

# Triple Helix Relations in Local and International Scientific Collaborations: A Case Study of Thailand, the US and China

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## ABSTRACT

Scientific collaboration is a driver of innovation and sustainable development, with countries globally, including those in the ASEAN region, leveraging collaborative efforts to enhance their scientific capacities. The changing structure and dynamics of the research and innovation ecosystem, shaped by collaborative efforts within and beyond their borders, have created a research gap. There is a scarcity of studies that comprehensively examine the innovation ecosystem in these nations. This article delves into the intricate dynamics of Triple Helix Relations among local sectors, universities, government entities and industries within the collaborative landscapes of Thailand, the United States and China. Using the data from 2006 to 2022, the study employs Shannon's mutual information, refined by Loet Leydesdorff, to analyze co-authored publications across the fields. We distinguish collaborations by the nationality of collaborative partners (Thai-China vs. Thai-U.S. collaboration) and by subject area (engineering, medicine and agricultural and biological sciences). The findings support the notion that international collaborations contribute to stronger Triple Helix relationships in specific ways within local settings. When Thailand partners with the United States, we observed weaker trilateral relationships but stronger bilateral ties between the Thai government and universities, particularly in the field of Medicine. Conversely, collaborations with China revealed stronger Triple Helix relations, as Thai industry became more involved in research collaborations, notably in agricultural and biological sciences and engineering. The analysis highlights the nuanced influence of international research collaboration on Thailand's national science and innovation system. These findings lay the groundwork for further investigation into the factors shaping these observed patterns.

**Keywords:** Triple Helix Relations, Scientific Collaboration, Innovation Ecosystem, Thailand-US-China Relations, Co-Authored Publications, International and Local Partnerships.

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## INTRODUCTION

In recent years, Thailand has achieved significant progress in both social and economic development. Successful initiatives targeting development and poverty reduction have propelled the country from a low-income status to an upper-middle-income classification in 2011.<sup>[1,2]</sup> Despite this progress, Thailand's economic growth has experienced a slowdown since 2011. The nation now grapples with uncertainties surrounding economic growth. To break free from the middle-income trap, Thailand must strive for sustainable growth, aspiring to per capita income levels comparable to advanced economies.<sup>[3]</sup> The previous strategy of development through exports and attracting Foreign Direct Investments has failed to provide a sustainable path to continued

improvements in living standards. Recognizing this, Thailand is pursuing a transition toward a knowledge-based economy.<sup>[4]</sup>

Thailand's recent economic development initiative, Thailand 4.0, aims to establish an economy built on value, driven by innovation, technology and creativity. Enhancing competitiveness and ensuring long-term economic development can be achieved by fostering collaboration with international partners.<sup>[5,6]</sup> International collaborations are integral to the strategic plans and priorities of various Thai agencies, facilitated through initiatives such as exchange programs, research partnerships and talent mobility programs. Not only collaborations with foreign countries, but the Thai government also actively encourages universities and the corporate sector to play a more prominent role in the nation's research and innovation endeavors. The anticipated outcome of the new national innovation system is to foster self-reliance and sustainable development.<sup>[7,8]</sup>

## Objectives and Scope of the study

The effort raises questions regarding the potency of scientific collaboration as a development strategy and the challenges faced



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by Thai researchers. For instance, what are the interconnections between international and local collaborations? How does international collaboration contribute to the local scientific capacities? However, to address this question comprehensively, we require a wealth of quantitative and qualitative data from various contexts due to the multifaceted nature of the issue. In this paper, we examine this broad and complex set of questions through a more focused analysis of the relationship of international collaboration to triple-helix relations. According to the triple-helix theory, an innovation system requires mutually reinforcing relations among university, industry and government sectors. Therefore, an evaluation of the relationship of international collaboration to the development of triple-helix relations is a crucial intermediate question in evaluating collaboration as a knowledge society strategy. Our primary focus in this paper is on understanding the differences in Triple Helix relations within the local scientific community when operating solely locally compared to engaging in international research collaborations. The answer to this question could help us understand the dynamics of the national science and innovation ecosystem in different contexts, as depicted by the interaction of the country's local sectors. We give particular attention to Thai collaborations with the United States and China. The goal is to uncover variations in collaboration dynamics. The examination will also address disparities between partner countries, particularly in light of the global North-South divide.

### International collaboration and the triple helix

International research collaboration has become a widespread practice in contemporary scientific endeavors and is viewed as an important pathway for developing local scientific capacity in low and middle-income countries.<sup>[9]</sup> Ensuring equality and fostering negotiation among partners is a crucial aspect of such collaborations.<sup>[10]</sup> The global South, comprising developing countries, is culturally, politically and economically reliant on the developed world.<sup>[11]</sup> Collaboration between the Global North and South has undergone historical transformations, marked by giver-receiver relationships that underscore an inherent imbalance in collaboration dynamics. Moreover, less advanced nations might prioritize allocating resources from local concerns to international issues, seeking acceptance from the Western scientific community.<sup>[12]</sup> While many express concerns about inequality, some have discovered a more positive aspect of the collaborations. Some recent research has found that despite the disadvantaged position of researchers in the Global South, international collaboration, even by elite researchers, can contribute to strengthening the local research capacity.<sup>[13]</sup> Collaborations between countries in the North and South should incorporate capacity building as an integral component of their initiatives such as technical assistance, training and institution building.<sup>[10,14]</sup> Boshoff<sup>[15]</sup> recommends fostering South-South cooperation. Promoting collaborative initiatives and strategically

leveraging the strengths of Southern research can elevate the global recognition of science in developing regions and amplify the South's participation in global scientific endeavors. Moreover, given the South's familiarity with its regional challenges and constraints, South-South cooperation may yield more effective solutions for issues encountered by developing countries.<sup>[16,17]</sup> According to this body of literature, we can infer that there are connections between international and local scientific collaborations. Some researchers suggest a negative correlation, citing issues such as unequal resource allocation and power dynamics. Conversely, other researchers have identified positive correlations, highlighting contributions from international research activities to local science capacity.

An approach to explore a nation's science and innovation system is to analyze the dynamics of interactions among key sectors driving science and innovation. In local collaborations, variations among partners may manifest through sector-specific characteristics. The Triple Helix (TH) framework, formulated by Henry Etzkowitz and Loet Leydesdorff, revolves around the interactions and dynamics among key actors in local collaborations, namely universities, industry and government. These collaborations and knowledge-sharing between organizations are crucial for fostering a country's long-term capacity in the knowledge-based economy.<sup>[18]</sup> Taking an evolutionary perspective, Etzkowitz and Leydesdorff<sup>[19]</sup> employ this model to investigate the relationships between the three sectors, with a focus on institutional transformations, evolutionary mechanisms and the emergence of new institutional positions. In this framework, the three sectors take on new roles, resulting in overlapping areas and intersecting institutional boundaries in knowledge production, commercialization and controls, thereby inducing changes in national systems and novel institutional arrangements.<sup>[20]</sup> Nevertheless, distinct patterns of Triple Helix relationships may be observed in different cultures.<sup>[21]</sup> Triple Helix synergy has been identified as aligning with other economic growth indicators.<sup>[22]</sup>

Numerous researchers have delved into the dynamics of the interplay between international and local collaborations.<sup>[6,23]</sup> Choi *et al.*<sup>[24]</sup> discerned that developed and developing countries exhibit distinct sectors that play pivotal roles in assimilating foreign-generated knowledge through international collaboration. For example, the researchers found that universities in some wealthier countries tend to be more actively involved in international collaborations, whereas governments of less affluent countries exhibit a higher level of activity. The creation, transfer and absorption of scientific knowledge occur at the juncture where collaborative actors interact.<sup>[25]</sup> Therefore, comprehending knowledge production and the ramifications of international and local collaborations necessitates careful consideration of the roles and interactions among these collaborative actors.

Various researchers have delved into the impact of internationalization on local research collaboration, uncovering

distinctive patterns in different countries. For instance, Leydesdorff and Sun<sup>[26]</sup> employed Shannon's entropy analysis to scrutinize the situations in Japan and Canada, revealing unique dynamics. In Japan, despite having a robust national system, the synergy within its local system has dwindled, particularly since 1995, coinciding with increased involvement in international research. The critical factor is the decoupling between Japanese universities, which historically played a central role in local collaborations<sup>[27]</sup> and the industrial sector. A parallel pattern was identified in Canada, where internationalization commenced earlier than in Japan, leading to decreased synergy in domestic collaboration due to limited engagement between Canadian universities and the government. Similar studies were conducted to examine the evolving domestic and foreign mutual information of research collaboration in many countries such as China, Korea and West Africa as well as G7 and BRICS countries.<sup>[28,29, 30]</sup> The researchers discovered distinct patterns in different countries as a result of their research. A common observation, however, is the globalization of the university publishing system during the 1990s and 2000s.

Concerns about resource distribution compel many countries to prioritize either local or international collaborations.; however, some researchers have identified positive connections between local and international research collaborations. According to Barnard, *et al.*<sup>[13]</sup>, researchers actively involved with international partners demonstrate a proactive approach, possessing ample resources. They can initiate and maintain their relationship network at both local and international levels without sacrificing resources. Consequently, these researchers engage in active collaboration with their local peers when they see opportunities. Contrary to individualistic views, according to Müller *et al.*<sup>[31]</sup> and Bozeman *et al.*,<sup>[32]</sup> the connection with international partners is not merely an individual asset but a form of social capital collectively shared. In simpler terms, the spill-over effects and personal motivations of star researchers play a pivotal role in transferring resources from international collaborations to local partnerships. Simultaneously, a robust local scientific system fosters the acquisition of ties with foreign counterparts. Allison and Long<sup>[33]</sup> refer to this phenomenon as the departmental effects on an individual's productivity.

The forms and dynamics of interactions between international and local scientific collaborations vary across nations. Undoubtedly, international collaboration has emerged as a crucial strategy adopted by many countries. However, the effectiveness of this strategy varies, with some nations successfully integrating global knowledge into their local systems, while others experience challenges in maintaining synergy within their local sectors. It is imperative to conduct additional case studies encompassing diverse countries to account for the myriad conditions and factors at play. Therefore, conducting case studies that include

new countries and utilize recent-year data becomes particularly valuable to capture the evolving landscape of international and local scientific collaborations.

To gather more evidence and comprehend the relationship between international and local scientific collaboration, we ask: What types of Triple Helix relations are involved when Thailand collaborates with the United States and China? Our objective is to help identify the potential benefits of international collaboration in fostering partnerships among local sectors within the research community.

### **Triangular Relationship between Thailand, the United States and China**

The United States had been Thailand's most significant research partner in terms of quantity of coauthored publications. However, in 2021, China nearly caught up in both the number and proportion of publications with Thailand. Thailand engages in collaboration with these two partner countries through diverse channels, including exchange programs, research partnerships and initiatives promoting talent mobility. For instance, the Thai government established representative agencies and sent officials to work locally in both countries. The Office of Science and Technology at the Royal Thai Embassy in Washington, D.C. and in Beijing focuses on initiating and promoting science and technology collaborations between Thailand and its American and Chinese partners. Rather than seeking assistance, Thailand aims to showcase its readiness to engage in substantive collaborations with more advanced countries. This shift underscores Thailand's commitment to fostering mutually beneficial partnerships and leveraging its strengths in the global arena. However, the nature and dynamics of collaborations between Thailand and the United States differ from those between Thailand and China.

Research cooperation between Thailand and the United States has been active for several decades. The collaborations cover a variety of topics such as medical research and innovation, environment management and energy management.<sup>[34]</sup> While the United States may retain its dominance in international science and technology (SandT) 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 and 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.<sup>[35]</sup> 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.

**Table 1: Data sample of ten 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

## Research design and methods

Our research aims to explore the correlation between international and local collaborations and investigate whether international collaboration contributes to enhancing capacity within the local research system. Our case studies involve local collaborations among sectors in Thailand and international collaborations between Thailand and the United States, as well as Thailand and China. The analysis is centered on both the quantity and dynamics of co-authored publications resulting from these scientific collaborations using Leydesdorf's mutual information model.

We examine Triple Helix relationships among local sectors using an analysis based on Shannon's entropy.<sup>[36]</sup> 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. Shannon's entropy formula is expressed as:

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

Here:

- $P(x_i)$  is the probability of the  $i$ -th value occurring,
- $\log_2$  is the base-2 logarithm.

Leydesdorff<sup>[37]</sup> extends this concept by developing transmission of uncertainty (T values), enabling the calculation of the synergy or interdependence between variables in a triple helix model.

The calculation for two dimensions is:

$$H(X, Y) = - \sum_i \sum_j P(X_i Y_j) \log_2 P(X_i Y_j)$$

$$T(ui) = H(u) + H(i) - H(ui)$$

The calculation for three dimensions is:

$$T(ugi) = H(u) + H(i) + H(g) - H(ui) - H(gi) - H(ug) + H(ugi)$$

We obtained Scopus publication data limited to the article type, covering the period from 2006 to 2022. The downloaded data, in Excel files, was processed and prepared using a Python application. Initially, we classified the affiliations' addresses of each publication into three collaborative settings:

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

We also aim to discern variations across different disciplines and subject domains. Therefore, we analyze the patterns of Thailand's domestic and international publications in three fields: medicine, agricultural and biological sciences and engineering. These disciplines exhibit distinctive characteristics, particularly regarding trends observed at local levels and in Thai-U.S. and Thai-China collaborations. Additionally, it is noteworthy that medicine and agricultural and biological sciences lean more towards basic science, while engineering represents a technologically oriented applied field.

To disaggregate the data into disciplinary groupings, we applied a subject area filter to select publications in medicine, engineering and agricultural and biological science. Then, publications in each group were classified using the addresses of Thai affiliations to categorize types of local collaborations (U-University, G-Government, I-Industry, UG, UI, GI, UGI) in different collaborative settings.



**Table 2: 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

**Table 3: 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

Table 1 illustrates the categorization of publications into different types of local collaborations. The sample data is 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:

$$H(U) = - \left( \frac{7}{10} \right) \log_2 \left( \frac{7}{10} \right) - \left( \frac{3}{10} \right) \log_2 \left( \frac{3}{10} \right) = 0.881$$

Table 2 shows the computation of H values (uncertainty) for each variable, we have H(U)=0.88, H(G)=0.97 and H(I)=1.00.

We repeat the process using Shannon's formula to get all the values we need to calculate the mutual information of the three-dimension relationship (Table 3).

Since the actual publication data could be several tens of thousands of papers every year in each category, for convenience, we 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.<sup>[20]</sup>

## FINDINGS

In tackling our research inquiries, we employ co-authored publication data alongside mutual information analyses. These methodologies empower us to investigate the patterns of research collaborations within local sectors in Thailand and between Thailand and international partners, with a focus on collaborations with the United States and China. The objective is to explore potential correlations between local and international scientific collaborations, thereby enhancing our understanding of the collaborative landscape in Thailand and shedding light on factors that might influence these collaborations. Initially, we present an overview of Thailand's research landscape and collaboration patterns by examining the number and proportion of co-authored publications. Then, we depict the dynamics of local sector interactions in various collaborative settings using whole numbers, mutual information and cross-sectoral circles. Finally, we discuss the insights gained from the analysis.

### Overview of Thailand's research landscape

The quantity of journal publications published by Thailand between 2006 and 2022 reveals a noticeable upward trend. Throughout the study period, the proportion of domestic collaborations fluctuated between 50% and 60%, resulting in 40% to 50% of international publications. Notably, the share of co-authored publications involving Thailand and other countries (excluding the United States and China) has consistently held at 30%.

Our attention is directed towards the United States and China, given their relative prominence as collaborative partners. Publications co-authored by Thailand and the United States represent the highest number (1,929 publications in 2022). While co-authored publications between Thailand and China show the highest Annual Growth Rate (AGR) at 22.82% after India (23%); however, China has a significantly larger publication count.

Although the number of Thai-U.S. and Thai-China co-authored publications has shown an upward trend and the co-authored publications with the United States remain higher than those with China (Figure 1). Intriguingly, the proportions of these two types of co-authored publications nearly converged in 2022. The

diverging trends in the proportions of Thai-US and Thai-China publications originated in 2006 and became more pronounced in 2017 (Figure 2).

The ratio between Thailand and its international collaborators, excluding the United States and China, has remained relatively constant. This implies that, despite a consistent rise in the number of Thai-U.S. co-authored publications, the overall proportion has been on a decline, influenced by a notable surge in Thai-China co-authored publications. An examination of the annual growth rate of Thai international publications with the United States and China from 2006 to 2022 reveals that the annual growth rate of Thai-China co-authored publications consistently outpaces those between Thailand and the United States almost every year (Figure 3).

Next, we delve into the distinctions between the chosen areas of study. As depicted in Figure 4, a significant proportion of Thai publications in the field of Medicine originated locally. The ratios of international publications involving Thailand and the United States have remained relatively consistent, with a slight decline observed after 2019. Conversely, the proportions of international publications between Thailand and China have consistently risen especially after 2017.

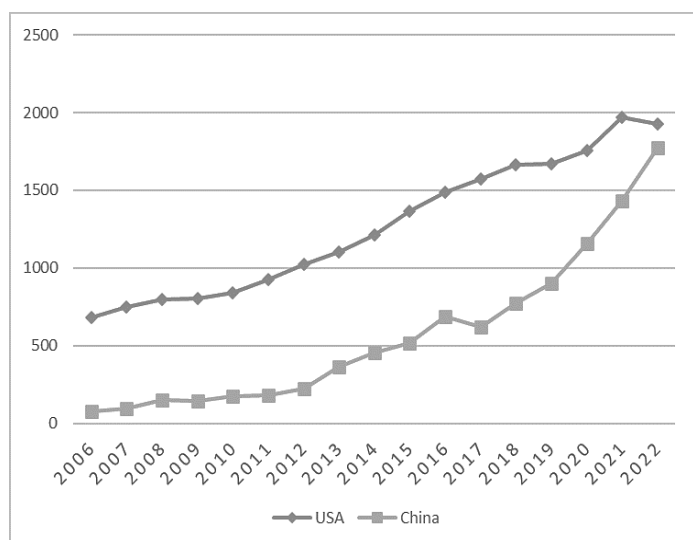
The number of Thai-U.S. and Thai-China co-authored publications in agricultural and biological sciences both increased throughout the observation period, with the noteworthy occurrence of Thai-China co-authored publications surpassing Thai-U.S. co-authored publications in 2020. Figure 4 illustrates a consistent increase in the percentage of local publications in the field of agricultural and biological sciences. the proportions of Thai-U.S. co-authored publications are on a steady decline, while those between Thailand and China continue to rise.

As depicted in Figure 4, international publications have increased in engineering, as a proportion of all publications. Notably, the number of Thai-U.S. co-authored publications in engineering remained stable from 2006 to 2020 and saw a significant uptick after 2020. In contrast, the number of Thai-China co-authored publications exhibited a distinct upward trend since 2014. This trend leads to a noticeable convergence in the proportions. 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.

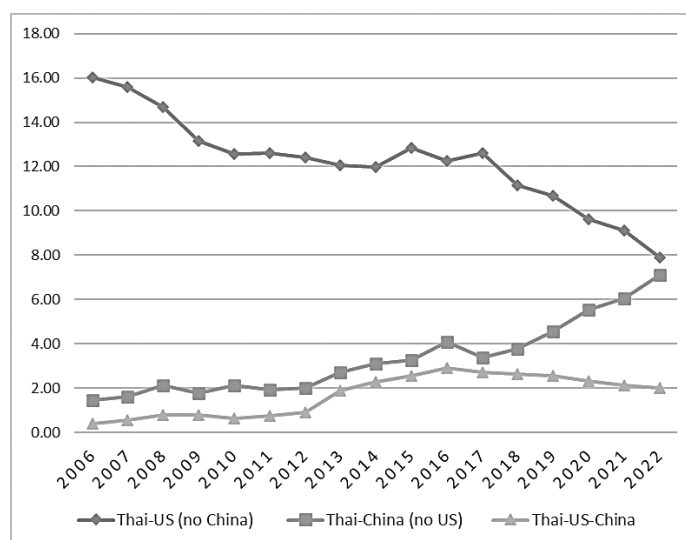
## The collaborations between local sectors in Thailand in different collaborative settings

We categorized Thai publications generated by distinct sectors, including co-authored publications involving different sectors. The notation U is employed for university, G for government agencies and I for the private sector. Figure 5 presents the counts of Thailand's Local Publications across all disciplines, including medicine, agricultural and biological sciences and engineering. Our findings reveal that university publications predominate in all disciplines, as well as in agricultural and biological sciences and engineering. Notably, medical publications witness a significant contribution from both governmental agencies and university-government collaborations (Figure 5, top right).

Next, we conducted a comparison of local and international collaborations using co-authored publications data in all subject areas. Figure 6, covering all disciplines, illustrates the comparison by showcasing the count of Thai domestic and international publications involving Thailand and all other countries, the United States and China. The findings point out that Thai universities play a primary role in contributing to both domestic and international publications. However, a notable distinction



**Figure 1:** The number of Thai-US and Thai-China co-authored publications from 2006-2022.



**Figure 2:** The proportions of Thai-US and Thai-China co-authored publications from 2006-2022.

arises when examining Thailand-U.S. co-authored publications, emphasizing the substantial participation of government entities in research (Figure 6, bottom left).

When comparing disciplines, we discovered comparable findings with slight nuances specific to distinct subject areas. We first examine the count of Thai domestic and international publications in the field of medicine. Surprisingly, despite universities being the predominant contributors to both domestic and international publications, as well as co-authored publications with China, Thai government agencies emerge as the primary collaborators in publishing papers with the United States.

We observed comparable outcomes in the numbers of Thai domestic and international publications within the fields of agricultural and biological sciences, as well as engineering. Notably, Thai universities play a predominant role as the most active contributors to both local and international publications in both fields. Particularly in the field of engineering, the number of publications from all other sectors, excluding universities, remains notably small and has exhibited minimal changes in recent years.

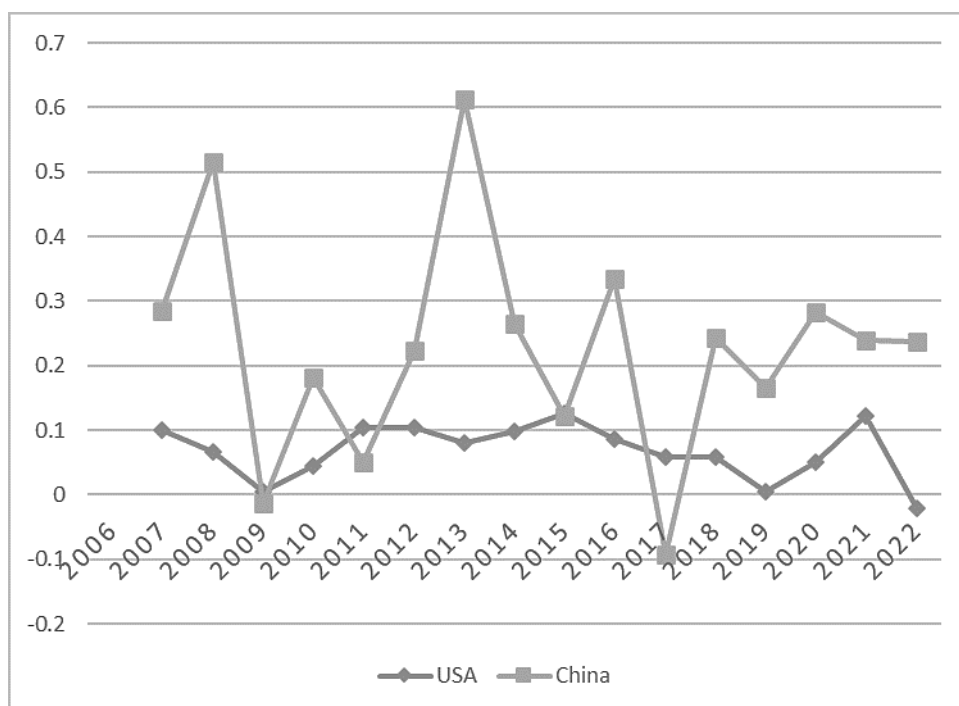
### Analyzing local and international collaborations through the mutual information model

To explore the connections between local and international scientific collaborations, we begin by employing mutual information, a metric developed by 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

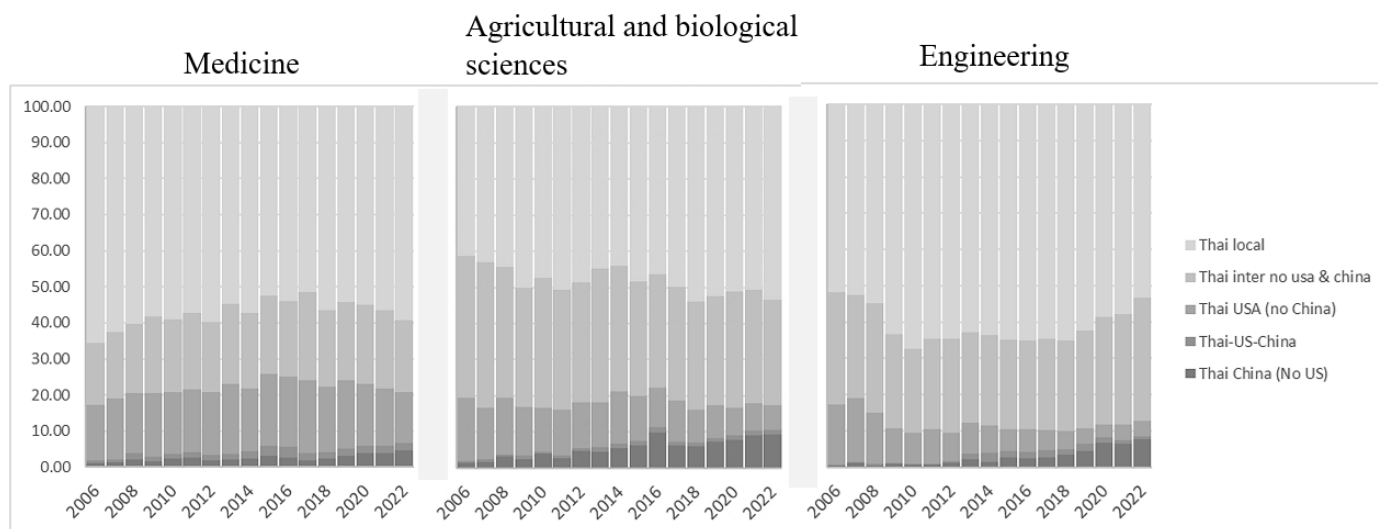
this study, we use mutual information to assess the relationships between universities, government entities and industries in both two-dimensional and three-dimensional contexts. We also investigate how the synergy of their collaborations evolves between 2006-2022. This methodology enables us to explore the interdependent relationships among these sectors, taking into account their individual-sector 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.

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 no 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.

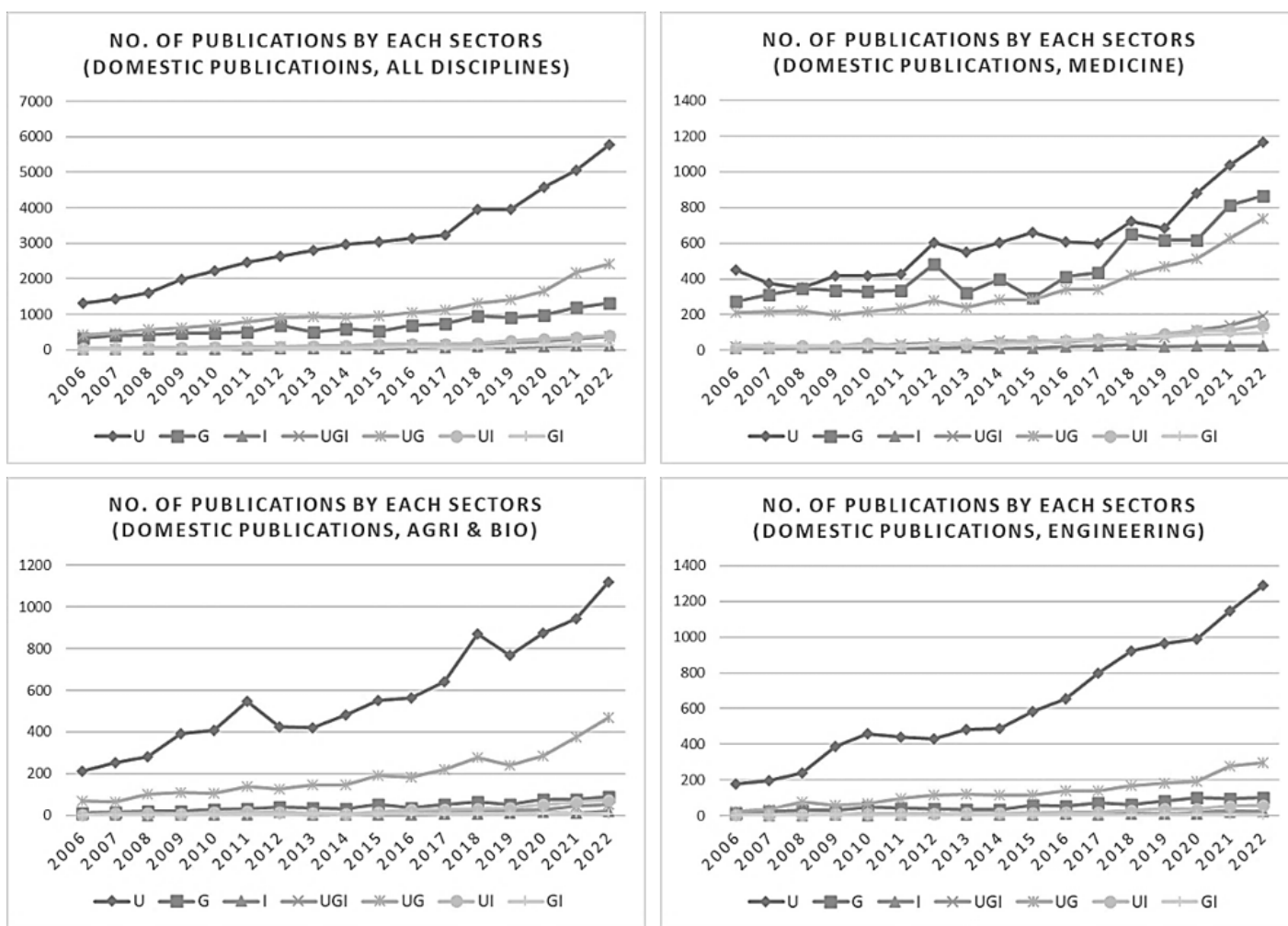
Figure 7 shows the mutual information of domestic collaborations among local sectors in Thailand across different disciplines, including all subject areas, medicine, agricultural and biological sciences and engineering. At the local level, collaborations between Universities and Governments (UG), as well as between Government and Industry (GI), exhibit significantly higher synergy compared to University-Industry collaborations (UI),



**Figure 3:** The annual growth rate (percentage) of Thai international publications with the US and China from 2006-2022.

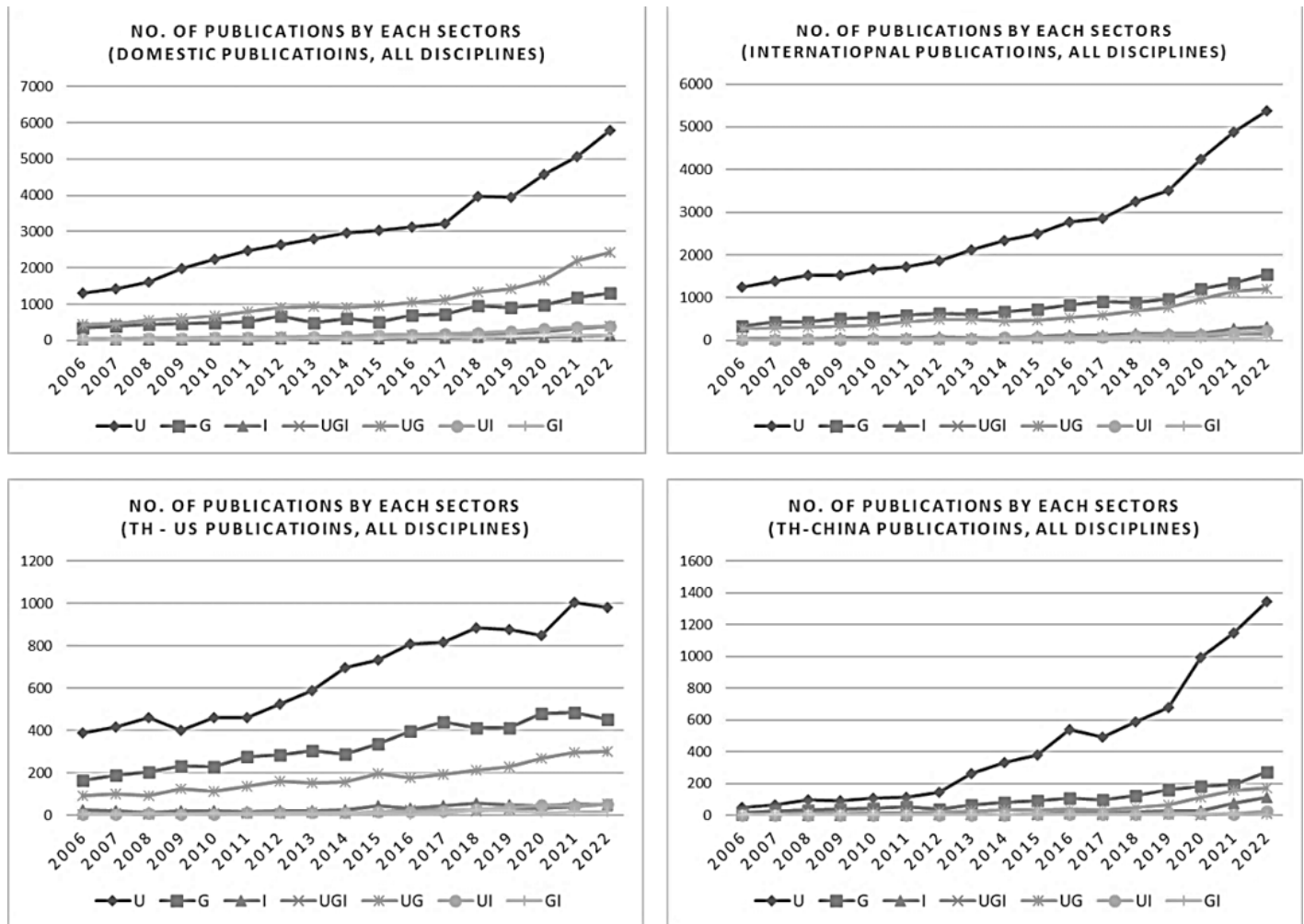


**Figure 4:** The proportion of Thailand's local and international publications in medicine, agricultural and biological sciences and engineering between 2006-2022.



**Figure 5:** 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).





**Figure 6:** 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 all disciplines

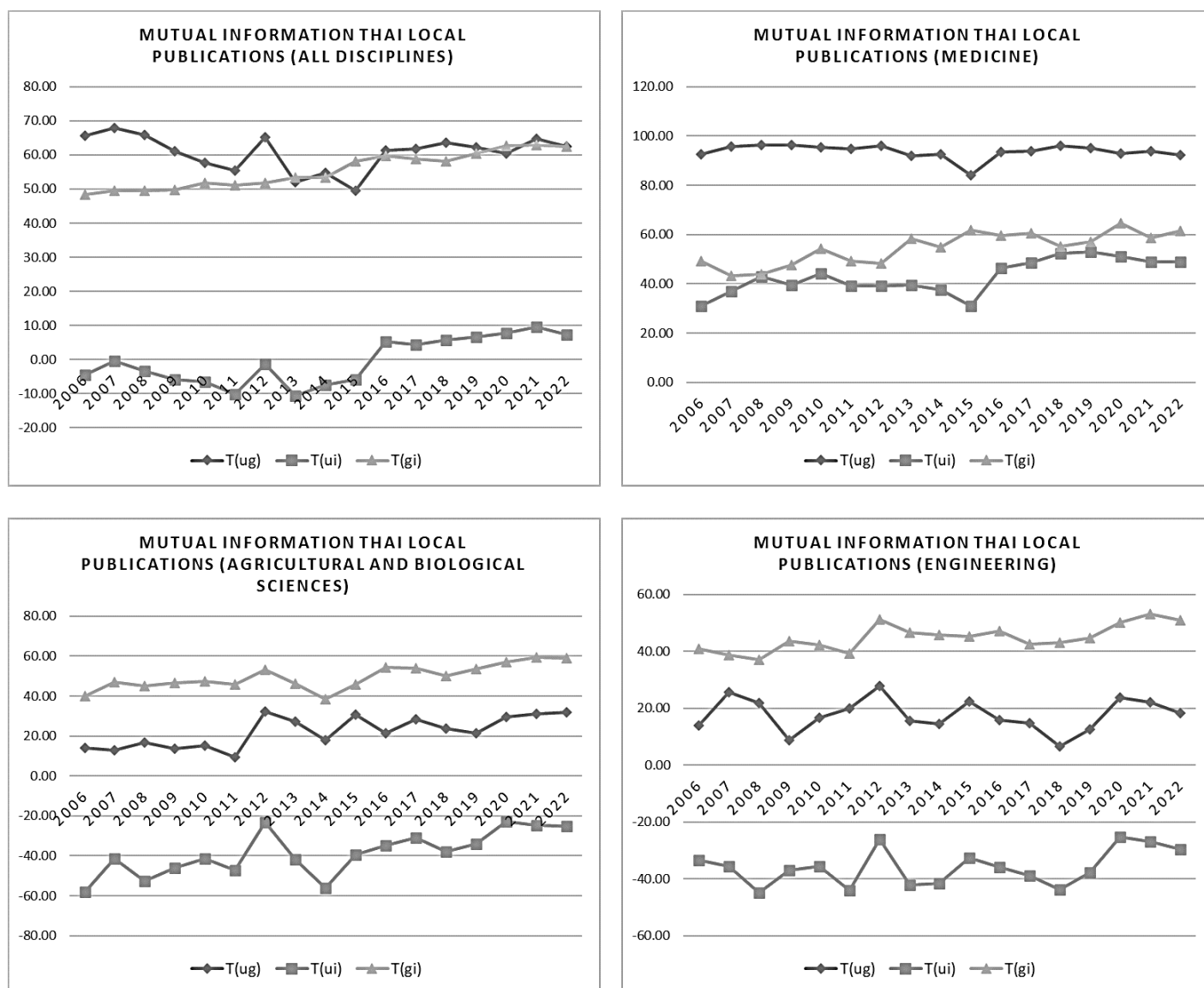
which display much lower synergy. Research collaborations in the field of medicine at the local level are exceptionally vibrant when universities collaborate with government agencies. In all areas except medicine, the T values of University-Industry (UI) interactions are below zero, indicating that university-industry 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 8 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.

### Comparing mutual information in local and international collaborations

Beyond evaluating the synergy of interactions among local sectors, various studies explore these interactions within the context of incorporating international research into the national system. For example, Kwon *et al.*<sup>[29]</sup> observed that the integration of publications with foreign partners into the national research system resulted in increased synergy among local sectors in Korea. To deepen our comprehension of this topic, our study examines T values or the synergies of collaborations between local sectors



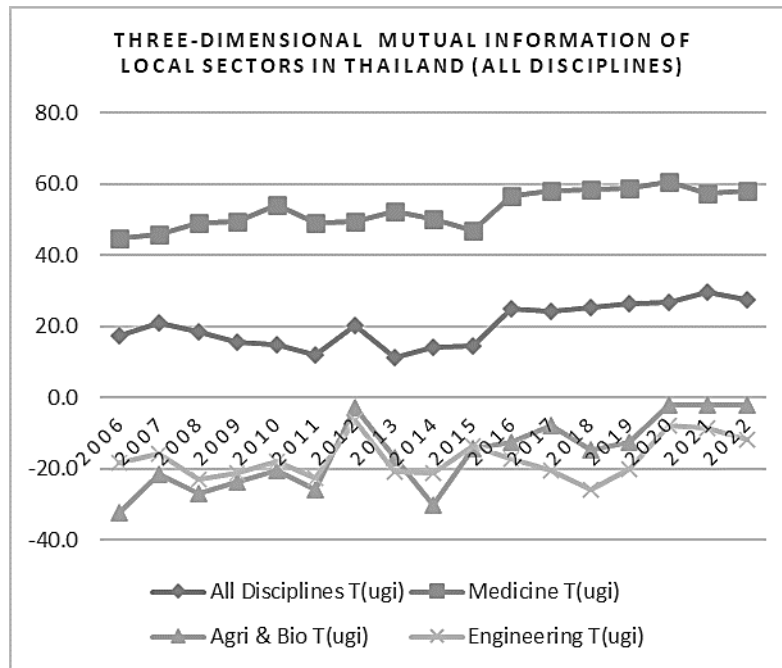
**Figure 7:** The mutual information of domestic collaborations among local sectors in Thailand in all disciplines (top, left), Medicine (top, right), Agricultural and biological sciences (bottom, left) and Engineering (bottom, right).

when incorporating foreign co-authored publications, including those with the United States and China, into the analysis.

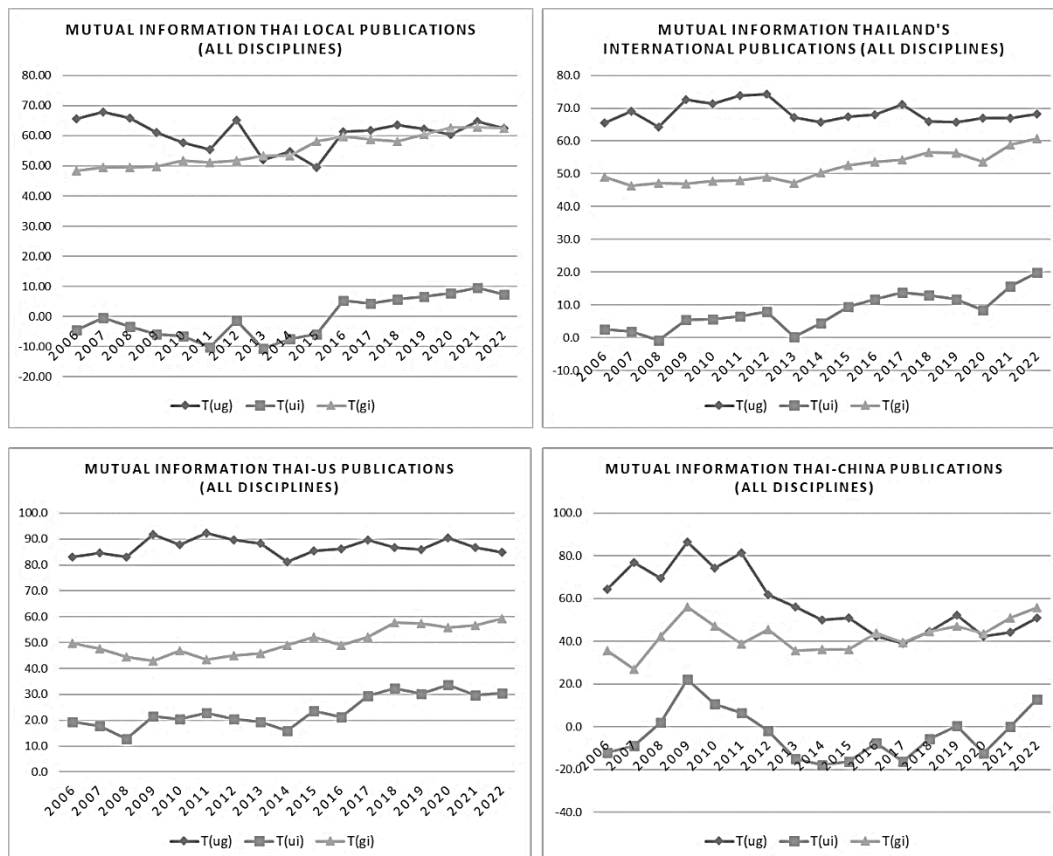
Figure 9 illustrates a comparison of two-dimensional mutual information within local and international configurations. Our findings reveal that the two-dimensional synergy of collaborations between local sectors in both local and international contexts exhibits a relative similarity. Notably, collaborative synergies between University-Government (UG) and Government-Industry (GI) partnerships are more pronounced than those observed in University-Industry (UI) collaboration. When focusing on collaborations with American partners, the synergy of bilateral relationships between University-Government (UG) remains steady, while those between University-Industry (UI) and Government-Industry (GI) show a slight increase. The key distinction is that the majority of Thai-U.S. collaborations predominantly revolve around interactions between Universities

and Government entities (UG). However, in the specific context of collaborations between Thailand and China, the bilateral relationships between University-Government (UG) exhibit a minor decrease in synergy, whereas those between Government-Industry (GI) and University-Industry (UI) demonstrate a slight improvement in synergy. In 2009, the systemness of cooperation between the university and the government was surpassed by government-industry partnerships.

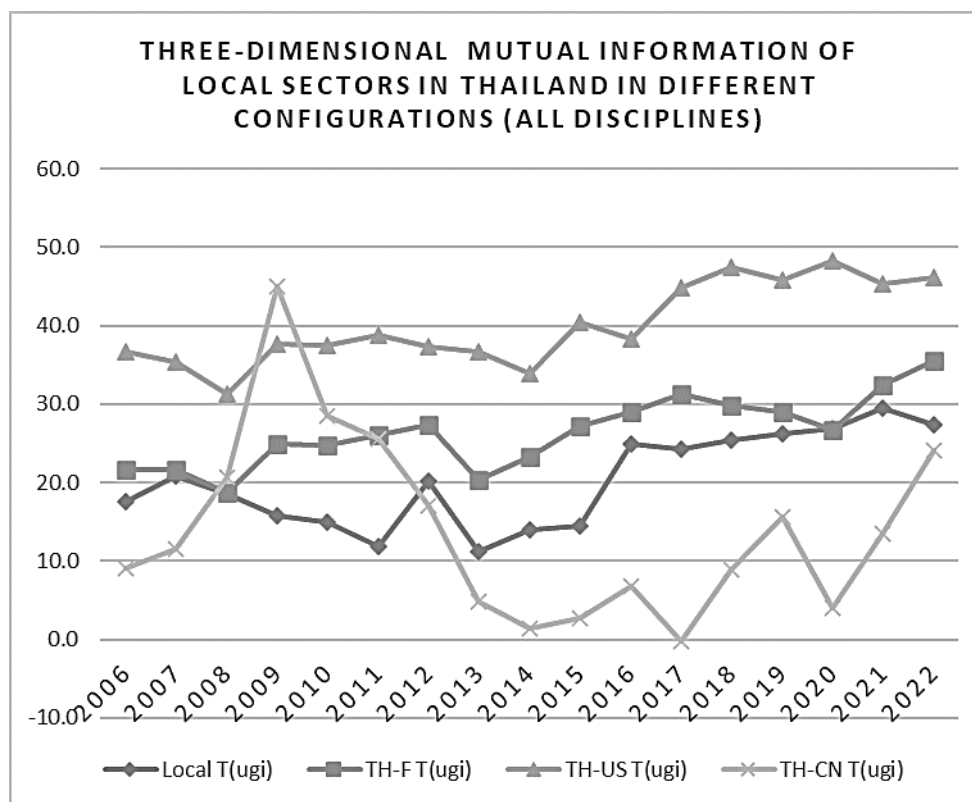
Figure 10 illustrates the three-dimensional synergy among core sectors within the national system, where lower T values indicate a higher degree of integration. Particularly noteworthy is the trilateral mutual information among local sectors, which exhibits the lowest synergy in the configuration of Thai-U.S. collaborations (indicated by the highest T values). This observation may be attributed to the fact that the majority of Thai-U.S. collaborations predominantly involve contributions



**Figure 8:** The three-dimensional mutual information among local sectors in Thailand regarding the generation of domestic publications.



**Figure 9:** The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-US publications (bottom, left) and Thai-China publications (bottom, right) in all disciplines.



**Figure 10:** Three-dimensional mutual information of local sectors in Thailand in different configurations (all disciplines).

from the university-government partnership. In contrast, 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 notably strong, 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 only slightly lower.

Figure 11 indicates that the synergy of interactions among Thai local sectors remains similar when considering both inclusive and exclusive scenarios with international partners. In the field of medicine, the collaboration between Universities and Government agencies (UG) emerges as a crucial factor in collaborations, spanning international and local levels and involving both the United States and China. However, in the context of Thai-China collaborations, the synergies of Government-Industry (GI) and University-Industry (UI) partnerships have experienced rapid growth since 2020, approaching a level of parity with the University-Government (UG) partnership.

The diminishing three-dimensional relationships among local sectors in medicine are evident in Figure 12, with increasing T values over the study period. Collaborations among local sectors are undergoing a decline in synergy over time, both at the local and international levels.

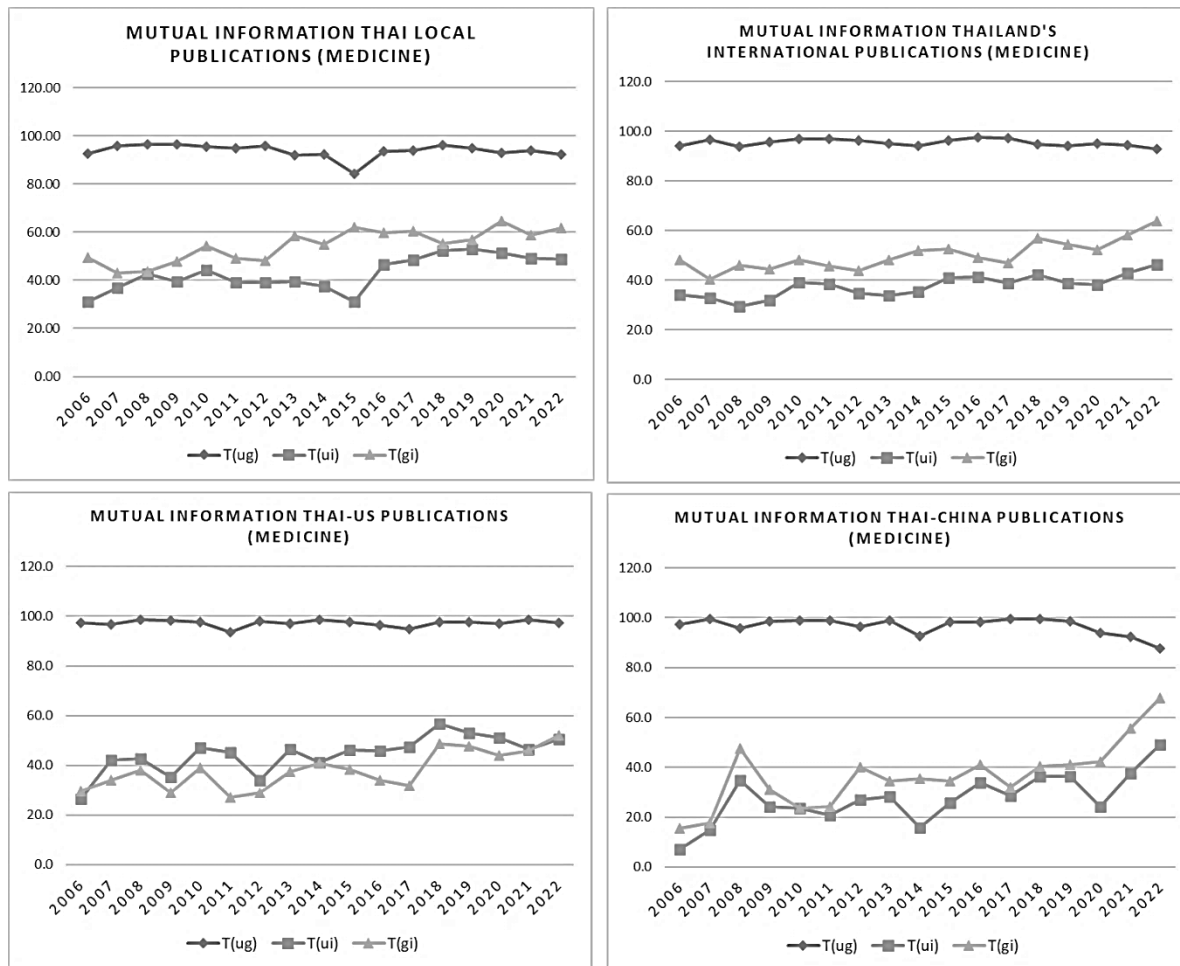
According to Figure 13, the bilateral relations among local sectors in Agricultural and Biological sciences have exhibited an increase in synergy at the local level. Nonetheless, these relationships seem to be losing synergy at the international level, with the exception being the partnerships between Government and Industry (GI), which have become stronger across all levels.

As depicted in Figure 14, an examination of the three-dimensional mutual information of collaborations in agricultural and biological sciences reveals a strengthening synergy among local sectors when collaborating with foreign partners, while it remains stable in collaborations with the United States. However, there is 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 increasing proportion of publications within the university sector, as indicated in Figure 5.

According to Figure 15, 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.

In engineering, the three-dimensional mutual information of local sectors at both the local and international levels remain





**Figure 11:** The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-US publications (bottom, left) and Thai-China publications (bottom, right) in Medicine.

consistent and steady throughout the study period, as depicted in Figure 16.

## DISCUSSION

Our examination reveals a variety of collaboration patterns across different settings and disciplines. The analyses underscore several observations and assumptions that require further discussion. The three main observations for discussion are 1) different patterns of Triple Helix relations among Thailand's local sectors when operating locally versus when engaging with international partners, 2) the varying triple helix synergy for Thai international collaborations with the United States and China, 3) distinctive collaboration patterns in medical science.

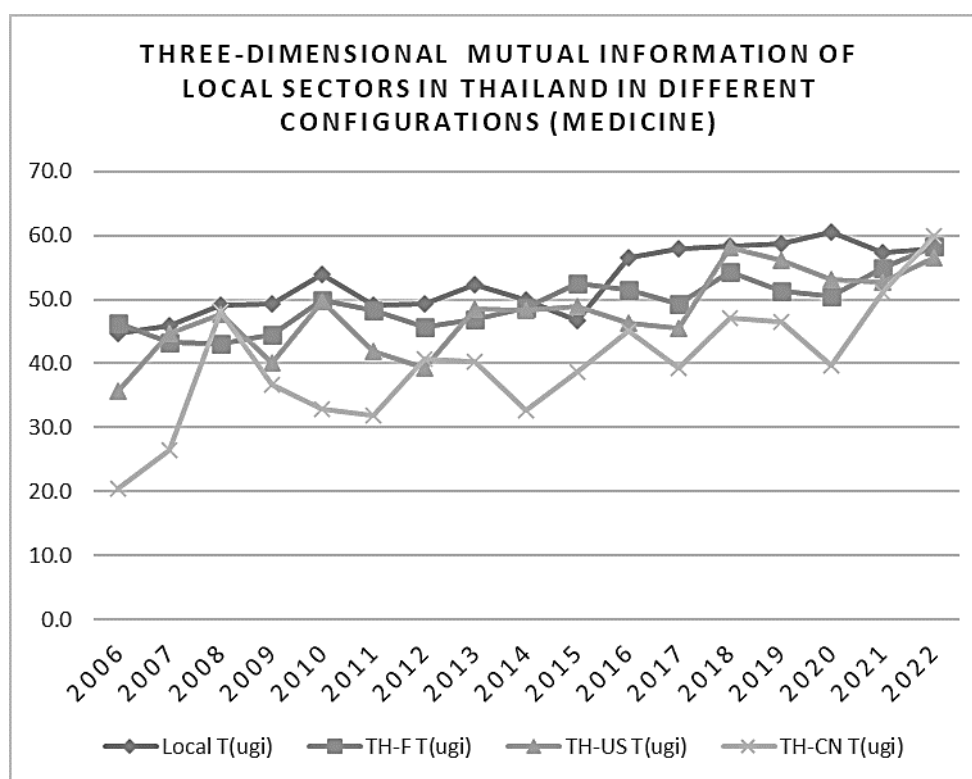
### Triple Helix relations among Thailand's local sectors when operating locally versus when engaging with international partners

The central finding of our study, crucial for addressing our primary question, revolves around the dynamics of the local scientific community when operating locally and when engaging with international research collaborations. Given our assumption

that stronger collaboration among local sectors, universities, government and industry is a key factor in enhancing a country's research and innovation system, ultimately leading to economic development, the envisioned state prioritizes heightened collaboration synergy among local sectors.<sup>[22]</sup> This objective is also mirrored in Thailand's national policy.

We observed that while Thailand experiences a growing level of international collaboration annually, the ratio of local publications compared to international publications has remained relatively stable, fluctuating between 52% and 55%. Nevertheless, when examining collaborations with specific countries, heightened international engagement with certain nations, such as China, may come at the cost of collaboration with other countries.

The mutual information analysis revealed the contribution of international collaboration to stronger Triple Helix relationships in specific ways within local settings. However, while local sectors are increasingly engaging across sectors in research collaborations, this synergy is not consistently mirrored at the national level. This is evidenced by weaker trilateral mutual information values across all disciplines. In our globally



**Figure 12:** Three-dimensional mutual information of local sectors in Thailand in different configurations (Medicine).

**Figure 13:** The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-US publications (bottom, left) and Thai-China publications (bottom, right) in agricultural and biological Sciences.

interconnected society, collaboration with foreign countries has become standard practice. The university, government and industry actively participate in international collaborations, often excluding collaborations with other local sectors. Furthermore, in the context of Thailand, the private sector still lags in terms of involvement in research activities, particularly in the field of medicine and collaborative projects with partners from the United States.

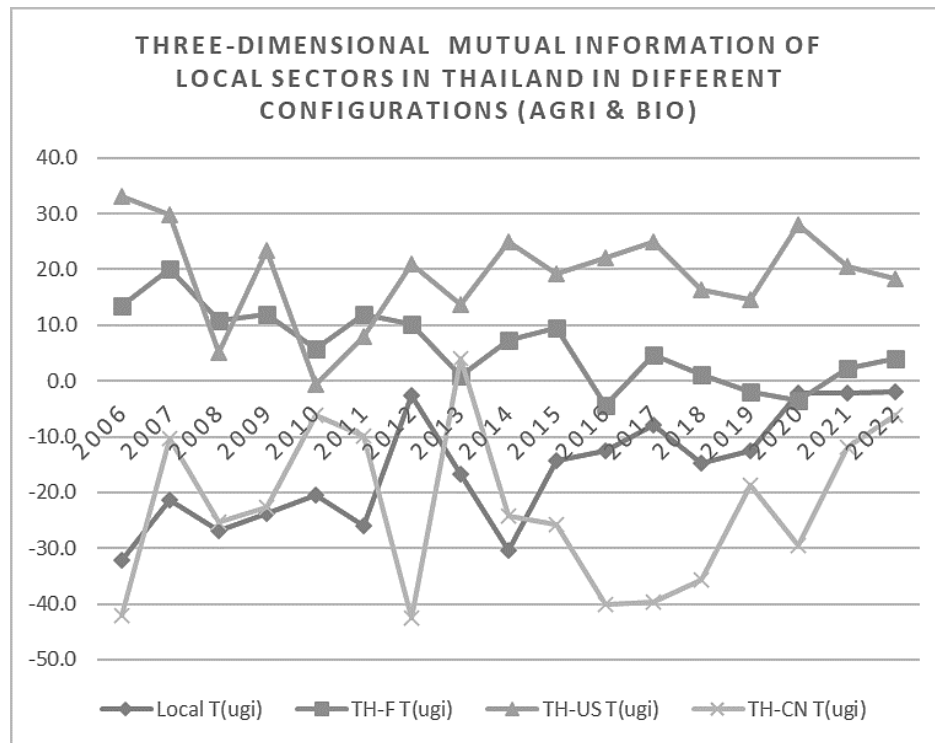
Furthermore, we noticed that international collaboration contributes to stronger bilateral relations between specific sectors. This observation is further elaborated in the following section when we compare Triple Helix relations between Thai local sectors collaborating with the United States versus with China. While collaboration with international partners may result in stronger collaborations between some local sectors, this phenomenon did not necessarily lead to a stronger national Triple Helix relation, which requires strong synergy from all three sectors.

### The trends of Thailand-US and Thailand-China collaborations

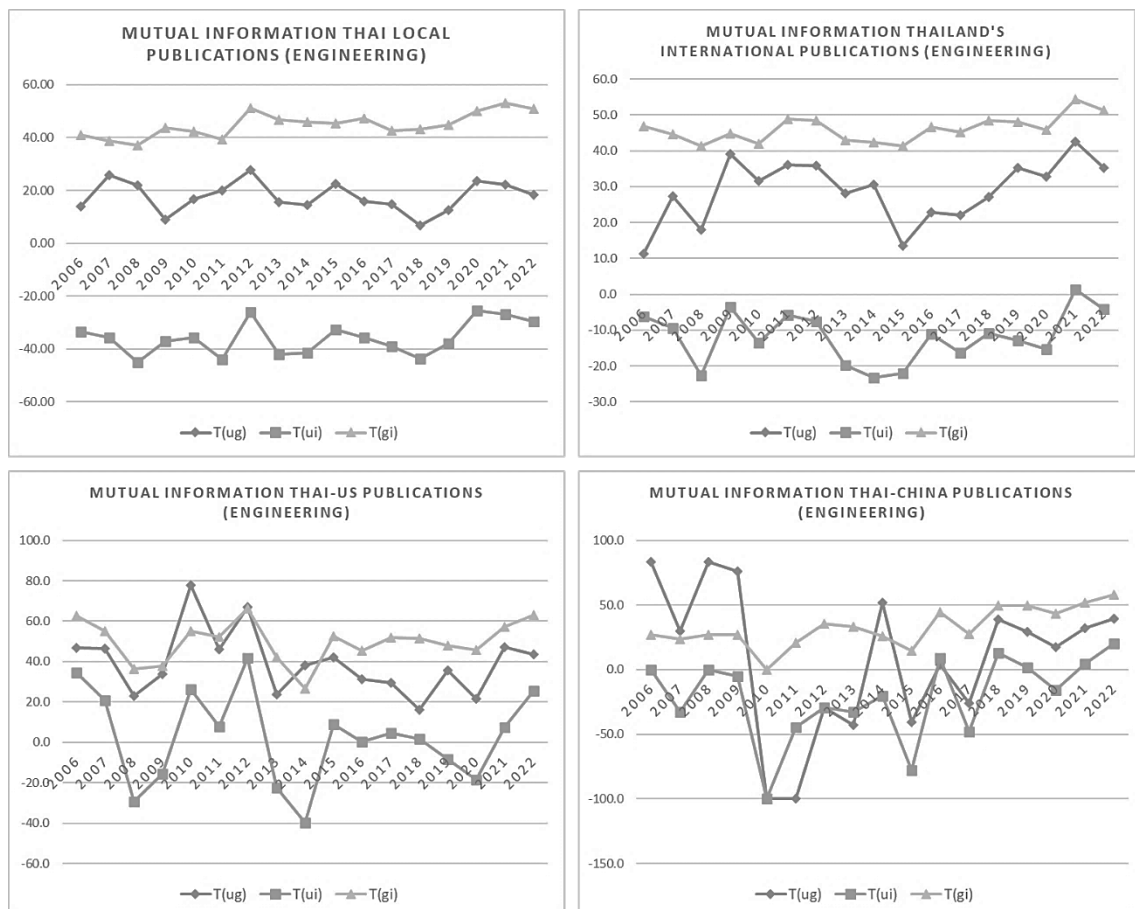
Despite the continuous growth in the number of co-authored publications between Thailand and the United States, as well as between Thailand and China, the proportions present a contrasting

narrative. Over the study period, the proportion of co-authored publications between Thailand and the United States has experienced a decline, whereas the proportion between Thailand and China has seen an increase, with both proportions nearly converging in 2022. China's collaboration strategy has shifted from a predominant focus on Western countries for learning purposes. In recent times, there has been a diversification in China's collaborative landscape, extending partnerships beyond major Western powers. Government-led initiatives, including the Belt and Road Initiative, aim to strengthen ties with nations across Asia, Europe, Africa and Latin America.<sup>[38]</sup> The effort has also impacted Thailand's international collaboration landscape.

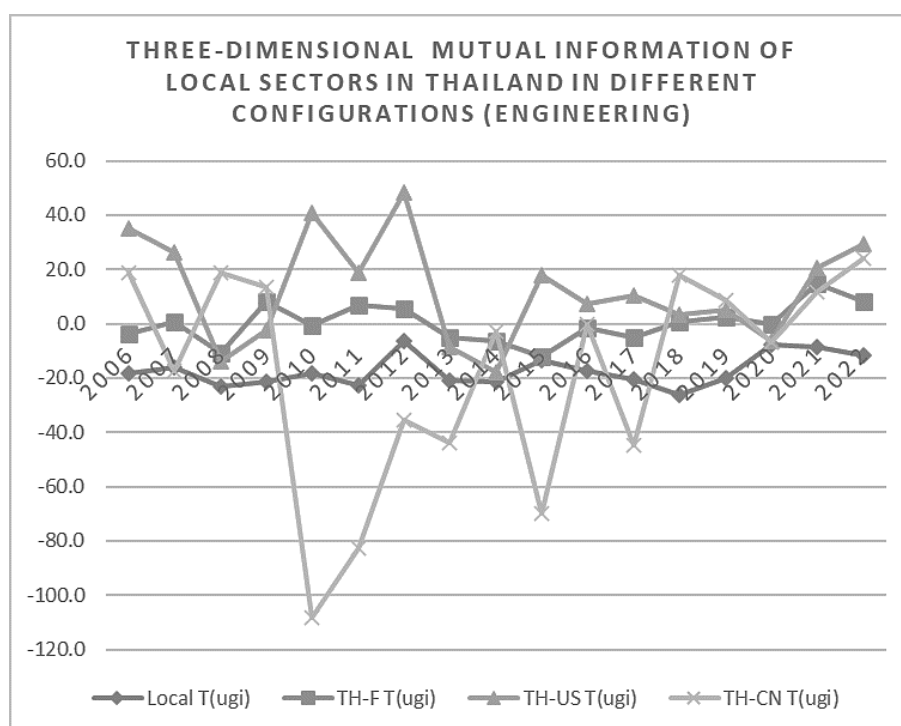
When evaluating the three-dimensional synergy of interactions among local sectors in Thailand, both with and without foreign partners, our analysis reveals that Thailand-U.S. collaboration demonstrates the weakest synergy, while Thailand-China collaboration showcases the strongest synergy among the interactions of local sectors (Figure 10). The diminished synergy in Thailand-U.S. collaborations can be attributed to the predominant roles of universities and government entities, with limited participation from the private sector in collaborations with the United States (Figure 9). In contrast, the Thai private sector plays a more substantial role in collaborations with China



**Figure 14:** Three-dimensional mutual information of local sectors in Thailand in different configurations (agricultural and biological sciences).



**Figure 15:** The mutual information between local sectors in Thailand calculated using domestic publications (top, left), international publications (top, right), Thai-US publications (bottom, left) and Thai-China publications (bottom, right) in Engineering.



**Figure 16:** Three-dimensional mutual information of local sectors in Thailand in different configurations (Engineering).

compared to their involvement in collaborations with the United States.

We observe the remarkable productivity of universities in publishing research papers in all disciplines and collaborative settings. However, a distinct trend emerges in the co-publications between Thailand and the United States. Thai government agencies show a more substantial contribution to co-authored publications with the United States compared to other collaborative settings, resulting in weaker trilateral but stronger bilateral (U-G) Triple Helix relationships. Specifically, in the field of medicine, Thai government agencies have generated a greater number of co-authored publications with the United States than Thai universities. This observation suggests that collaborations with the United States may involve more formal relationships, often facilitated through governmental institutions. This corresponds with Choi *et al.*'s findings,<sup>[24]</sup> indicating that government agencies of less developed countries play a crucial role in collaborating with more advanced nations.

### The unique characteristics of research collaborations in medical science

Upon examining data across various disciplines, our findings reveal a declining trend in the proportions of collaborations between Thailand and the United States in diverse fields, except for medical science. Although there is a slight decline in the proportions of collaborations between Thailand and the United States, they remain notably higher than those with China.

Examining the trend through the lens of the Triple Helix framework using mutual information analysis with domestic publication data, we observe that medical science displays a weaker synergy in three-dimensional interactions among the three local sectors in Thailand (Figure 8) with local collaborations predominantly revolving around partnerships between universities and government (Figure 11). Notably, in the medical sciences, when analyzing the number of publications produced by local sectors in Thailand (Figure 5), universities emerge as the primary contributors to domestic research publications. However, government agencies and collaborations between universities and government entities exhibit high productivity, nearly reaching the level of output seen by universities in terms of publishing publications. This suggests the significance of medical science with potential impact on the Thai population, possibly with limited involvement or insufficient support from private companies for medical research in Thailand. Additionally, the three-dimensional synergies among Thai local sectors in the field of medical science remain consistent, whether foreign partners are included or excluded, indicating minimal influence from foreign partners on shaping the engagement of local sectors in this domain.

### Implications and recommendations

Our study delves into collaboration patterns at both local and international levels, examining the interactions among local sectors in Thailand and the nation's international collaborations with foreign countries, with a specific focus on the United States and China. Moreover, we examine the contribution of



international collaborations to the synergy of local partnerships by analyzing the mutual information within the Triple Helix framework across different collaborative landscapes. The findings from our study offer valuable insights and pave the way for intriguing questions that could shape future research endeavors.

Firstly, the acknowledged rise of Chinese research activities on the global stage is further substantiated by our study. We highlight China's strategic positioning to catch up with leading countries in scientific research, particularly evident in its collaboration with Thailand. Our findings reveal a significant surge in Thailand-China research collaboration across all disciplines, although it falls short of surpassing the United States in the medical field. Additionally, despite starting with a smaller initial count, Thai-China co-authored publications have consistently maintained a higher annual growth rate, particularly since 2006, with a notable increase in the number of such publications around 2017.

Secondly, drawing from Thailand's national science and innovation system, we identify distinctions among scientific disciplines, with medicine standing out as the most distinct in various aspects. This includes the more active role of government agencies and unique collaboration patterns between universities and the government in medical research.

Thirdly, we identify different interaction patterns among local sectors when engaging with partners from the United States and China. The Thai government plays a more important role in collaborations with the United States, while the industry has more access to research collaboration with China. This sheds light on the diverse strategies employed by developing countries like Thailand when interacting with advanced nations such as the United States, as opposed to engaging with fellow developing countries like China, which share similar social contexts. The collaboration pattern uncovered in our study offers guidance for the Thai government in future planning. For instance, the government could bolster support for specific sectors to enhance collaborations in targeted areas. For example, promoting collaboration between government research agencies and universities could strengthen cooperation between Thailand and the United States in the medical field, facilitating the pursuit of discoveries and innovations. Alternatively, incentivizing private companies to participate in national research and collaborate more with other sectors could contribute to the development of a more robust national research and innovation system, given the potential for increased private sector engagement in this domain.

This insight isn't just confined to Thailand; it holds broader implications for other developing countries grappling with similar dynamics. By comparing interaction patterns between local and international partners in other contexts, we could

acquire valuable insights into the underlying mechanisms driving collaboration. Furthermore, delving into project-level analysis can uncover nuanced differences in research conducted by various sectors, providing crucial insights into their impacts on national sustainable development efforts.

Fourthly, we demonstrate the versatility of using different tools in our study. We 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.*<sup>[39]</sup> and Zhang *et al.*,<sup>[40]</sup> 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:

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.

We present observed indicators and provide reasonable explanations for the phenomena. However, actual explanations for the observed patterns could be obtained through qualitative methods such as surveys, interviews and policy analysis. We acknowledge that the analysis using co-citation data may not fully capture the complexity and robustness of the national science and innovation system. This study aims to propose a method for examining an aspect of the system and to provide some evidence for further investigation.

Several additional questions have arisen from this research, warranting exploration in future studies:

- 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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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

## ABBREVIATIONS

**ASEAN:** Association of Southeast Asian Nations; **G7:** The Group of Seven; **BRICS:** Brazil, Russia, India, China, and South Africa; **LMICs:** Low- and Middle-Income Countries.

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