. originate from initiatives by U.S. organizations, emphasizing more official and sustainable collaborative efforts. For example, collaborative projects between the US Geological Survey (USGS), Mahidol University and government research centers were initiated under the UN One Health initiative. The program's objective is to prevent pandemics at their source. As per P14

Med U, the United States Geological Survey (USGS) is committed to sharing information and assisting other countries in enhancing their research capacity on environmental issues. These national-level initiatives necessitate collaboration between the Thai government and universities.

Between 2019 and 2020, co-authored publications in agricultural and biological science between Thailand and China surpassed those of Thai-US co-authored publications in both quantity and proportion. The majority of international investments in Thailand's agricultural sector come from the private sector, particularly from middle-income countries such as China and India. These investments predominantly target areas like food processing, plant breeding, agricultural machinery, and chemical applications in agriculture (Suphannachart, 2019). As of 2011, China emerged as the leading financial supporter of agricultural research and development (R&D), allocating an annual budget exceeding \$10 billion to agricultural R&D (U.S. Department of Agriculture Economic Research Service, 2022).

Thailand has abundant natural resources and skilled researchers. To enhance its research capabilities, the country seeks to acquire know-how through collaborations with more advanced nations, such as the United States. These international partnerships have played a vital role in strengthening the research capacity of Thai local sectors, empowering them to pursue independent studies collaboratively (P4 Bio G and P15 Bio G). While building local research capacity remains a priority for the Thai government, the findings indicate a decline in three-dimensional synergy within the local collaborative landscape, coupled with an increase at the international level. This trend underscores the importance of international collaboration in addressing global challenges, including pandemics and wildlife conservation. Collaborating with foreign partners serves as a catalyst for enhancing the synergy of collaboration among local sectors.

Highlighted case study in agricultural and biological sciences: a collaborative strategy to escape the semicolonial model. P4 Bio G, a senior government researcher engaged in several collaborative projects between USAID and the Thai government, shared a compelling case illustrating how a developing country like Thailand collaborates with a more advanced country like the US, along with the strategies employed to safeguard the benefits for his country. According to him, Thailand is well-known for its wealth of national resources, including rare species and emerging viruses.

“Thailand is located in Southeast Asia, a region rich in biodiversity. We have many types of bats like... Lyle's flying fox and many other types. So, they want to do something. They call this approach “stop pandemic at the source.” - P4 Bio G

The network of relations also plays a role in the collaborative projects. When USAID initiated the infectious disease detection and surveillance program, the Food and Agriculture Organization of the United Nations (FAO) reached out to the informant's team.

“So, USAID initiated this project. When they gave us grants, they needed to give us through FMO. FMO is an international agency that is related to livestock. FMO came to us, we had projects together before. They already had partners who would work with us... So, this is the beginning. We started with USAID, then FMO, and Thai agencies.”- P4 Bio G

To meet the requirements of the funding agency, the research team needed to reach out to experts in universities, leading to collaborative activities between the Thai government and

universities. The prospect of securing grants and collaborating with American partners motivates Thai researchers to collaborate and fulfill the necessary criteria.

“Mahidol University had a professor who had a degree in Math Modeling. He can develop models to predict how a pandemic will spread. I knew him so we decided to work together in the area that we could work on. I have expertise in Spatial Analysis, and I know what I can do, I would do the project related to the area... We need to find out what resources we have and then create projects” - P4 Bio G

P4 Bio G realized that Thailand's most important resource is biodiversity. Although this attribute could attract research partners from other countries, it did not necessarily lead to equal partnerships. Numerous international collaborative projects were assessed within the semicolonial model or parachute research framework (Costello, 2000), where local priorities are disregarded, and local talent is redirected from addressing local issues (Edejer, 1999). Therefore, he needed to form a strong team of experts to strengthen the negotiation power and request the addition of other components to the projects—components he believed would be beneficial to Thailand.

“They want us to collect and test samples to look for diseases. But we negotiated with them. We told them that just by collecting and testing the samples, Thailand gained almost nothing from the project.” - P4 Bio G

The researcher didn't want to merely collect data and provide it to the funding agency, as that wouldn't yield much learning from the process. He endeavors to establish scientific authority by assembling a team of skilled experts, aiming to enhance his negotiation power (Bourdieu,

1999). In addition, to maximize the benefits of their efforts, he requested to undertake additional tasks and involve as many Thai researchers as possible in the team.

“So, when I saw the opportunity (to collaborate with foreign countries), my goal was to have not only publications but also applications that we could use in Thailand. Secondly, we would use only Thai researchers because I know that Thai researchers can do research on our own. We have enough resources. Many people had a chance to study abroad. We have resources everywhere, in universities and government agencies. That was the reason for my effort.” - P4 Bio G

Efforts to counteract collaborations resembling the semicolonial model don't solely originate from the Thai side. P15 Bio G discussed the effort to foster equal collaboration from the US side. He has actively participated in a project known as the Twinning Project, a collaboration between the US Geological Survey, Mahidol University, and the Thailand National Health Centre facilitated by the World Organization of Animal Health. The objective is to establish a collaborative center with the aim of transferring skills and knowledge to the new center, aiding in the development of its capacity. The critical aspect of the project is to identify the needs and knowledge gaps in Thailand so that the program can effectively address them.

“We did a series of workshops based on wildlife and surveillance, wildlife and health information management. But simultaneously we also get a survey, an online questionnaire survey, interviews with the stakeholders regarding wildlife and health surveillance. We ask what to value for them, what are the limitations, what are the opportunities.” - P15 Bio G

He recognized that there are factors that could hinder the success of the project, such as cultural barriers, miscommunication, and skepticism from certain groups of stakeholders. To overcome these obstacles, the inclusion of stakeholders becomes a crucial function within the project. This approach empowers unspoken stakeholders and helps reduce pressure in maintaining collaborations (Kotze and Dymitrow, 2022).

“But we always make sure that we fully engage Thai partners... We want to make sure what we did match with certain needs of stakeholders on the ground.” - P15 Bio G

The case study in agricultural and biological sciences confirms the disparity in scientific capacity between developed and developing countries. Many collaborations between countries in the north and south still focus on capacity building (Chandiwana & Ornbjerg, 2003). To promote and support research activities in less developed countries, more advanced countries feel the necessity to provide technical assistance, overseas training, institution building, and collaborative research partnerships (Gaillard, 1994). Meanwhile, less developed countries like Thailand also need to take proactive approaches, not merely accepting what is offered but also negotiating for their best interests. One approach is to establish local networks and leverage their strengths from local resources. This strategy allows for a symbiotic relationship between local and international collaborations, complementing each other's efforts.

Scientific collaboration in engineering

The field of engineering is marked by the execution of numerous projects that often unfold in advanced facilities and necessitate the use of specialized tools. These projects typically involve allocated budgets due to the financial demands associated with advanced technologies

and equipment. Consequently, larger and more economically developed countries may possess advantages over smaller nations in the pursuit of such projects.

In contrast to agricultural and biological sciences, engineering experiences high levels of competition and commercialization. The impact of engineering projects is widespread, as technology is intricately woven into various aspects of human life, ranging from everyday gadgets like cell phones to complex infrastructure. Some engineering projects may have a shorter life span, focusing solely on the development or production of a specific innovation. Moreover, this field offers a broad spectrum of career options, allowing professionals to work in diverse settings such as universities, government agencies, and private companies. Many Engineering projects take place in advanced facilities and require specific tools. These require budgets.

Thailand's engineering research has consistently increased over the years. This increase can largely be attributed to the heightened activity of universities, which serve as the primary publishers of most engineering publications. However, the quantity of publications resulting from bilateral and trilateral collaborations between local sectors is significantly lower compared to those in Medicine and Agricultural and Biological Sciences (Fig. 35).

The triple helix relations in Engineering are comparable to those in Agricultural and Biological Sciences. Despite a small number of publications from the industry, those co-authored by the Thai government and industry demonstrate the strongest synergy. Conversely, publications co-authored by universities and industry exhibit the weakest synergy (Fig. 44). Although the number of publications by universities drastically increased, the two-dimensional synergy of collaborations between local sectors remained unchanged during the study period. Notably, the three-dimensional mutual information (Tgui) indicates that collaboration in engineering became the strongest among the three disciplines after 2016 (Fig. 37).

Interviews revealed that all participants from the engineering field had engaged in collaborations between universities and private companies (P1 Eng I, P6 Eng U, P9 Eng U, and P10 Mat U), this is not observed among participants from other fields. Collaborations between Thai government agencies and industry (Tgi) exhibit the strongest synergy in all collaborative settings except when the United States is included as part of the research landscape. Industries often get more involved in research in engineering because engineering is closely related to market-driven and profit-driven innovation and the activities involved in creating and producing products and services. Therefore, industries have a strong incentive to invest in engineering research to stay competitive, meet consumer needs, and capitalize on market trends. Meanwhile, government agencies need to provide support or incentives to businesses, leveraging the legal system to encourage creativity.

In comparison to other sectors, collaboration between Thailand and the United States in Engineering exhibits slower growth. Between 2019 and 2020, co-authored publications in engineering between Thailand and China surpassed those between Thailand and the United States both in quantity and proportion. (Fig. 30). Similar patterns are observed across various study domains, with Thai universities and the government (Tug) showing stronger synergy when engaging with American partners.

In recent years, there have been several factors contributing to the increased collaboration between Thailand and China in many fields including engineering. According to Chik (2022), Thailand serves as a significant partner in China's Belt and Road Initiative, which extends beyond infrastructure projects to include the strengthening of ties in science, technology, and education. Multiple cooperation centers have been established in Thailand in alignment with these objectives. Furthermore, as a component of Thailand's diplomatic approach to maintaining

a robust equal relationship with China, scientific collaborations between the two countries are not only supported by the government but also receive endorsement from the Royal Family. Thai Princess Maha Chakri Sirindhorn, known for her close ties with China, holds a significant position in various projects led by China, engaging Thai scientists extensively. The strong bond between the two countries, often described as being "as close as one family" by officials, likely contributes to the notable increase in collaborations, particularly in fields such as biological and agricultural sciences and engineering, which align with China's Belt and Road Initiative objectives (see Fig.29-30, P10 Mat U).

Additionally, the establishment of trust through face-to-face interactions is facilitated between Thai and Chinese partners due to the proximity of the two countries. Traveling between Thailand and China is more convenient and cost-effective compared to collaborations with countries in other regions.

Examining the two-dimensional synergies in local collaborations, I observed that the collaboration between government and industry exhibits the strongest synergy at both local and international levels. However, mirroring the findings in agricultural and biological science, the collaboration between government and university becomes strongest when American research partners are included in the collaborative setting, as indicated in Figure 44. This trend finds support in interviews with individuals experienced in international collaboration between Thailand and the United States, consistently emphasizing the participation of government entities. This suggests that collaboration with the US requires more formalized efforts and channels involving government participation.

As illustrated by P13 Eng I, for instance, the NASA training program for Thai students required crucial support from the Thai government. Access to various NASA facilities and

resources, including those related to sensitive security issues, was granted through the program. The involvement and endorsement of the Thai government played a vital role in securing the acceptance of Thai students into the program. Additionally, some projects with substantial budgets, as emphasized by P2 Med U and P3 Med G, depended on financial support from the government for their success.

On the other hand, collaboration with China is more informal, personal connections and culture play significant roles in the interaction. For example, P6 Eng U talked about her experience working with a Chinese partner on a Space project.

“For the first TSC, we had to go to China to learn from them. I wasn't part of the core working group, but a close friend was the program manager. He asked me to help with capacity building and writing supporting papers. He asked me what we should learn from China. I told him we needed to learn about satellite control. I don't care about other topics. When our team talked to the Chinese partner, they said they could teach us anything but satellite control. They needed to talk to their high-ranking officials first. I know that this topic was quite sensitive for them. They didn't answer right away. But I understand their culture. I need to keep convincing them. When we got there, we just needed to keep asking them here and there. That's how you deal with Chinese.” - P6 Eng U

Despite the varying social dynamics observed in Thai-U.S. and Thai-China collaborations, these differences are not presented in the two- and three-dimensional mutual information metrics. As illustrated in Figures 44 and 45, the dynamics of interaction among local sectors in engineering showcase are not much different at both local and international levels.

Highlighted case study in engineering: seamless connection between global and local collaborations. One common theme emerging from the interviews with engineering researchers is the recognition that the knowledge they are producing and the problems they are solving are shared issues present in every institute within the field and across various countries.

P11 Mat U is a senior Chinese researcher from Shanghai University (SHU) and P7 Mat G is a junior researcher from NANOTEC, a Thai government research agency. They both are working on a new type of bead used for Electromagnetic Interference (EMI) shielding applications. P11 Mat U expressed his interest in collaborating with NANOTEC due to the agency's numerous initiatives that encourage engagement from the Thai industry. This aligns with the mission of SHU, which focuses on promoting knowledge and technology transfer from the laboratory to the market. In his lab, they are actively working on developing new materials that not only hold significance for the market but also contribute to enhancing the quality of people's lives. Due to the nature of knowledge and technology in engineering fields, there is a greater need to collaborate with other sectors, particularly with private sector, to facilitate the transition of technology from the lab to real-life applications.

“ Because of our center, we develop nanomaterials that can be applied to various applications. Therefore, collaboration is very helpful. Local sectors and industries are also crucial. We recognize the need for industry change, so we must work collaboratively with companies to apply these materials to products. Since this topic is quite specific, we can use our materials in electronic products to shield against magnetic interference. Thus, we need to work closely with both our industry partners and research partners to develop new ideas.” -

P11 Mat U

Moreover, collaborating with the industry also results in incentives for the research team that can be utilized for future projects.

“I think from the university level... because of the encouragement from the government... First of all, they agree that we can use the resources to collaborate with the industry, with the Thais, to industrialize our technology and knowledge. Secondly, if you successfully transfer technology to the industry, the money from the industry, most of it will be given to the team. The university will get only a small part of it. I think this is a very good policy for scientists.” - P11 Mat U

Interestingly, expanding research from the lab to the real world is not the primary goal of Thai researchers. While the Thai government has included collaboration with private sectors as part of its national policy, researchers in Thailand still need to prioritize knowledge production as a central responsibility in their roles.

“On our side, we still focus on publications. Part of our KPI is to have publications from international and local collaborative projects. We haven’t expected to see our works be applied to the real world.” - P7 Mat G

While collaboration across sectors is encouraged, Thai researchers often engage more frequently in collaborations with other organizations within their own sector or with universities. For example, P7 Mat G mentioned several collaborative efforts, but primarily focused on other governmental agencies and only slightly on universities.

“Our researchers work with both local and international organizations. Even inside MHESI, we constantly discuss the potential to collaborate across

agencies. We have many collaborative projects between NANOTEC, MTEC, BIOTEC... Anything we can work together, we try to make it happen

We also have collaborative projects across sectors such as universities. We signed MOUs between Chulalongkorn University and NANOTEC and Mahidol University with NANOTEC, for instance. We are trying to create a research network with various agencies. When we collaborate with universities, we expect to develop personnel. We trained university students. That's one of our KPIs. We need to develop next-generation researchers.” - P7

Mat G

In the preceding sections, I discuss the findings derived from both quantitative and qualitative analyses. These examinations revealed nuances in various collaborative landscapes across different disciplines. The collaboration between Thailand and the United States holds significant importance and enjoys support from the governments of both countries, but challenges persist in achieving widespread synergy, especially with the private sector. The collaboration between Thailand and China results in stronger synergy among local sectors in Thailand. This collaboration is primarily driven by commercial incentives and investments from China. Thai Medicine research exhibits the most distinct collaboration patterns, as the field primarily involves collaboration between universities and government entities. Overall, strategic approaches are essential to foster comprehensive, sustainable, and diverse collaborations between Thailand and other countries in various scientific domains.

Correlations between local and international collaborations through the Triple Helix framework

Various researchers have delved into the impact of internationalization on local research collaboration, uncovering distinctive patterns in different countries. Through Shannon's entropy analysis, researchers have observed varying trends regarding the synergy within local systems across different countries. While some have noted a decline in synergy with increased involvement in international research, others have found the opposite trend in certain countries. (Leydesdorff & Sun, 2009; Ménégnibêto, 2015; Kwon et al., 2012; Ye et al., 2013). Another group of literature has identified positive connections between local and international research collaborations. These connections are attributed to spill-over effects, personal motivations of star researchers, and departmental effects on an individual's productivity (Barnard, et al., 2012; Müller et al., 2023; Bozeman, et al., 2001; Allison & Long, 1990).

Based on the interview, active researchers, at any stage of their careers, play a crucial role in fostering collaborations between local and international networks and in facilitating the transfer of knowledge across these levels. For instance, P6 Eng U, actively participates in collaborative projects to advance her career. Her active involvement has led to the development of an extensive network, positioning her as a key point of contact when others need to establish connections. P8 Bio G, a senior researcher in biology, consistently creates collaborative opportunities and assists younger colleagues in establishing connections with potential partners both locally and internationally. His goal is to support the next generation of researchers and contribute to building human capital in the country. Regardless of the reasons, when researchers see alignment between potential partners and opportunities, they actively invest their efforts to make the collaboration happen.

I anticipated observing accelerated growth in international collaborations, considering the prevailing trend and increasingly common practice, particularly for nations aspiring to enhance their competitiveness in science and technology. I found that both local and international collaborations in Thailand have been on the rise, and the proportion of the two has remained relatively constant over time. This suggests that Thailand has been consistently increasing both local and international collaborative efforts (Fig. 11). The trend aligns with what many other interviewers (P1 Eng I, P2 Med U, P3 Med G, P5 Bio G, P15 Bio G, and P13 Eng I) suggest. P7 Mat G emphasized that collaborative research networks can exist at various levels, encompassing both international and local dimensions.

“They [the agency] encourage any form of research collaborative network. Our researchers work with both local and international organizations. Even inside MHESI, we constantly discuss the potential to collaborate across agencies. We have many collaborative projects between NANOTEC, MTEC, BIOTEC...”

P7 Mat G

I found that in almost all collaborative settings—domestic collaboration, international collaboration, Thai-US collaboration, and Thai-China collaboration—show stronger two-dimensional but weakening three-dimensional mutual information or T values. These findings could be attributed to the active promotion of both local and international collaborations by the Thai government. As a result, collaborations seem to unfold spontaneously, with the capacity and inclination for local collaboration operating independently of international collaboration, and vice versa.

The preceding sections provide information about Thailand's national research system, highlighting key actors and policies aimed at promoting collaboration and knowledge

management. However, the effort to integrate knowledge derived from international collaborations into creating a robust local research system is still in its early phases. Research activities primarily occur within single sectors or collaborations between two sectors, with the private sector playing a marginal role in most areas and collaborative landscapes. As countries with higher three-dimensional synergy tend to experience a greater rate of technology transfer (Mêgnigbêto, 2015; Xu, et al., 2017), Thailand appears to be losing out on technology transfer and transformation opportunities.

The question here is whether it is essential for all disciplines and countries to exhibit the same trends or patterns of movement. Among the three disciplines examined in this study, medicine exhibits the most distinctive collaboration patterns among local sectors. In comparing the number of publications across all three disciplines, although universities contribute significantly more publications than other sources, I observed that the number of publications in medicine, whether solely by universities, government entities, or through collaborations between universities and government, does not differ significantly. While P2 Med U strongly suggests that Thailand needs a stronger national research system by involving the private sector to play a more significant role and promote commercialization, P3 Med G argues that producing basic knowledge is also important. His research lab is advocating for the engagement of the private sector, but it's not the top priority. What is more important is to generate knowledge through publications, which serve as the foundation for future discoveries. The question appears to be debatable in this domain. This highlights a broader conflict between the goals of commercialization, which prioritizes applied research and market-driven outcomes, and the pursuit of basic research, which focuses on expanding knowledge without immediate practical

applications. The balance between these competing priorities remains a subject of debate in this domain.

Kapás (2008) and Etzkowitz (1994) have explored the pressures for the transformation of institutional systems and regulations to increase society's innovation-absorptive capacity in response to new innovations. I observe this macro-innovation in the case study, especially in medicine and engineering. Thai researchers recognize the need for such changes, including new regulations to expedite research and the creation of a new ecosystem that can support the entire research cycle. The informants suggest fostering more collaboration across sectors, specifically increasing engagement with private sectors. Unlike medical science, scientific activities in engineering require the engagement of various stakeholders, especially private companies. Additionally, researchers in agricultural and biological sciences do not view national borders as constraints on their knowledge production. I observe efforts reflected in the increased synergy in the interaction between the Thai government and industry in the two disciplines, both locally and internationally. While the number of co-authored publications between the government and industry remains relatively modest compared to other collaboration types, there is noticeable progress in the two-dimensional mutual information (Tgi) over the observation period. One contributing factor could be the growing responsibility of the government to drive research towards commercialization, adding another dimension to its role (P12 Eng I, P11 Mat U, and P12 Eng I).

Cycle of Credibility: Investment strategy and decision-making in scientific collaborations

The cycle of credibility implies that collaborations are perceived as investments, involving a process of achieving conversions across various elements such as arguments, data, personnel, resources, recognition, and publications. The interviewed researchers prioritize

projects that maximize their investment by yielding the most credibility, which can be reinvested in the future. These projects could also benefit national or organizational goals and enhance the researchers' own reputations. This is often done by referencing national policies or the traditional roles of their institutions. I have observed how credibility conversion occurs in diverse contexts. Firstly, researchers across various disciplines value different sources of credibility based on distinct cognitive and social factors. Secondly, researchers target diverse resources from various partner countries depending on their expertise and objectives. Thirdly, while all credibility resources hold significance, they are valued disparately, leading to unequal power dynamics between partners. Lastly, relationship networks can be regarded as another significant resource of credibility, as they assist researchers in seeking and enhancing their negotiation power within resource conversion cycles.

According to Merton (1973), various scientific disciplines exhibit unique structures in the distribution of power and resources among institutions and scientists. These distinct norms and practices can significantly impact scientists' decisions and actions. I observed differences in the distribution of power and resources among the three disciplines. According to the interviews, researchers in the medical and engineering fields experience a more decentralized distribution of power, while researchers in agricultural and biological science face challenges associated with centralized control.

“However, if you want to collaborate or sign an MOU, you must follow the same procedures as other institutes. Our highest authority must give their approval. In my experience, no one has ever had a problem with that. No matter if it is Thai agencies or agencies from other countries. As long as working people have done their work...They could verify the reasons to

collaborate, they talked to their potential partners and were able to identify common interests, they can start the project with that plan.” - P3 Med G

As Bourdieu (1999) argues, scientific authority and interests, much like those in other domains, are shaped by political interests and conflicts in addition to epistemological considerations. The statement from P3 Med G, who heads a Thai government university, resonates with the experiences of other informants in the engineering field. If researchers believe that the collaborative projects, they are pursuing are worthwhile and can substantiate their points, their supervisors are likely to approve their proposals. In contrast, researchers from both Thai and U.S. sides in agricultural and biological science mentioned struggling to gain trust from higher authorities in Thailand. However, both of them successfully won the battle by showcasing the success of their projects and gaining trust for future endeavors. This experience aligns with credibility in Latour and Woolgar’s (1986) sense. Gaining credibility means they are not only accredited for what they have done but also credible for what they will do in the future.

As depicted in Fig. 26, 28 and 30, there is a trend of declining proportions in Thai-U.S. coauthored publications, coupled with an increase in Thai-China coauthored publications, specifically in the fields of biological and agricultural sciences and engineering. However, it is noteworthy that in the field of medicine, Thai-U.S. coauthored publications have only experienced a slight decrease in recent years, while Thai-China coauthored publications in medicine have seen a slight increase. Examining the investment strategy employed by researchers, the collaboration between Thailand and the United States in medicine holds greater value compared to China.

According to insights from P4 Bio G, Thailand possesses significant natural and human resources that are required in all fields. Consequently, Thailand remains an appealing and

worthwhile partner for investment by the United States. Thailand places significant value on the knowledge and expertise offered by foreign experts, considering them as crucial resources for credibility enhancement. Strong collaborations between Thailand and the United States in medicine could be because Thailand stands for the best investment in medical research for advanced countries. P15 Bio G mentioned that the reason that the reasons that USGS prefers to work with Thailand are not only because Thailand has many required natural resources but Thailand has readiness in many aspects. This allows the U.S. partner to focus on further study instead of building basic capacity.

I found that while cross-sector and cross-national collaborations lead to scientific progress, scientists face challenges such as the need to maintain their research agenda while dealing with partners who have different characteristics, as well as evaluating the worthiness of resource exchanges. Despite the arguments of several interviewees stating that the Thai government prioritizes local collaborations (P1 Eng I, P2 Med U, and P3 Med G), Figure 37 indicates that the mutual collaborations among local sectors at the local level have been losing synergy over the observation period. P9 Eng U contends that Thailand still needs to depend on larger countries that possess more advanced tools or facilities not available in Thailand.

According to the multivariate logistic regression analysis, it was surprising to find that industry funding is strongly associated with higher odds of collaborating with foreign and American research partners. Conversely, government funding is more closely linked to an increased likelihood of collaborating with Chinese partners. From the interviews, I can observe the needs and efforts of industry in engaging in research collaborations (P2 Med U and P11 Mat U). For instance, P6 Eng U discusses the importance of research as part of the commercialization process. To ascertain the practical viability of a target technology from China in the market in

Thailand, a space company provided research funding to universities. This funding enables the universities to conduct studies that assess the feasibility of implementing the technology in the real market. These efforts are typically long-term engagements. P9 Eng U provides another example of the collaboration between a university and a private company where SCG established a lab within the engineering department at Chulalongkorn University. The establishment of the lab creates ongoing opportunities for continuous collaboration between the company and the university. To be able to be part of international research collaboration, Thai industry need to invest in the form of research funding.

While interviewees from industry suggest that they aim to contribute to collaborations, it's important to note that such investments are not guaranteed and are often driven by business considerations. For example, as mentioned by P1 Eng I, the primary motivation may be to assist university students, with any market-related gains seen as an additional bonus. According to P12 Eng I, collaborating with universities is driven by a desire to enhance the reputation and visibility of his company in specific fields. However, more tangible returns may be expected through collaboration with government entities, as noted by P9 Eng U. He emphasized that partnering with the government is preferable due to their possession of advanced tools and resources that his university may lack. The relatively weak returns associated with university collaborations might explain why the industry often prioritizes partnerships with government entities, as reflected in the observed weak two-dimension $T(ui)$ values.

Researchers expect different outcomes from different partners, including when they collaborate with local or foreign partners. Some interviewees (P14 Med U, P17 Bio I, and P18 Med U) posit that international collaboration can enrich local research, insights from P14 Med U, P17 Bio I. However, P18 Med U suggests that researchers engaged in local and international

projects may harbor different motivations and objectives, further emphasizing the complexity of collaborative dynamics. Latour and Woolgar's Cycle of Credibility provides insights into why scientists engage in scientific collaborations beyond what Merton's approach offers. By examining micro-level interactions and practices, the Cycle of Credibility highlights the social construction of knowledge through interactions within the scientific community. This perspective allows us to understand how credibility is built and exchanged among scientists, driving collaborative efforts. Recognition from institutions for their contributions is an important motivator for scientists. It places them under pressure to ensure that others acknowledge their contributions to knowledge. However, the institutional norms and values that govern scientists' behavior cannot explain everything. Scientists acquire credibility through the successful production of knowledge, which in turn attracts more resources, allowing them to continue producing credible results. This cycle is dynamic and self-reinforcing. Higher citation scores and impact contribute to professional advancement certain researchers prioritize engaging in international collaborative projects as it offers the potential for increased visibility and a broader impact on their work (P8 Bio G; Katz & Martin, 1997; Coccia & Bozeman, 2016). While scientific knowledge may be universal and applicable across different contexts, the unique and specific issues present in Thailand require special consideration and focused efforts.

In addition to the varying degrees of recognition gained from engaging in local versus international collaborations, collaborations with different countries could also lead to unequal levels of recognition, which may influence researchers' decision-making processes. For instance, P6 Eng U mentioned that since she graduated from China, she is not as well recognized compared to other researchers who graduated from the United States or European countries.

“In terms of recognition, I got nothing, honestly. Ha ha. I feel like most Thais, especially people at my level (having PhD), overlook me. They think working with Chinese is nothing special.” - P6 Eng U

This could be the consequence of Thai people perceiving Chinese individuals as equals. As a result, they may believe that collaborating with Chinese partners would not provide much additional knowledge or expertise. This belief could impact the reputation of researchers who hold educational credentials or have work experience in China.

The observations demonstrate the exchanges of credibility resources including financial support, expertise, advanced tools, arguments, publications, and reputation. Besides the resources proposed by Latour and Woolgar, I found that researchers dedicate a significant amount of time and resources to building and sustaining relationship networks as it increases the potential of participating in the resource conversion cycle. When discussing the expectations of engaging in collaborative projects, most participants mention making connections or networking as the first thing that comes to mind. The majority of the projects discussed during the interviews were the result of organic connections, such as college friends, and inorganic connections, such as meeting someone at a professional conference. Connections are a personal asset that requires effort to maintain. This could prove advantageous either now or later time. Participants stated that on numerous occasions, they invest considerable effort in collaborative endeavors to nurture or expand their network, even when tangible returns are not immediately apparent. Furthermore, relationship networks facilitate collaborations across sectoral and national boundaries more seamlessly, as they foster familiarity and trust among partners.

While relational networks may not be traditionally viewed as a source of credibility in recognizing one's ability to generate future knowledge, they play crucial roles in facilitating

resource conversion opportunities, empowering negotiation capabilities, and enhancing collaboration possibilities. Networks of relationships serve as both personal assets and forms of social capital collectively shared among colleagues within a team or department (Müller et al., 2023; Bozeman et al., 2001).

Recognizing this significance, the Thai government has undertaken several initiatives to foster collaborations with the United States, with a specific focus on expanding connections with U.S. agencies. One mechanism employed for this purpose is the establishment of a governmental unit in the U.S. The Office of Science and Technology at the Royal Thai Embassy in Washington has played a pivotal role in initiating numerous collaborations between Thailand and the United States, as noted by interviewees P13 Eng I, P17 Bio I, and P18 Med U.

The cycle of credibility framework can elucidate the relationships between international collaborations and collaborations among local sectors by providing insights into the dynamics of credibility resources. In the context of the study, the framework enables an understanding of how credibility-building processes at the international and local levels intersect and influence one another. Researchers invest their resources to acquire various other resources to strengthen their credibility. However, the value of each resource varies depending on factors such as the research partner, the nature and requirements of each discipline, and the scale of the collaborations. Here's a breakdown of how the cycle of credibility framework can explain these relationships:

1. **Resource overlap:** The framework suggests that different types of resources contribute to researchers' credibility. In the context of international and local collaborations, there may be an overlap of resources that researchers gain from participating in both spheres. For example, P4 Bio G's research team not only obtained the information required by USAID's grant

but also acquired data that can assist Thailand in addressing emerging diseases. The data from the project can bolster a researcher's credibility both internationally and domestically.

2. **Personal drive and Institutional Support:** The cycle of credibility encompasses both personal drive and institutional objectives and backing. Institutions involved in international collaborations can directly or indirectly enhance the credibility of researchers engaged in local projects, and vice versa. Support from institutions, including funding, infrastructure, and recognition, can be extended across various levels of collaboration. Meanwhile, personal motivation and interests also influence scientific collaboration.

3. **Knowledge Transfer:** Scientific collaborations often involve the exchange of knowledge and expertise which are the credibility resources. The acknowledges that the learning and skills gained from one project contribute to a researcher's credibility in subsequent research activities. In the context of the research, insights gained from international collaborations can positively impact the credibility of researchers engaged in local collaborations and vice versa.

4. **Collaborative Networks:** The framework recognizes the importance of collaborative networks in building credibility. Researchers involved in both international and local collaborations may participate in overlapping networks. These networks facilitate the exchange of ideas, resources, and opportunities, creating a mutually reinforcing cycle of credibility.

5. **Personal Recognition:** At the individual level, researchers gain personal recognition through their contributions to collaborative projects. The cycle of credibility emphasizes that personal rewards enhance researchers' credibility. Participating in international collaborations can bring recognition that, in turn, boosts the credibility of researchers involved in local collaborations and vice versa.

In summary, the cycle of credibility framework provides a lens through which I can understand the interconnectedness of international collaborations and collaborations among local sectors. It highlights the shared resources, institutional dynamics, knowledge transfer, collaborative networks, and personal recognition that contribute to the relationships between these collaboration levels.

In this chapter, I conducted an integrative analysis using data collected from both quantitative and qualitative methodologies. The next chapter provides a brief summary of how I answered the research questions, along with a discussion on the limitations of the study and suggestions for future research.

Chapter 9

Discussion and Suggestions for Future Research

In the previous chapters, I provided comprehensive literature reviews, background information, research questions, methodology, and data analysis. I discussed the data and evidence that helped us address the research questions. In this chapter, I present a brief summary of the insights gained from this study and how I have answered the research questions. This summary encapsulates the key findings and interpretations, highlighting how the data has contributed to resolving the queries posed at the outset of our research.

The first research question, “What are the connections between local and international research collaborations, with a comparative analysis of Thailand, the United States, and China?” examines the connections between local and international research collaborations, specifically comparing Thailand, the United States, and China. To explore these connections, I utilized co-authorship data and Leydesdorff’s measurement of triple helix relations to analyze the patterns of local collaborations between sectors in Thailand in different collaborative settings.

I found that while research collaboration is increasing, the dynamics of collaborations vary across different collaborative landscapes and areas of study. Thailand exhibits distinct collaborative patterns with the United States and China due to historical, economic, and political factors, which influence how scientific activities are conducted and the roles of local sectors. For example, Thailand’s collaborations with the United States are predominantly government-led, with significant involvement from Thai government-sponsored initiatives. In contrast, collaborations with China are less formal, allowing greater participation from the Thai private sector.

Furthermore, while cross-sector and cross-country collaborations are encouraged, their outcomes differ across various fields of study. In medicine, research activity is primarily driven by universities and the government, with minimal involvement from the private sector. The collaboration between the Thai government and universities is particularly strong when working with the United States in the medical field. Conversely, greater synergy is observed in engineering and agricultural and biological sciences, where private sector involvement is more pronounced.

For the second research question, "How do social factors and strategic considerations influence the pursuit of scientific collaborations?" I conducted qualitative interviews and analyzed the data using Latour and Woolgar's Cycle of Credibility concept. Our findings indicate that six sources of credibility are actively converted during collaborative research activities, driven by both organizational and individual motivations. Resources such as funding and data are perceived as particularly valuable, providing significant negotiation power to researchers and organizations that control them. However, the value of these resources varies depending on the individual, especially for scientists at different stages of their careers. While some researchers view international collaborations as prestigious opportunities that promise greater returns, resources can be gained and utilized across both local and international research collaborations. Different levels of collaboration can complement and enhance one another, demonstrating how strategic considerations and social factors shape the pursuit of scientific partnerships.

In this section, I return to my central question: Can scientific collaboration help Thailand overcome the middle-income trap, and if so, how? The findings of my research point to both the potential and the challenges of leveraging collaboration for economic growth.

From the study, scientific collaboration is primarily building networks of knowledge exchange, resource sharing, and expertise development across sectors and countries. These collaborations between universities, industries, and government bodies, particularly in the context of Thailand's partnerships with the United States, and China, are fostering deeper relationships that enhance scientific productivity and innovation. These partnerships help create mutual trust, credibility, and a flow of information, positioning Thailand to leverage external expertise while strengthening local research capacity.

Thailand's economic challenge lies in its position as a country that excels in various sectors but remains dependent due to two major factors: a lack of a highly skilled labor force and insufficient investment in science and technology. The government has recognized these issues and has introduced several initiatives, such as the BCG (Bio-Circular-Green) economic model, which aims to promote sustainable development and attract foreign direct investment (FDI). This model, by fostering new business and circular production processes, also opens opportunities for scientific collaboration and innovation.

My research shows that the Thai government's policies have indeed encouraged both local and international scientific collaborations, as evidenced by the growing number of co-authored publications and increased interaction across sectors. However, according to the Triple Helix framework, there is still work to be done to fully integrate these collaborations into a robust national science and innovation system. In particular, the industry sector, especially in fields like medical science, needs to play a more prominent role. Industry involvement is essential because, unlike government or university-driven research, industry tends to focus on commercializing innovations and responding to market demands more quickly. The stronger

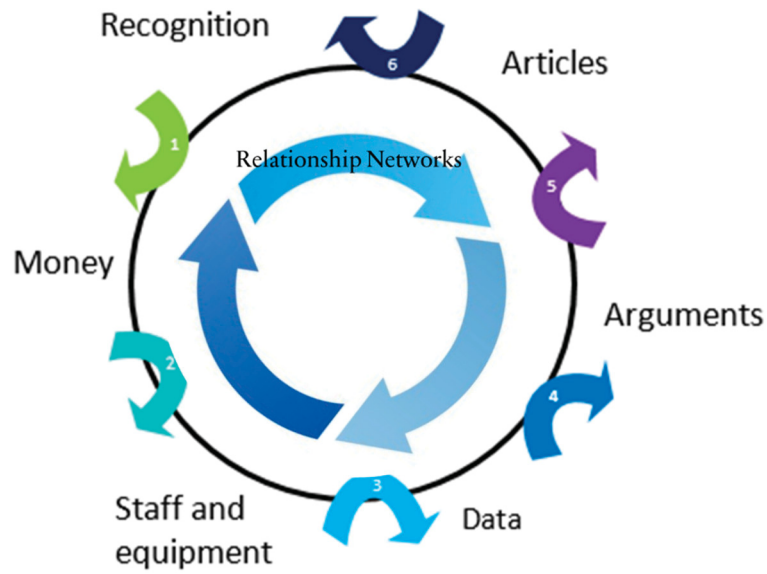
interaction between the three sectors could lead to faster knowledge transfer and higher-value scientific outputs, which are key to moving beyond a middle-income economy.

One of the critical issues I identified in my study is the disconnect between high-level policymakers and the researchers working on the ground. While top-level government policy pushes for increased collaboration, these initiatives often fail to translate into tangible outcomes at the researcher level. Traditional boundaries between government, universities, and industries persist, limiting the flow of knowledge and collaboration. To truly leverage scientific collaboration as a tool to overcome the middle-income trap, more proactive engagement from the industry is required, and the government needs to implement policies that respond directly to market needs.

A key tool the Thai government can utilize is promoting the creation of network relationships among scientists, both across different sectors and internationally. Relationship networks play a critical role in scientific collaboration for several reasons and should be integrated into Latour and Woolgar's Cycle of Credibility model. While relationship networks may not be considered traditional sources of credibility, they significantly enhance a researcher's reputation by demonstrating their participation in multiple projects and collaborations with experts. These networks also facilitate important processes such as negotiation, identification of research topics, role assignment, and the management of daily activities. Ultimately, they strengthen the credibility of resource exchanges and promote more effective collaboration.

Figure 46

Proposed Modified Cycle of Credibility



Consistent with the findings of Müller et al. (2023) and Allison and Long (1990), my research also highlights the pivotal influence of "star" researchers and departmental dynamics. Prominent scientists with strong connections both domestically and internationally play a crucial role in bridging local and global collaborations as well as across sectors, helping introduce peers to new networks and facilitating the transfer of knowledge. They also play a significant role in mentoring and connecting the next generation of researchers to their networks. Their efforts also contribute to developing Thailand's research workforce. By creating opportunities for younger researchers to engage in international collaborations and access valuable resources, they help cultivate a skilled labor force that is essential for driving innovation and supporting Thailand's long-term economic development. By focusing on shared challenges, leveraging expertise within specific fields, and strategically utilizing relationship networks, Thailand has the potential to

maximize the benefits of both local and international collaborations, particularly through the efforts of a group of "star" researchers. If integrated into formal policies, this approach could foster sustainable development, with knowledge generated from these collaborations mutually reinforcing each other.

In addition, Thailand can gain valuable insights from this research by understanding the different forms of partnership it has with the United States and China, as well as the underlying factors that contribute to these differences. By developing policies that effectively balance these partnerships, Thailand can capitalize on their unique strengths to foster growth essential for sustainable economic development. The main goal of Thailand is to create independence in its scientific and technological capabilities, which can be achieved through strategic collaboration with both global powers. Engaging with the United States offers Thailand access to advanced research methodologies, cutting-edge technologies, and strong institutional support, which can enhance local expertise and foster innovation. Conversely, collaboration with China presents opportunities for increased investment, technology transfer, and access to rapidly growing markets. By leveraging the strengths of both partnerships, Thailand can build a more resilient economy that reduces dependency on any single nation.

Thailand can also learn valuable lessons from its partnership with the United States and apply them to its collaboration with China for better outcomes. For example, the structured approach to project management and collaboration seen in U.S.-Thailand partnerships can be adapted to enhance the effectiveness of joint initiatives with China. This could involve establishing clearer communication channels, setting shared goals, and defining roles within collaborative projects. On the other hand, Thailand can also adapt successful strategies from its collaboration with China to enhance its partnerships with the United States. For instance, the

more informal and flexible nature of Thailand-China collaborations can inspire Thai researchers and institutions to seek similar flexibility in U.S. partnerships. This might involve advocating for streamlined funding processes, fewer bureaucratic hurdles, and more opportunities for rapid project initiation. By fostering a culture of agility and responsiveness in U.S. collaborations, Thailand can enhance its ability to innovate and adapt to changing circumstances.

The insights gained from this study extend beyond Thailand, offering valuable lessons for other countries seeking to use scientific collaboration as a tool to build scientific capacity, especially those facing similar challenges. The study provides important information not only for high-level policymakers but also for scientists looking to explore effective ways to engage in collaboration and maximize their efforts. By understanding the dynamics of these partnerships, countries and researchers alike can strategically enhance their roles in global science and technology development.

While, in this study, the Cycle of Credibility provides a valuable framework for understanding the motivations behind researchers' engagement in collaborations, the concept and its applicability to scientific collaborations raise important questions regarding the model's limitations and its ability to capture the complexities of scientific work.

First, scientific collaborations often involve unpredictable dynamics, varying goals, and external factors that the model may not fully encapsulate. The interplay of social, economic, and institutional influences can shape research outcomes in ways that extend beyond the credibility sources outlined in the cycle. The Cycle of Credibility primarily focuses on individual and organizational motivations for collaboration, but it may not adequately address the resulting outputs or impacts of these collaborations. For instance, while the model highlights the importance of credibility, it might overlook the significance of other factors, such as the quality

of the research, the novelty of the findings, or the broader societal implications. Collaborations might yield significant advancements or unexpected results that the model does not account for.

Second, if scientists concentrate heavily on their investment and returns from engaging in collaborations, it could lead to a more transactional view of research. This perspective may prioritize projects that promise immediate financial or reputational gains, potentially restraining exploratory or high-risk research that might not yield quick returns but is essential for long-term innovation and scientific progress. To ensure that scientific collaborations remain impactful, stakeholders should cultivate a culture that values not only credibility but also innovation, risk-taking, and long-term vision. By encouraging researchers to engage in collaborations that may not promise immediate returns but hold the potential for transformative discoveries, the scientific community can foster an environment conducive to sustained progress.

Implications and recommendations

In this research, I have demonstrated the usefulness of Science and Technology Studies (STS) concepts in understanding contemporary science, particularly through the lens of scientific collaboration at various levels. By applying the Triple Helix framework and the concept of the Cycle of Credibility, I have explored the dynamics and drivers of scientific collaboration. These frameworks provide insights into how universities, industry, and government interact, revealing the complexities of collaboration in different contexts.

Moreover, the knowledge gained from this study is applicable to countries facing similar challenges, particularly those striving to enhance their scientific and technological capacities. The findings illustrate how these concepts and frameworks can serve as analytical tools for examining a nation's science and innovation systems. By understanding the interactions between

different sectors and the factors that influence scientific collaboration, nations can tailor their policies to foster more effective partnerships.

This research not only sheds light on the specific case of Thailand but also offers valuable lessons for other countries in navigating their own scientific landscapes. By adapting the insights from the case studies presented, policymakers can design strategies that encourage collaboration, enhance credibility among researchers, and ultimately contribute to sustainable development and economic growth.

Lastly, I demonstrate the versatility of using different tools in our study. I utilize whole numbers and proportions of co-authored publications to showcase collaboration trends and employ mutual information to examine collaboration synergy among local sectors in Thailand across various research landscapes. These tools enable us to showcase collaboration trends, examine synergy, and illustrate interaction contributions effectively. As suggested by Xu et al. (2017) and Zhang et al. (2019), scientific collaboration is complicated, and there is no single perfect indicator that can comprehensively capture the entire picture of what is transpiring. A combination of indicators is required, and the analysis should be conducted within the context to gain a comprehensive understanding.

However, our study has several limitations that could be addressed differently in future research:

1. Many other indicators can be used as proxies for research collaborations. Co-authored publications represent only one form of collaboration, and other informal collaborations, such as exchange programs or professional conferences, should be considered.

2. Comparing the three selected disciplines for various reasons, they differ in size, with engineering having a very small number of co-citation data. This small number could hinder the performance of quantitative analysis, especially the mutual information model.

3. While focusing on three disciplines, each discipline is still broad in terms of practices or technologies involved. A deeper analysis in a particular area could be conducted to gain a better understanding of scientists' activities.

Several additional questions have arisen from this research, warranting exploration in future studies:

- One crucial area for further investigation is a deeper examination of the limitations and impacts of using the Cycle of Credibility concept in understanding scientific collaborations. Future research could focus on identifying specific contexts where the Cycle of Credibility may fall short, such as in capturing the influence of external social, cultural, or political factors that affect scientific partnerships.
- Further investigation into factors such as policy, social dynamics, and geopolitics that contribute to distinct collaboration patterns between Thailand and the United States, as well as between Thailand and China.
- Investigating the cognitive and social aspects that distinguish medical science from the other two disciplines.
- Exploring whether enhanced synergy between local sectors genuinely results in greater advancements in science and innovation development, across diverse contexts such as different countries and disciplines.

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Appendix A



Division of Scholarly Integrity and
Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
<http://www.research.vt.edu/sirc/hrpp>

MEMORANDUM

DATE: April 4, 2022
TO: Daniel Breslau, Bunyakiat Petri
FROM: Virginia Tech Institutional Review Board (FWA00000572)
PROTOCOL TITLE: The Relations between International Research and Local Triple Helix Collaborations Through Cycle of Credibility: The Case study of Thailand
IRB NUMBER: 21-818

Effective April 4, 2022, the Virginia Tech Human Research Protection Program (HRPP) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104(d) category (ies) 2(ii).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit an amendment to the HRPP for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<https://secure.research.vt.edu/external/irb/responsibilities.htm>

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As: **Exempt, under 45 CFR 46.104(d) category(ies) 2(ii)**
Protocol Determination Date: **April 4, 2022**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

Appendix B

INSTRUCTIONS:

- Use this “*TEMPLATE PROTOCOL (HRP-503)*” to prepare a study protocol outlining your research plan.
- Depending on the nature of your study, some major sections might not be applicable to your research. If so, simply mark as “N/A.” For example, a simple survey might have many sections with “N/A.” For subsections (e.g., 1.x or 8.x) you can mark as “N/A” if you are certain that the subsection is not applicable.
- Once the IRB/HRPP approves your submission, your latest approved version of the protocol will be stored in the IRB Protocol Management online system.
- If your research plan changes and you need to modify the protocol, please submit an amendment to Protocol Management with the requested modifications. Download your current protocol from Protocol Management and indicate the changes/revisions using the track changes feature in order to make review of the modifications easier to follow. If you are unable to use track changes, please create a new paragraph wherever you need to make a change, and indicate “Amendment: Date” before making a change to any section. Protocol management will store the older versions of your protocol if the IRB or HRPP staff need to compare them during the review.

PROTOCOL TITLE:

Include the full protocol title.

The Relations between International Research and Local Triple Helix Collaborations Through Cycle of Credibility: The Case study of Thailand

PROTOCOL NUMBER:

Include the number assigned in Protocol Management (verify this has been added before submitting protocol to HRPP).

21-818

PRINCIPAL INVESTIGATOR:

Full Name and Degrees: Dr. Daniel Breslau, Associate Professor
Department: Department of Science, Technology, and Society, Virginia Tech
Telephone Number: 540-231-8472
Email Address: dbreslau@vt.edu

FUNDING:

Sponsor(s): N/A

Funded already or in the proposal phase?: N/A

Is Virginia Tech the primary awardee or the coordinating center of this grant or contract? If not, list the primary institution: N/A

VERSION NUMBER/DATE:

Include the version number and date of this protocol. Versions should start at 1.0.

2.0

REVISION HISTORY:

Use this table to keep track of changes. Add more rows as needed.

Revision #	Version Date	Brief Summary of Changes (i.e., the different sections)	Consent Change?
2.1	1/24/2021	- Remove comments - Remove pronounces - Revised sections: 6.1, 8.2, 8.4, 8.5, 9.1, 9.5, 14.3, 15.1, 16.1, 16.3, 17.1, 19.5, 24.1, 25.1, 25.2, 26.1	

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1.0 Study Summary

Study Title	The Relations between International Research and Local Triple Helix Collaborations Through Cycle of Credibility: The Case study of Thailand
Study Design	<p>This study will combine both quantitative and qualitative techniques.</p> <p>For quantitative analysis, co-authorship and citation data between 2009 - 2020 will be collected from citation databases, then analyzed using statistical tools.</p> <p>For qualitative analysis, semi-structured interviews with 24 participants from different groups of people who have been involved with research collaborations will be conducted.</p> <p>Potential participants will be identified on the basis of published records, online government and university directories, and professional referrals.</p> <p>Each interview will be conducted in person in a location of the participants' choosing. With their permission, the doctoral student will record the interviews using a digital voice recorder, as well as take notes during the interview. An interview will last approximately 1 hour. For the analysis, the interview will be transcribed. Non-English interviews will be translated into English.</p>
Primary Objective	To investigate the relations between local and international research collaboration and the organizational and social factors that impact the relationship.
Secondary Objective(s)	To make policy recommendations to help policymakers and researchers promote local and international research collaborations and maximize the benefits of resources spent on collaborative activities.
Study Population	Policy makers, researchers, and decision makers who have roles in planning, designing, initiating, and/or conducting collaborative research activities.
Sample Size	24 people
Research Intervention(s)/ Investigational Agent(s)	Semi-structured interviews
Study Duration for Individual Participants	The doctoral student expects to conduct a single interview, 1 hour in duration, with each participant. If clarification is

	needed, the doctoral student will contact them by mail or phone.
Acronyms and Definitions	

2.0 Objectives

2.1 Describe the purpose, specific aims, or objectives of this study:

- to investigate the patterns and the impacts of co-authored publications among local sectors in Thailand as well as between Thailand and China and Thailand and United States
- to find the relations between local and international research collaborations
- to reveal the organizational and social factors that impacts local and international research collaborations
- To make policy recommendations to help policymakers and researchers promote local and international research collaborations and maximize the benefits of resources spent on collaborative activities.

2.2 State the hypotheses to be tested:

Null Hypothesis 1: There are no strong relations between the productivity and the impact of international research collaborations and the domestic collaboration.

Alternative Hypothesis 1: There are strong relations between the two types of collaboration. The more robust international research collaboration is, the more active domestic collaboration become.

Null Hypothesis 2: Both international and local Triple Helix collaborations are not influenced by social and organizational factors.

Alternative Hypothesis 2: Both international and local Triple Helix collaborations are influenced by social and organizational factors.

3.0 Background

3.1 *Summarize the relevant prior research on this topic and gaps in current knowledge within the field of study:*

Prior research has focused on the definitions, costs, outcomes, factors, and measurements of international scientific collaborations and Triple Helix collaborations (collaboration between university, government and industry). A number of research studies focuses on the interactions and relations between different levels of collaborations such as the relations between local and international research collaborations. For instance, some discuss on hierarchical structure of collaborative networks. Some argue that while international collaboration has become more important, the synergy between local sectors became waned in some countries. On the other hand, too much synergy locally could hinder cooperation with foreign partners. Several researchers are trying to comprehend the relations between the two types of collaborations. However, they discovered discrepancies between the results across case studies and nations. Therefore, the doctoral student believes this topic is intriguing and needs further investigation.

3.2 *Describe any relevant preliminary data:*

Data on co-authored publications between Thailand and other countries from 2009 - 2020 was collected from Scopus in order to select case studies for this study. Co-authored publications between Thailand and China and Thailand and the U.S. are selected as case studies.

3.3 *Based on the existing literature, provide the scientific or scholarly rationale for and significance of your research and how will it add to existing knowledge:*

This study will contribute to the body of literature on science and technology collaboration by focusing on the relationships between local and international collaboration between developed and developing countries. This project will provide a new comparative case study by contrasting local collaboration among Thailand's government, universities, and industry with international collaboration between Thailand and China and Thailand and the U.S. The analysis will delve deeper into the institutional and individual levels and will employ STS frameworks to provide a better understanding of knowledge production in the modern world.

4.0 Study Endpoints

- 4.1 *Describe the primary and secondary **study** endpoints. See links below for discussion of study endpoints and how they may differ from study objectives. These are most common in clinical trials but are sometimes applicable to other types of biomedical research, as well as social, behavioral, or educational research. See link below for a discussion.*

https://docs.google.com/document/d/1Wocz7K7a0hCOJPP0_khh511SOQjh_GDDGHzcOPRHR5Tw/edit?usp=sharing

The primary end point is when all 24 informants are interviewed and answered all the questions.

However, more informants could be added if the complete range of constructs that make up the theory is not fully represented by the data.

- 4.2 *Describe any primary or secondary **safety** endpoints. These should be included for all studies that are greater than minimal risk. (Minimal risk: The probability and magnitude of harm or discomfort anticipated in the research that are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.):*

N/A - study is of minimal risk.

5.0 Study Design and Statistical Analysis Plan

- 5.1 *Describe the basic study design/approach (e.g., qualitative study using five focus groups of first year students to describe assimilation into the university community; randomized controlled trial of a behavioral change intervention to increase dietary intake of whole grains; pre- post-test evaluation of new pedagogical techniques to improve adult literacy):*

For the quantitative component, the number of publications and cited/citing ratios will be analyzed in order to explore the patterns, the intensity, and the impacts of co-authored publications by local sectors in Thailand, by Thailand and China, and by Thailand and the US.

Qualitative study using semi-structured interviews with 24 researchers, policy makers, and decision makers to explore organizational and social factors that impact research collaborations.

- 5.2 *Describe corresponding data analysis plan/approach (e.g., content analysis of focus group transcripts; descriptive analysis followed by linear regression modeling; nonparametric analysis of pre- and post-test measures):*

Citation analysis followed by linear regression modeling and content analysis of interview transcripts.

6.0 Setting

6.1 *Describe the sites or locations where your research team will conduct the research. Consider each of the items listed below:*

- *Identify where your research team will identify and recruit potential subjects.*
- *Identify where the team will perform the research procedures.*
- *Describe the composition and involvement of any community advisory board(s).*
- *For research conducted in other locations, describe:*
 - *Site-specific regulations or customs affecting the research at those locations.*
 - *Local scientific and ethical review structure at those locations. Examples include work in other cultures or ethnic groups (within or outside of the U.S.) and work with churches. The HRPP will provide additional guidance for international research.*

Potential participants will be identified on the basis of published records, online government and university directories, and professional referrals. They will be recruited via direct contact through email, personal and professional connections as well as expert recommendations. Some interviewees will be in the United States, while others will be in Thailand. Email will be used to send the interview invitation, permission form, and other information.

The interviews will take place in various sites across geographical locations. The interviews with Thai and Chinese interviewees will be conducted in Thailand. The interviews with American interviewees will be conducted in the U.S. Each interview will take place in person at a venue chosen by participants such as their offices, meeting rooms at their organizations, and so on. No one else but the interviewer will be present unless the participants would like someone else to be there.

Ethical justification for conducting the research in an international setting:

- The study aims to examine the relations between local research collaboration and international research collaboration as well as the factors that influence them. This study will compare and contrast the relations between the local collaboration in Thailand with the international collaboration between Thailand and China as well as the collaboration between Thailand and the U.S. China and the U.S. are selected because they are both important scientific collaborators for Thailand.

- The study is expected to provide useful insights that will assist Thailand enhancing local sector scientific collaboration and boosting engagement with foreign partners, particularly China and the United States. The findings could also be applied to other countries that are involved in developing-developing country and/or developing-developed country collaborations.

The doctoral student's experience with conducting research in each country:

- Thailand: The doctoral student has designed and conducted questionnaires and qualitative interviews with research participants. The majority of the participants are government officials, researchers, and private-sector coordinators.
- United States: The doctoral student has designed and conducted questionnaires and qualitative interviews with research participants. The majority of the participants are government officials, researchers, and private-sector coordinators.
- China: Although the doctoral student has no experience conducting research in China, she has conducted a few qualitative interviews with diplomats and researchers who worked in Washington D.C.

The current socio-political environment/current events of that areas:

- Thailand: Thailand has gone through a lot of changes in the last several years. The country adopted a new economic growth model and reorganized national agencies responsible for increasing the country's competitive capacity in science and research, with the goal of creating a value-based economy powered by innovation, technology, and creativity. Thailand is attempting to foster both international and local scientific collaboration in order to achieve long-term economic development despite its low resources. This study is looking at the efforts and examines the outcomes using the concepts and theories that focus on collaborations among local sectors and international partners. Hopefully, this study will provide a better understanding of the complex interactions between policymakers and collaborators in the two intertwined collaborative networks.
- United States: Thailand and the United States were chosen as a case study for this project because Thailand produces the most international coauthored scientific articles with the United States each year. The findings of this research could be useful in assisting the United States in better understanding and cooperating with its developing country partners.
- China: Thailand-China research partnership was chosen since the number of co-authored publications between the two nations is growing at the second-fastest rate after Thailand-India. The number of Thailand-China coauthored publications, on the other hand, is substantially higher. The conclusions of this study may be useful in assisting China in better understanding and cooperating with its regional partners.
- Having the comparisons of two nations will help increase the study's global validity and transferability.

What is the potential subject population's languages and dialects?

- American subjects: English

- Chinese subjects: The communication and interviews will be conducted in English.
- Thai subjects: English and Thai (which is the first language of the doctoral student)

Do they have any specific mores surrounding written versus verbal communications?

- No

Does the country require local ethical or IRB review or not?:

The doctoral student contacted the National Science and Technology Development Agency's (NSTDA) Office of Research Integrity (ORI), which is in charge of IRB in Thailand. According to the response, this study does not need permission to interview people in Thailand because the study is not affiliated with any Thai agency and the doctoral student is recruiting participants in general, rather than focusing on specific agencies. The doctoral student can conduct interviews in Thailand as long as the study is approved by VT IRB.

7.0 Study Intervention(s)/Investigational Agent(s)

7.1 Describe the study interventions (including behavioral interventions) and/or investigational agents (e.g., drugs or devices) to be used in this study. Consider each of the items listed below:

- *Drug/Device Handling: If the research involves drugs or devices, describe your plans to store, handle, and administer the drugs or devices so that they will be used only on subjects, and only by authorized investigators.*
- *Describe whether any of the following will be used: microwaves, X-rays, DEXA scans, general anesthesia, or sedation*
- *If control of the drugs or devices used in this protocol will be accomplished by following an established, approved organizational SOP (e.g., Research Pharmacy SOP for the Control of Investigational Drugs, etc.), please reference the SOP in this section.*

N/A

7.2 List the name of all drugs (including any vitamins, supplements, herbs, or nicotine) to be used in the study. Indicate whether they have FDA approval, and list any limitations for their use:

N/A

7.3 List all devices, how they will be used, their purpose in the study, and if they will be used in a manner consistent with their approved uses. If they will be used in ways that are not yet FDA approved, indicate whether they need an IDE or a determination that they are exempt from the IDE Determination. If a determination of significant risk or non-significant risk is needed for any of the devices, include the researcher’s recommendation for each of those devices:

N/A

7.4 If the drug is investigational (has an IND) or the device has an IDE or a claim of abbreviated IDE (non-significant risk device), include the following information:

- Identify the holder of the IND/IDE/abbreviated IDE.
- Explain procedures followed to comply with sponsor requirements for FDA regulated research for the following:

<i>FDA Regulation</i>	<i>Applicable to:</i>		
	<i>IND Studies</i>	<i>IDE studies</i>	<i>Abbreviated IDE studies</i>
<i>21 CFR 11</i>	<i>X</i>	<i>X</i>	
<i>21 CFR 54</i>	<i>X</i>	<i>X</i>	
<i>21 CFR 210</i>	<i>X</i>		
<i>21 CFR 211</i>	<i>X</i>		
<i>21 CFR 312</i>	<i>X</i>		
<i>21 CFR 812</i>		<i>X</i>	<i>X</i>
<i>21 CFR 820</i>		<i>X</i>	

N/A

8.0 Procedures Involved

8.1 Describe and explain the study design:

This study will combine both quantitative and qualitative techniques.

For quantitative method, co-authorship and citation data of co-publications by Thailand local sectors, by Thailand and China, and Thailand and the U.S., between 2009 - 2020 will be collected from citation databases. The data will then be analyzed using a linear regression model and the calculation of cited/citing ratios.

For qualitative analysis, semi-structured interviews with 24 participants will be conducted. Potential study participants will be recruited via personal and professional connections as well as expert recommendations. Each interview will

be conducted in person in a location of the participants' choosing such as their offices, meeting rooms at their organizations, and so on. The quantitative study's findings will be used to develop interview questions. With participants' permission, the doctoral student will record the interview using a recording device as well as take notes during the interview. An interview will last approximately 1 hour. If clarification is needed, the doctoral student will contact them by mail or phone. For the analysis, the interview will be transcribed and non-English interviews will be translated into English.

8.2 *Provide a description of:*

- *All research procedures being performed*
- *If the study has more than one procedure, session, and/or subject population, describe each procedure, session, and/or study population separately. For complex studies, you are encouraged to include a figure or chart.*

Data for quantitative study:

- Co-authored publication data between local sectors in Thailand, between Thailand and China, and between Thailand and the U.S. between 2009 - 2020 will be collected from Scopus and Thai local databases (eg. Thai National Research Repository - TNRR and Thai Digital Collection - TDC). The data will be stored on Virginia Tech Google Drive account which is available to other researchers.

Data for qualitative study:

- Potential study participants will be recruited via personal and professional connections as well as expert recommendations. Recruiting emails and consent forms will be sent to their emails. Personal information and signed consent forms from the subjects will be printed out and assigned unique codes to maintain anonymity. The hard copy records will be stored in a locked cabinets at the doctoral student's house.

- The 24 interview participants will include:

A) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with research collaborations among local sectors in Thailand (code: TT1, TT2, and so on),

B) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with research collaborations between Thailand and China (code: TC1, TC2, and so on),

C) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with collaborative activities between Thailand and US (code: TA1, TA2, and so on),

D) Three Chinese policy makers and scientists who have been involved with research collaborations between Thailand and China (code: C1, C2, and so on), and
E) Three American policy makers and scientists who have been involved with research collaborations between Thailand and the U.S (code: A1, A2, and so on).

- The doctoral student will meet and interview each participant in person at their preferred location. The interview could take place in their office, one of their organization's meeting rooms, or elsewhere. If a face-to-face meeting is not possible, the interview can be conducted online using Zoom Meetings (provided by Virginia Tech).

- With their consents, the doctoral student will record the interview with a voice recording device and take notes during the interviews. An interview will run between one hour.

- The audio recordings will be stored in a researcher's personal Google drive which has encryption and requires two-factor authentication to access the data. The recordings in the voice recording device then will be deleted. The audio files will be kept for future validity checks and will be permanently deleted from Google drive in two years after the project is completed and the study is closed with the IRB.

- The interview recording will be transcribed and any personal data (e.g., participant names) will be removed. The interview transcripts will be translated into English if the interviews are conducted in Thai. The transcripts will be stored in the doctoral student's Virginia Tech Google drive account which has encryption and requires two-factor authentication to access the data. The doctoral student will also make the database available to other researchers.

- The interview transcripts and the result from the quantitative study will be analyzed using Science and Technology Studies (STS) frameworks that focus on organizational and social aspects that may influence scientific cooperation.

8.3 Describe:

- *Procedures or safeguards intended to reduce the probability and magnitude of risks. (For example: Reducing the risk of injury in a virtual reality study either by having the subjects sit during the study or by providing an obstacle-free space for walking.)*
- *Be sure to describe all drugs and devices used in the research, when they will be administered or used, and their purpose.*
- *Methods used to collect data about subjects. Please upload all data collection forms to Protocol Management. Some common examples are:*
 - *Screening questionnaires*
 - *Survey(s), including online surveys*

- *Demographic questionnaire(s)*
- *Interview guide(s), e.g., questions or pool of questions for semi-structured interviews*
- *Focus group guide(s)*
- *Other documents used to collect data*

Participants can opt out of answering certain questions or disclosing certain information provided during the interview to reduce the risks to themselves. Only the information they grant permission for will be used in the study.

Participants' names, positions, the names of organizations/companies, years of experience, and projects in which they have been involved will be collected during the interview. However, they can choose between three levels of privacy:

Tier I is complete anonymity, with just a basic description of their professions (eg. a researcher, a coordinator, and a policy maker) and broad categories of their organizations/companies (eg. a government research agency, a university, a private company) mentioned in the study.

Tier II: the study specifies a wide category of their occupations as well as the name of their organization/company.

Tier III: the study includes their names, positions, and the names of organizations/companies.

No one will be given access to your personal information. Copies of their consent form and interview guides will be provided to all participants.

8.4 *What data will you collect during the study and how you will obtain them? Please include descriptions of electronic data collection, database matching, and app-based data collection:*

Participants' names, positions, and names of organizations/companies will be obtained through public sources such as organizational websites and LinkedIn prior to the interview as part of the participant selection process. More information about their work experiences will be requested from potential subjects through emails. More discussions on their works, opinions, and personal experiences will take place during the interviews. The interviews will be in person. If face-to-face interviews are not possible, the interview will be conducted over Zoom Meetings.

8.5 *Who will transcribe or code audio and/or video recordings?:*

The doctoral student will be transcribing the voice recording. If needed, TranscribeMe will be used.

8.6 *Include a description of any deception to be used in the study. Include justification for the use of deception (why the deception is necessary), describe the debriefing process, and describe how the study meets all the following criteria for alteration of consent (deception is considered an alteration of informed consent):*

- *The research involves no more than minimal risk to the subjects*
- *The alteration will not adversely affect the rights and welfare of the subjects*
- *The research could not practicably be carried out without the alteration/deception*
- *(Optional but encouraged in most cases) Subjects will be provided with additional pertinent information after participation (i.e., debriefing for studies involving deception)*

N/A

8.7 *If the study involves long-term follow-up (once all research related procedures are complete), describe what data will be collected during the follow up period and when it will occur:*

N/A

9.0 Data and Specimen Long Term Storage and Use

9.1 *If you will store data or specimens for future use, describe where you will store the data or specimens, how long they will be stored, and how and by whom the data or specimens will be accessed:*

- Recruiting materials and consent forms will be sent to the participants' emails. Personal identifiers will be stored on a paper sheet, keyed to anonymous case numbers. This sheet, with the signed consent forms will be kept in locked cabinet at the doctoral student's home. Because the doctoral student is a Northern Virginia Center (NVC) student, all hard copies will be kept at the doctoral student's home which is more convenient for the doctoral student. The hard copies will be destroyed in two years after the project is completed and the study is closed with the IRB.

- The interview recordings will be stored in the doctoral student's personal Google drive which has encryption and requires two-factor authentication to access the data. The recordings in the voice recording device then will be deleted. The audio files will be kept in Google drive for future validity checks and will be permanently deleted from Google drive in two years after the project is completed and the study is closed with the IRB.

- Interview transcripts will be stored in the doctoral student's Virginia Tech Google drive account which has encryption and requires two-factor authentication to access the data. the doctoral student will also make the database available to the PI. The transcripts will be deleted in two years after the project is completed and the study is closed with the IRB.

9.2 *For specimens, list the data to be stored or associated with each specimen:*

N/A

9.3 *Describe the procedures to release data or specimens outside of the research team, including the process to request a release, approvals required for release, who can obtain data or specimens, and what data will be provided with specimens:*

The data will not be released outside of the research team.

9.4 *Describe the identifiers to be included with stored data or specimens, as well as any key or code that could be used to make them identifiable. Describe where the code will be stored, who will have access to it, and when it will be destroyed:*

Interview participants will be assigned codes for anonymity (eg. TT1, TT2, TC1, TC2, and so on.) For participants do not want to disclose their names, codes will be used as identifiers. The coding sheet will be stored in a locked cabinet at the doctoral student's home

9.5 *Please select the identifiers you will obtain (whether directly from participants or from another source), including but not limited to:*

<input checked="" type="checkbox"/>	Name
<input checked="" type="checkbox"/>	Geographical subdivisions smaller than a state, including street address, city, county, precinct, zip code, and equivalent geocodes (note, the initial three digits of a zip code are not considered identifiable)

<input type="checkbox"/>	<i>Elements of dates (except year) for dates directly related to an individual, including birth date, admission date, discharge date, date of death, and single year of age over 89 and all elements of dates (including year) indicative of such age (note, such ages and elements may be aggregated into a single category of age 90+)</i>
<input checked="" type="checkbox"/>	<i>Phone numbers</i>
<input type="checkbox"/>	<i>Fax numbers</i>
<input checked="" type="checkbox"/>	<i>Electronic mail addresses (e-mail)</i>
<input type="checkbox"/>	<i>Social Security numbers</i>
<input type="checkbox"/>	<i>Medical record numbers</i>
<input type="checkbox"/>	<i>Health plan beneficiary numbers</i>
<input type="checkbox"/>	<i>Account numbers</i>
<input type="checkbox"/>	<i>Certificate/license numbers</i>
<input type="checkbox"/>	<i>Vehicle identifiers and serial numbers, including license plate numbers</i>
<input type="checkbox"/>	<i>Device identifiers and serial numbers</i>
<input checked="" type="checkbox"/>	<i>Web Universal Resource Locators (URLs)</i>
<input type="checkbox"/>	<i>Internet protocol (IP) address numbers</i>
<input checked="" type="checkbox"/>	<i>Biometric identifiers, including finger and voice prints (audio recording)</i>
<input type="checkbox"/>	<i>Full face photographic images and any comparable images (including video recording)</i>
<input type="checkbox"/>	<i>Student record number or identification number</i>
<input type="checkbox"/>	<i>User name for online or computer accounts</i>
<input type="checkbox"/>	<i>Any other unique identifying number, characteristic, or code (note this does not mean the unique code assigned by the investigator to code the data): Click here to explain.</i>

10.0 Sharing of Results with Subjects

10.1 Describe whether you will share results (study results or individual subject results, such as results of investigational diagnostic tests, genetic tests, or incidental findings) with subjects or others (e.g., the subject's primary care physician). If so, describe how you will share the results and include this information as part of the consent document. Upload materials you will use to explain the results to subjects:

Participants will receive the transcript of their interviews and be given the opportunity to correct any factual errors.

11.0 Study Timelines

11.1 Describe:

- *The duration of an individual subject's participation in the study (for example, 1 hour, 2-4 weeks, 3-5 years).*

- *The amount of time expected to enroll all study subjects (weeks, months, years, etc.)*
- *The amount of time expected for the investigators to complete this study including primary data analyses.*

Each interview takes 1 hour. Follow-ups may be needed for added clarification. If so, the doctoral student will contact participants by mail/phone to request more information.

The doctoral student will take 12 weeks for recruitment, 12 weeks for interviewing, and 16 weeks for transcribing, translating and analyzing.

12.0 Inclusion and Exclusion Criteria

12.1 Describe how you will screen individuals for eligibility. When will screening occur and what procedures will you use? Upload any screening scripts or surveys to Protocol Management:

Names, positions, and organizations/companies of potential participants will be obtained through personal/professional connections and public sources such as official websites.

Screening and recruiting will take place in February - May 2022.

12.2 Describe the eligibility criteria that define who will be included and who will be excluded from enrollment for each procedure of your study. Include any geographic criteria (e.g., Virginia Tech undergraduate students, a national sample of adults with engineering degrees, minors aged 8-12 in the New River Valley, university faculty in Virginia and Paris, France):

Eligible subjects are researchers, policy makers, and decision makers with experience working on research collaborations among local sectors in Thailand, between Thailand and China, and Thailand and the US. Participants with more than 5 years of experience are preferred.

12.3 Indicate specifically whether you will include or exclude each of the following special populations: (You may not include members of these populations as subjects in your research unless you indicate them in the description of your subject population.)

- *Minors, as defined by state law where the study is performed (infants, children, teenagers)*
- *Pregnant women (can be included in minimal risk studies by mentioning in section 13.1)*
- *Prisoners (including all incarcerated individuals)*
- *Adults not capable to consent on their own behalf*

N/A

13.0 Vulnerable Populations

13.1 If the research involves individuals who are vulnerable to coercion or undue influence, please describe additional safeguards you will include to protect their rights and welfare. Consider the applicable items listed below:

- *If the research involves Virginia Tech students, indicate whether these are students of any of the investigators. If so, describe whether the activities will take place during class time as part of the curriculum and the steps you will take to reduce the possibility that students feel obliged to participate in order to improve their course grade. The HRPP can provide further guidance as needed. Describe whether you will request access to student records (e.g., SAT, GPA, GRE scores).*
- *If the research involves employees of Virginia Tech or the research sponsor, describe steps you will take to ensure that the employees are freely participating and describe how their data will be protected from inspection by their supervisors.*
- *If the research involves Virginia Tech NCAA athletes, you must obtain approval from the athletic department.*
- *For research involving Montgomery County Public Schools, you must obtain county approval (after obtaining contingent Virginia Tech approval). Other locales have different requirements; please check on these and describe here. Approval is typically granted by the superintendent, principal, and classroom teacher (in that order). Approval by an individual teacher is insufficient. School approval, in the form of a letter or a memorandum should be uploaded as a supporting document.*
- *If the research involves pregnant women, review “CHECKLIST: Pregnant Women (HRP-412)” to ensure that you have provided sufficient information in this protocol.*
- *If the research involves prisoners, review “CHECKLIST: Prisoners (HRP-415)” to ensure that you have provided sufficient information in this protocol.*
- *If the research involves persons who have not attained the legal age for consent to treatments or procedures involved in the research (minors), review the “CHECKLIST: Minors (HRP-416)” to ensure that you have provided sufficient information in this protocol.*

- *If the research involves cognitively impaired adults, review “CHECKLIST: Cognitively Impaired Adults (HRP-417)” to ensure that you have provided sufficient information in this protocol.*

N/A

14.0 Number of Subjects

14.1 Indicate the total number of subjects to be enrolled and how this number was determined (e.g., sample size calculation [show], number of available subjects in a finite pool, number of tests funding award would allow):

The 24 interview participants will include:

A) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with research collaborations among local sectors in Thailand,

B) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with research collaborations between Thailand and China,

C) six policy makers and scientists from Thai government agencies, universities, and companies who have been involved with collaborative activities between Thailand and US,

D) three Chinese policy makers and scientists who have been involved with research collaborations between Thailand and China, and

E) three American policy makers and scientists who have been involved with research collaborations between Thailand and the U.S.

The number was determined to cover different groups of people who are involved with research collaborations between different partners and at different levels.

14.2 If this is a multi-site study, indicate the number of subjects to be enrolled at this site and the total to be enrolled from all sites:

N/A

14.3 If applicable, indicate the number of potential subjects you expect to screen for enrollment, and the number of subjects you will need to complete the research procedures:

The doctoral student expects to screen a maximum of 72 potential subjects to hit the target enrollment of 24

14.4 *If the study has more than one procedure, indicate the total number of subjects to undergo each procedure separately:*

N/A

15.0 Recruitment Methods

15.1 *Describe when, where, and how you will recruit potential subjects:*

Recruitment process will start in February - May 2022. The doctoral student will search for potential participants through public sources such as official websites and LinkedIn. The doctoral student will also use her personal/professional networks to search for qualified subjects. The communication and recruitment will take place via email.

Email Subject line: "Research collaboration has become so important. How can we improve collaboration in science? Your perspective can be helpful."

Dear [Name]:

A research team from Virginia Tech's Department of Science, Technology, and Society is conducting a study on the relationships between international and local collaborations, using local collaboration in Thailand as a case study, as well as collaboration between Thailand and China and Thailand and the United States. We are inviting you to participate in this study because we believe your perspective as a [researcher/policy maker/decision maker] with experiences in scientific collaborations [among local sectors/between Thailand and China/between Thailand and the United States] can greatly contribute to our understanding and knowledge of the factors that drive and impact scientific collaborations.

This study will require you to participate in a one-hour interview in a location of your choice. If you're interested, please fill out the consent form and follow the instruction in the Google Form link. A separate email will be sent with additional instructions. We are hoping you'll be able to assist us in learning more about scientific collaboration. We are excited to collaborate with you.

If you have any questions, please feel free to contact me via email at gambun13@vt.edu or via phone at +1 (202) 820-3580.

Sincerely,

Bunyakiat Petri
PhD Candidate,
Department of Science, Technology, and Society, Virginia Tech

15.2 Describe the source of subjects (for example, clinic patients with specific conditions, students in the library, community members at a gathering, or members of a local gym):

People who work at research agencies, private companies, or governmental agencies in Thailand, China, and US.

15.3 Describe the methods that you will use to identify potential subjects:

Eligible subjects are researchers, policy makers, decision makers with experience working on research collaborations among local sectors in Thailand, between Thailand and China, and Thailand and the US. Participants with more than 5 years of experience are preferred.

15.4 Describe materials that you will be use to recruit subjects. Attach copies of these documents with this protocol in Protocol Management and be sure to include the IRB protocol number on each document.

- *For flyers, attach the final copy of printed flyers.*
- *For Virginia Tech News, Facebook postings and ads, newspaper ads, websites, MTurk/SONA/online survey systems, etc., attach the final wording and graphics to be used.*
- *For email recruitments, please include the subject line.*
- *For advertisements meant for audio broadcast, please submit the wording of the advertisement prior to taping (to avoid having to re-record with approved language) and submit the final recorded version for IRB review before use.*
- *Describe any compensation to subjects. Separate compensation into appropriate categories, such as: reimbursement for expenses, time and effort, and additional incentives for study participation. For each category, specify the amount (including any pro-rated amount), schedule, and method of payment.*

Email recruitments using Virginia Tech student Email (vt.edu).

Subject line: "Research collaboration has become so important. How can we improve collaboration in science? You can help."

There is no compensation to subjects.

16.0 Withdrawal of Subjects

16.1 Describe circumstances under which you anticipate subjects could be withdrawn from the research without their consent:

Someone is a no show or becomes belligerent during the interview.

16.2 If applicable, describe any procedures for orderly termination (e.g., discontinuation of a study drug or debriefing after a behavioral intervention):

N/A

16.3 Describe procedures that you will follow when subjects withdraw from the research, including partial withdrawal from procedures with continued data collection (e.g., participant declines to continue with regular blood draws, but continues with periodic behavioral questionnaires):

Participants can request to remove part of data they provide during the study or completely withdraw from the study at any time.

When the request is made before their participation is complete or before data analysis for the study has concluded, the doctoral student will exclude the participant's data from the study and destroy the data.

When the request is made after the participant's participation is complete and data analysis has concluded, the ability to honor a participant's request to withdraw from a study is limited. All such requests will be reviewed on a case-by-case basis.

17.0 Risks to Subjects

17.1 List the reasonably foreseeable risks, discomforts, hazards, or inconveniences to the subjects related the subjects' participation in the research. Include for the IRB's consideration a description of the probability, magnitude, duration, and reversibility of the risks. Consider physical, psychological, social, legal, privacy, and economic risks. Do not indicate "No risk" or "N/A." Instead, for studies with very low risk (e.g., anonymous online questionnaire on a mundane topic) indicate "The investigators are not aware of any risks from participation in this study." or "No more than risks than are found in everyday life." The example consent form

*presents a tabular method for risk information, which you can also use here.
Common risk types include:*

- *Physical (e.g., potential for pain, discomfort, infection)*
- *Psychological (e.g., potential for stress, discomfort, and/or embarrassment)*
- *Social (e.g., potential for discrimination or stigmatization and disruption of personal and family relationships)*
- *Legal (e.g., potential for disclosure of illegal activity, negligence)*
- *Privacy (e.g., potential for personal information being accessed, used, or disclosed without the subjects' knowledge or consent, breach of confidentiality/security)*
- *Economic (e.g., potential for individuals to lose access to economic services, employment, insurability)*

No more than minimal risk

17.2 Indicate the measures you will use to minimize risks and monitor subjects for safety. (e.g., asking a subject at regular intervals to rate how they are feeling from 1 to 10, or to slowly crouch in order to check their balance.)

Only the information participants grant permission for will be used in the study. In order to participate in the study, they can choose between three levels of privacy that they feel comfortable with. They can skip questions and request not to disclose the information they provided any time even after the interviews.

17.3 If applicable, indicate which procedures might have risks to the subjects that are currently unforeseeable. This will be rare, and usually applicable when testing a new drug or device or a new use of an existing drug or device:

N/A

17.4 If applicable, indicate which procedures might have risks to an embryo or fetus should the subject be or become pregnant:

N/A

17.5 If applicable, describe risks to others who are not subjects (e.g., collection of sensitive health data that might affect sexual partners if disclosed, mandatory reporting of abuse, DNA testing that might affect family members or relationships):

N/A

18.0 Potential Benefits to Subjects

18.1 Describe the potential benefits that individual subjects might experience from participating in the research. Include the probability, magnitude, and duration of the potential benefits, as this will be useful to the IRB's risk:benefit analysis. Do not include benefits to society or others. Do not list monetary or non-monetary compensation for participation, as this is not a benefit. These should be included in section 2 or 3 of this document:

There are no anticipated direct benefits for participants.

18.2 If applicable, specify that there are no anticipated direct benefits for participants:

There are no anticipated direct benefits for participants.

19.0 Data Management and Confidentiality

19.1 Describe procedures that you will use for quality control to ensure validity of collected data:

To ensure validity of collected data, participants will be sent the transcripts and given the opportunity to correct any factual errors.

The doctoral student will create participant folders for each participant which include their informed consent forms, their profiles and organizations'/companies' profiles that provided by the participants or obtained from public sources, their contact information, transcripts, follow-up notes, and any important communication with the participants.

The doctoral student will also create study binder which contain all protocol documents, recruitment materials, IRB approvals, important communications from IRB, participant identification codes, and so on.

19.2 Describe any existing data or biospecimens you will obtain as part of this study. Include:

- *Variables or samples to be obtained*
- *Source of the data or specimens*

- *Your authorization to access or receive the data or biospecimens*
- *Whether the data or biospecimens are publicly available*
- *Whether the data or specimens you receive will contain identifiers*

The data that will be collected in this study is participants' experiences, opinions, and perspectives on research collaborations. The participants will be provided the questions guidelines and asked for permission prior to the interviews.

In addition, factual information about their projects, organizations, and related policy will be acquired from the participants as well as from public sources.

19.3 Describe the steps that you will take to handle and secure study data during data collection, storage, use, and transmission. Include information about training of study staff, authorization of access, password protection, encryption, physical controls, certificates of confidentiality, separation of identifiers and data, etc.:

All the communications that are related to sensitive information will take place through Virginia Tech student email.

During the interview, the doctoral student will use a voice recording device as well as take note. The recording files will be transferred from the device and stored in the doctoral student's Google Drive. The notes will be kept at a secured place in the doctoral student's home.

The interview recording will be transcribed and any personal data (e.g., participant names) will be removed. The interview transcripts will be translated into English if the interviews are conducted in Thai. The transcripts will be stored in the doctoral student's Virginia Tech Google drive account which has encryption and requires two-factor authentication to access the data. The doctoral student will also make the database available to other researchers.

No one other than the PI and the doctoral student will have access to the storage facilities.

19.4 For multi-site studies, describe how data or specimens will be handled and secured for each site (e.g., central or disseminated data storage, data coordinating center):

The interview will take place at different locations. The doctoral student will be collecting, transmitting, and storing the information.

19.5 Describe the plan for data disposition following the conclusion of the study (e.g., long term maintenance of data, data destruction methods).

- *What information will be included in the long term storage of data or specimens?*
- *How long will the data or specimens be stored?*
- *Where and how data or specimens will be stored?*
- *Who will have access to the data or specimens during long term storage?*
- *Who is responsible for receipt or transmission of the data or specimens?*
- *How will data or specimens be shared or transported?*
- *When and how will personal identifiers be destroyed?*

- Recruiting emails and consent forms will be sent to potential participants via email. Personal information and signed consent forms sent from the subjects will be printed out and assigned unique codes to maintain anonymity. The hard copy records, including the code key, will be stored in paper form in a locked cabinet at the doctoral student's house.

- The doctoral student will meet and interview each participant in person at their preferred location. The interview could take place in their office, one of their organization's meeting rooms, or elsewhere. If a face-to-face meeting is not possible, the interview can be conducted online using Zoom Meetings (provided by Virginia Tech). With their consents, the doctoral student will record the interview with a voice recording device and take notes during the interviews.

- The audio recordings will be transferred from the recording device and stored in a researcher's personal Google drive which has encryption and requires two-factor authentication to access the data. The recordings in the voice recording device then will be deleted. The audio files will be kept for future validity checks and will be permanently deleted from Google drive in two years after the project is completed and the study is closed with the IRB.

- The interview recording will be transcribed and any personal data (e.g., participant names) will be removed. The interview transcripts will be translated into English if the interview was conducted in Thai. The transcripts will be stored in the doctoral student's Virginia Tech Google drive account which has encryption and requires two-factor authentication to access the data. The doctoral student will also make the database available to the PI.

20.0 Provisions to Protect the Privacy Interests of Subjects

20.1 Describe the steps that you will take to protect subjects' privacy interests.

“Privacy interest” refers to a person’s desire to place limits on with whom they interact or to whom they provide personal information (e.g., collecting the minimal amount of private information required to complete the study, protecting the data once it is obtained):

The study requires minimal amount of private information. Moreover, in order to participate in the study, subjects can choose between three levels of privacy (Tier I, Tier II, and Tier III).

Participants can refuse to answer questions during the interview. After the interviews, they can also request not to disclose information they provided or withdraw from the study.

20.2 *Describe steps that you will take to make subjects feel at ease with the research situation in terms of the questions being asked and the procedures being performed. “At ease” does not refer to physical discomfort, but the sense of intrusiveness a subject might experience in response to questions, examinations, and procedures (e.g., use of a same gender investigator to place sensors on the torso, a private changing area if clothing must be changed, sensitivity when discussing pregnancy testing with subjects, making it clear on surveys that participants can discontinue at any time, not asking questions about private or sensitive issues unless necessary for the research):*

Interview participants will be informed prior the interviews that they can refuse to answer particular questions. Furthermore, after the interview, they can request not to have their information or parts of their interview used in the study.

No one else but the interviewer will be present unless interviewers would like someone else to be there.

20.3 *Describe how you plan to access existing sources of information about the subjects (e.g., medical records, grades) and how you will protect participant privacy through the data security plan:*

Information about the subjects will be gathered from public sources such as their organizations'/companies' official websites, Linked profiles, and so on. The doctoral student will also directly request participants for additional information needed for the study.

20.4 *Describe any required reporting that might occur as a result of your research questions, study populations, and data collection methods. Examples for Virginia and Virginia Tech include:*

- **Any** suspicions (e.g., circumstantial, disclosed) of child abuse (physical, emotional, sexual) and neglect
- Sexual discrimination and/or sexual violence that involves a student
- Disclosure or signs of intention to harm oneself (i.e., suicidal ideation and/or plan)
- Disclosure or signs of desire to harm others (i.e., homicidal ideation and/or plan)

- *Suspected abuse, neglect or exploitation of vulnerable adults (e.g., individuals with a disability, elderly persons)*

N/A

21.0 Provisions to Monitor the Data to Ensure the Safety of Subjects

Safety monitoring is required when research involves greater than minimal risk and is sometimes appropriate for other studies.

21.1 Describe:

- *The plan to periodically evaluate the data collected regarding both harms and benefits to determine whether subjects remain safe (e.g., periodic reporting to the IRB, establishing a data monitoring committee, reporting data monitoring committee findings to the IRB and the sponsor).*
- *What data you will review, including safety data, unexpected events, and data that show the ability to produce the intended results.*
- *How the safety information will be collected (e.g., with case report forms, at study visits, by telephone calls with subjects).*
- *The frequency of data collection, including when safety data collection starts.*
- *Who will review the safety data and with what frequency.*
- *The statistical tests for analyzing the safety data to determine whether harm is occurring.*
- *Any conditions that will trigger an immediate suspension of the research (e.g., a serious adverse event).*

N/A

22.0 Compensation for Research Related Injury

22.1 If the research involves more than minimal risk to subjects, describe the available compensation in the event of research-related injury, if any:

N/A

22.2 Provide a copy of contract language, if any, relevant to compensation for research-related injury. At Virginia Tech, this is most common for sponsored research:

N/A

23.0 Economic Burden to Subjects

23.1 Describe any costs that subjects might be responsible for because of participation in the research, including any uncompensated costs for items such as transportation, missed work, and childcare:

Costs for missed work.

24.0 Consent Process

24.1 Indicate the process by which you will obtain consent for study participation. Please upload all consent, parental permission, and assent forms, documents, and scripts referenced in this section to Protocol Management.

Describe the following:

- Where the consent process will take place (e.g., clinic waiting area, classroom, online)
- The time interval between sharing the consent information with the prospective subject and obtaining consent. For lab, interview, and focus group studies, the Virginia Tech IRB prefers that subjects have at least 24 hours to review the consent form and study information before the appointment where consent will be obtained. For simple online survey studies, you can typically present the consent information immediately before subjects begin participation.
- If applicable, processes to ensure ongoing consent or assent (e.g., for multiple sessions; for research in which a minor will turn 18 during the study; for longitudinal research with minors who will later be asked to provide or affirm their assent).
- Please review “SOP: Informed Consent Process for Research (HRP-090)” for recommended procedure. Describe your process, being sure to include:
 - The name and role of all study personnel who will be trained and certified by the PI to conduct the consent process
 - The time that will be devoted to the consent discussion
 - Steps that you will take to minimize the possibility of coercion or undue influence
 - Steps that you will take to gauge or ensure the subjects’ understanding

- Consent forms will be sent to potential participants through emails. The potential participants have 7 days to review the consent forms and send back the

completed form. In the meantime, they can ask questions and the doctoral student will answer via email or phone.

- Before the interview, the doctoral student will ask if participants have any unanswered questions and understand everything about the interview. All questions will be answer before the interviews begin.

- Written documentation of informed consent will be provided to interview subjects at the interview.

Non-English Speaking Subjects

- *Indicate what language(s) other than English are understood by prospective subjects or representatives.*
- *If non-English speakers will be recruited, describe the process you will use to ensure that the oral and/or written consent information provided will be in a language that they understand.*
- *If you translate consent forms and study materials, please provide a certified translation of the form as well as the certification document.*
- *Indicate the spoken language that study personnel obtaining consent will use. Describe how you will assess fluency of personnel obtaining consent to ensure that the translation is accurate.*

Some Thai participants may prefer to use Thai language. The consent form will be translated into Thai and get translation certification.

Waiver or Alteration of Consent Process (consent will not be obtained, required information will not be disclosed, or the research involves deception)

- *Review the “CHECKLIST: Waiver or Alteration of Consent Process (HRP-410)” to ensure you have provided sufficient information for the IRB to make these determinations (i.e., that it meets the criteria for a waiver or alteration of the consent process).*

N/A

Subjects who are not yet adults (minors: infants, children, teenagers)

- *Describe the criteria that you will use to determine legal age for consent to treatments or procedures involved in the research under the applicable law of the jurisdiction in which the research will be conducted (e.g., in Virginia, individuals under the age of 18 years).*

- *For research conducted in Virginia, review “SOP: Legally Authorized Representatives, Minors, and Guardians (HRP-013)” to determine which individuals in the state meet the definition of “minor.”*
- *For research conducted outside of the state, please describe the legal requirements for the definition of “minor.”*
- *Describe the process for obtaining parental permission.*
 - *Permission from one parent is acceptable for studies that involve no greater than minimal risk OR involve greater than minimal risk but present the prospect of direct benefit to the minor subject.*
 - *Permission from both parents is required in all other cases (unless one parent is deceased, unknown, incompetent, or not reasonably available, or when only one parent has legal responsibility for the care and custody of the minor).*
- *Describe whether you will obtain permission from individuals other than parents or Legally Authorized Representatives, and if so, who will be allowed to provide permission. Describe the process you will use to determine these individuals’ authority to consent to the minor’s general medical care.*
- *Indicate whether you will obtain assent from all, some, or none of the minors. If you will obtain assent from some minors, indicate which minors will be required to assent. Consider chronological age and intellectual capacity when determining who will be required to provide assent (e.g., infants are unable to assent. However, teenagers are likely able to read and sign an assent form).*
- *When assent of minors is obtained, describe whether and how you will document it. Will minors sign an assent form or give verbal assent?*
- *Attach parental permission and minor assent forms or scripts in Protocol Management.*

N/A

Adults Unable to Consent

- *Describe the process you will use to determine whether an individual adult is capable of consent.*
- *List the individuals from whom you will obtain permission in order of priority (e.g., durable power of attorney for health care, court appointed guardian for health care decisions, spouse, and non-minor child).*
 - *For research conducted in the Virginia, review “SOP: Legally Authorized Representatives, Minors, and Guardians (HRP-013)” to determine which individuals in the state meet the definition of “legally authorized representative.”*
 - *For research conducted outside of Virginia, please describe the legal requirements for obtaining permission from a legally authorized representative in the state where the research will occur.*

- *Describe the process for assent of the subjects.*
 - *Indicate whether you will require assent from all, some, or none of the subjects. If some, indicate which subjects will be required to assent and which will not.*
 - *If you will not obtain assent from some or all subjects, please provide justification for not obtaining assent.*
 - *Describe whether and how you will document assent.*

N/A

25.0 Process to Document Consent in Writing

25.1 Consult “SOP: Written Documentation of Consent (HRP-091)” for recommended procedures, and describe whether and how consent of the subject will be documented in writing:

The long forms of consent documentation will be sent to all research subjects. Consent forms in Thai language will be sent to Thai participants. They can use the language they prefer. Then the forms will be collected from participants via email. Copies of the signed and dated consent documents will be provided to the subjects. Written documentation of informed consent will be provided to interview subjects at the interview.

25.2 If the research presents no more than minimal risk of harm to subjects and involves no procedures for which written documentation of consent is normally required outside of the research context, you can request that the IRB waive the requirement to obtain written documentation of consent (e.g., consent to participate is indicated by pressing a button for an online questionnaire – after the consent information is presented and before the questionnaire begins):

This research presents no more than minimal risk of harm to subjects.

25.3 If you will document consent in writing, attach a consent document with places for signatures. If you will obtain consent, but not document consent in writing, please attach the consent script or text. Review “CHECKLIST: Waiver of Written Documentation of Consent (HRP-411)” to ensure that you have provided sufficient information. You should use “TEMPLATE CONSENT DOCUMENT (HRP-502)” to create the consent document or script:

Consent document is attached with this form.

26.0 Resources Available

26.1 Describe the resources available to conduct the research. For example, as appropriate:

- Describe the PI's availability to supervise the research.
- Justify the feasibility of recruiting the required number of suitable subjects within the agreed recruitment period. For example, how many potential subjects do you have access to? What percentage of those potential subjects do you need to recruit?
- Describe the time that you will devote to conducting and completing the research.
- Describe your facilities.
- Describe the availability of medical or psychological resources that subjects might need as a result of an anticipated or unanticipated consequence of participation in the research.
- Describe your process to ensure that all persons assisting with the research are adequately informed about the protocol, the research procedures, and their duties and functions (e.g., training plans, detailed study notebooks).

- The interview recordings and transcriptions will be stored on Google Drive accounts. The PI will be granted access to the shared folders on the Google Drive Accounts in order to provide supervision.

- Snow ball technique will be used in this study. The doctoral student expects to reach a maximum of 72 potential subjects to hit the target enrollment of 24. Although the number of populations is unknown, recruiting 24 participants is feasible as the subjects will be recruited from various types of agencies in Thailand and the United States that are involved with research activities.

- Recruiting between February – April 2022 Conducting interviews between April – June 2022 Analyzing the data between July – October 2022

- This research does not take place in a laboratory. All data will be stored in cloud storages which all research team will have access in order to work on the project.

- This research presents no more than minimal risk. Therefore, there is no need for medical or psychological resources for unfavored consequences.

- The doctoral student is going to create and provide a protocol sheet and study notebooks to all persons assisting with the research. The protocol and the study notebook will be stored and accessible via Google Drive VT account. The study notebook will be updated regularly. Every person assisting with the research will be explained all the procedure and get opportunities to ask questions throughout the study.

27.0 Multi-Site Research

Contact the HRPP for multi-site research (involving multiple institutions) and the details required for this section will be provided. Otherwise, indicate N/A.

N/A