The Triple Helix Interactions among Universities, Industries and Governments: Case of Climate Change Field

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ABSTRACT
The Triple Helix interactions among different institutions have become increasingly important for science and technology development. In this study, we explore the synergic effect of the Triple Helix relationships of universities, industries, and governments in the field of climate change from the perspectives of vertical evolution and horizontal comparison. T indicators are utilized to measure the bilateral and trilateral institutional information transfer quantity based on the Web of Science core collection database from 2001 to 2021. The results indicated that the UIG collaborative innovation system of climate change is basically formed, but the synergic effect has been continuously eroded in recent years. In addition, we focus on a more detailed comparison among different topics and countries. Specifically, the bilateral and trilateral synergetic effects in the United States outperform that of other countries.

KEYWORDS
Triple Helix; Scientific collaboration; University-industry-government interactions; Climate change

INTRODUCTION
With the transition from the “small science” era dominated by independent scientific exploration to the “big science” era of collaborative innovation driven by multiple institutions (Vignieri et al., 2022), such as governments, enterprises, industries, universities, colleges, research institutions, governments, universities and institutions of society, scientific research collaboration has become an important approach to meeting the needs of national strategic development. The key to collaborative innovation lies in optimizing the cooperation system, leveraging the strength of different unites and effectively tackle complex challenges together (Walsh, Murphy, & Horan, 2020).

Climate change is a typical interdisciplinary research field with characteristics of complexity, variety, and comprehensiveness, requiring the integration of knowledge from social sciences, natural sciences, engineering, and technology (Bhaskar et al., 2010; Hellsten & Leydesdorff, 2016; McCright et al., 2013). It is also a global issue that affects the survival and development of humanity. Expanding the channels of interdisciplinary research cooperation and elevating the capacity for multilateral collaboration are contribute to promote the progress of interdisciplinary research on climate change (Rineau et al., 2016; Xu et al., 2016). We focus on the field of climate change, presenting a review of Triple Helix theory and relative literature in the second part, and the research method and data are discussed in the subsequent part. Then, by calculating the Triple Helix indicator, the study aims to analysis the evolution of collaborative processes among different institutions and compare the synergy effect of different research topics and countries. The main results and future research direction are summarized in the final part.

THEORY AND RELEVANT LITERATURE
The Triple Helix Theory, proposed by Henry Etzkowitz and Loet Leydesdorff (Etzkowitz & Leydesdorf, 1995), posits that innovation occur through the interaction and collaboration of three categories of entities: industry, government, and university. The theory emphasizes that it is the competition, collaboration and knowledge exchange among these institutions that drive innovation and growth (Etzkowitz, 1996; Etzkowitz, 2003; Etzkowitz & Leydesdorff, 2000). Loet Leydesdorff proposed the Triple Helix Algorithm based on the theory of information entropy, which quantitatively studied the nonlinear interactive relationship of Triple Helix innovation entities (Leydesdorff, 2003; Leydesdorff & Zhou, 2014). This method has attracted attention and has been widely used to measure the interaction relationships among different institutions. For instance, Kang (2019) measured the systemness of the triple helix relationships of universities, industries, and governments of Beijing and Shanghai, finding the synergy of university-industry cooperation and university-industry-government cooperation has decreased from 2008 to 2017. Similar trends also occurred in Japan, Brazil, Russia, India, China, South Africa, South Korea, and Netherlands (e.g., Leydesdorff & Sun, 2009; Ye et al., 2013; Leydesdorff, 2010; Xu et al., 2013). Zhang (2019) investigated the interactions among Chinese Academy of Sciences (CAS), industries and universities, indicating that bilateral and trilateral interactions not only improved the scientific performance but also the effects of research investments on that performance.

DATA AND METHOD
Data collection
In this research, the Science Citation Index Expanded (SCIE) and Social Science Citation Index (SSCI) are used to search for scientific publications in the WoS database. The keywords including "climate chang*", "climate

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variabilit*", "global warming", and "climate warming" present in the title or abstract are retrieved (Haunschild, Bornmann, & Marx, 2016; Li, Wang, & Ho, 2011; Wang et al., 2014). The time span of data is confined to 2001-2021, and the document types is limited to article and review. As a result, 194,954 publications are collected for analysis. The second step is to extract the information of the Institution and Country/Region by the ITG-Insight software (Wang, Zhang, & Liu, 2021). To reduce the impact of variations in institution names, such as "York Univ" and "Univ York", the text similarity calculation tool in the ITG-Insight is utilized, along with manual verification. The third step is to identify the nature of author's institutions. With reference to the triple helix theory and relevant research (Leydesdorff, 2003, 2012; Choi, Yan, & Park, 2015), the institutions are classified into three categories: universities, industries and governments. Finally, a total of 50,403 institutions and their corresponding classifications are successfully identified.

Method

The previous studies have adopted the information transmission indicator, T value, to measure the amount of mutual information among different institutions (Park & Leydesdorff, 2010; Ivanova & Leydesdorff, 2014). In this way, the dynamic interactions among institutions can be characterized quantitatively (Yoon & Park, 2017). Shannon has defined the information entropy H as the thermodynamic entropy S, where $S=K_B*H$, and $H=-\sum_i p_i * \log_2 p_i$.. K_B is probability entropy, which can increase the uncertainty of the system. In terms of three sets of information H_1, H_2, and H_3, the overlapping part is labeled as T_{123}, the calculation formula is $T_{123} = H_1+H_2+H_3-H_{12}-H_{23}-H_{13}+H_{123}$. When the interactions among the multiple sets is significantly enhanced, the uncertainty in the system will be reduced accordingly. The larger the absolute value of T, the tighter the relationships among them, and the stronger stability of the whole system will be (Shin, Lee, & Kim, 2012).

RESULTS

On the basis of the nature of author's institution, publications are classified into 7 categories, including publications co-authored by the individual institutions (U, I, or G), bilateral collaboration (UI, UG, or IG,) and university-industry-government (UIG) cooperation.

The dynamic synergic effect of the Triple Helix interactions

The number of publications from different categories are shown in Figure 1. In terms of individual output, universities (U) can be regarded as the primary institutions of scientific research, exhibiting a significant exponential growth trend from 2001 to 2021. The number of publications published by governments or industries displayed the logarithmic growth trend and linear growth trend, respectively. From the perspective of cross-organizational border collaboration, it can be observed that collaborative publications between universities and industries (UI) and between universities and governments (UG) both exhibit exponential growth in the number of publications annually. By contrast, the collaborative output between the governments and industries has always been relatively low in terms of quantity. The number of publications jointly authored by the governments, industries, and universities has shown an exponential growth trend. From 2001 to 2021, the number of publications increased from 1,443 to 28,080, reflecting the increasing participation of governments, industries, and universities in collaboration system in the field of climate change.

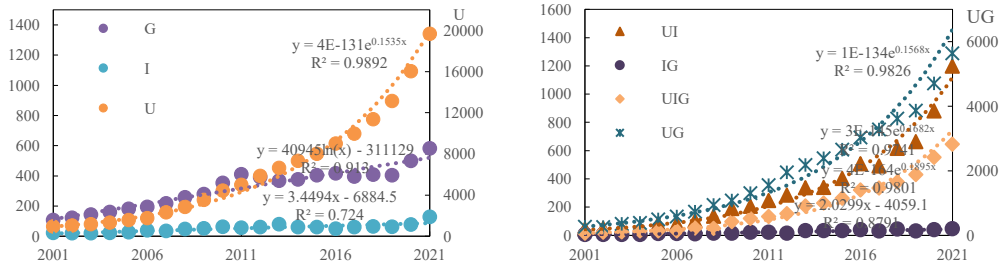

Figure 1. Trends of publications co-authored by various categories (2001–2021).

The in-depth analysis on the bilateral and triple helix relationships of UIG can indicate the dynamic synergic effect of the Triple Helix interactions. As shown in Figure 2, the tightness of university-government bilateral cooperation was decreasing from 2006 to 2021. On the other side, UI and IG bilateral cooperation systems have remained stable in the past 20 years. The values of T_{UIG} from 2001 to 2021 is negative, which shows that the UIG collaboration system of climate change is basically formed. In terms of the longitudinal trend, the tightness of the UIG relationships showed a downward trend, which implies that the synergies of UIG cooperation system eroded by the reduction of synergies in UG cooperation system during this period.

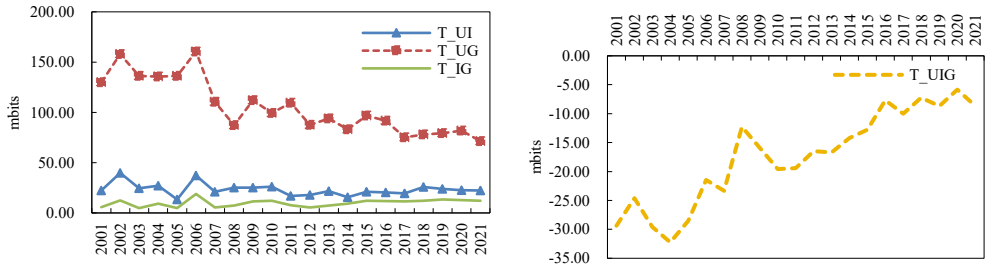

Figure 2. Two-dimensional and three-dimensional information transfer quantity (mbit) of the climate change.

The comparison research of Triple Helix interactions in different topics

The complexity of climate change issues has formed diversified research topics. NMF (Non-negative Matrix Factorization) topic modeling is utilized to analyze the distribution of research topics and scientific research cooperation in various topics (Seung & Lee, 2001). The publications in field of climate change focus on eight topics, including Climate simulation model, Climate technology, Biodiversity, Agriculture, Physical science basis, Paleoclimatology, Climate policy, and Vegetation. According to Figure 3, universities have a significant advantage in the number of publications. The average percentage of publications written by governments (G) is only 3.5%, while industries (I) only 0.49%, about one-seventh of the G. The number of publications co-authored by industries and governments (IG) is relatively low, accounting for only 0.11% of the literature in the Agricultural and 0.34% in the topic of Biodiversity. The percentage of UIG is relatively low, with an average percentage of 2.13%.

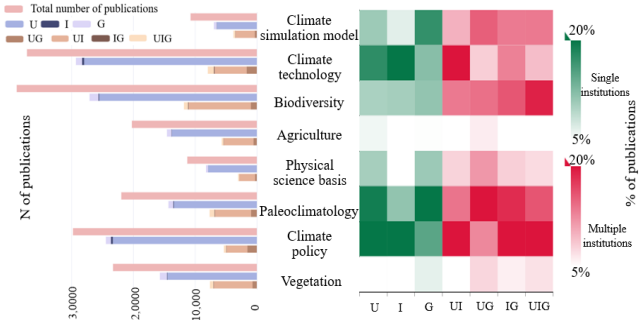

Figure 3. Publications co-authored by various categories of eight topics.

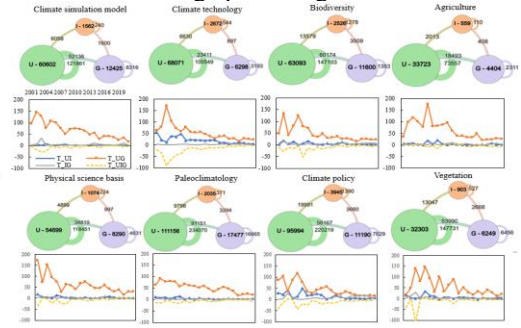

Figure 4. The triple helix cooperation network and the longitudinal trends of T values for eight topics.

The governments, universities, and industries focus on different topics. Climate technology is highly associated with energy, emissions, and pollution. The majority of outputs come from universities, while the participation of governments is relatively low. However, industries have a higher enthusiasm for participating in scientific research in the Climate technology. In the Climate Simulation Model and Vegetation, the participation of governments is relatively higher than U and I, and the percentage of publications written by G, UG, IG, and UIG is larger than other topics, which indicates that more governments are willing to participate in research and analysis climate models and vegetation. The topic of Biodiversity has the highest percentage of publications co-authored by UIG than the other topics, indicating that the issues related to biological diversity have aroused widespread attention of government, industries, and universities. The studies focus on Paleoclimate mainly comes from cooperation between the governments and universities.

There are significant disparities in the T values of institutional collaborations among the eight topics. Figure 4 presents the sketch maps of the triple helix cooperation network and the evolution trends in various topics. The T_{UI} values and T_{IG} values of Vegetation and Paleoclimatology are higher than the others, while the T_{UG} values of Agriculture are higher the others. Synergic effect of the triple helix relationships of Climate technology demonstrates a strong performance in the early stage (Figure 4). The trend of T values of paleoclimatology is stable, with a low three-dimensional information transfer quantity, which indicates to a certain extent that the efficient cooperation system has not yet formed. In addition, T_{UG} values of Agriculture, Vegetation, Physical science basic, Climate technology and Biodiversity fluctuate within 180-50 mbits (millibits) of information in the early stage, but the synergy effect gradually weakened in the middle stages and recent years.

The comparison research of Triple Helix interactions in different countries

This section illustrates the research collaboration situation of the top eight countries in terms of publication quantity. The institutions with the highest publications in every country are universities, with a proportion ranging from 41.63% to 74.22%, among which China has the highest proportion of U publications. The proportion of publications published by governments (G) is higher than industries (I), indicating that universities and government agencies in various countries are more actively involved in producing research in the field of climate change compared to industries.

Country	N	$U_{(\%)}$	$I_{(\%)}$	$G_{(\%)}$	$UI_{(\%)}$	$UG_{(\%)}$	$IG_{(\%)}$	$UIG_{(\%)}$
USA	58,851	62.32	0.59	2.86	4.19	25.77	0.42	3.86
China	31,276	74.24	0.06	0.72	2.72	20.79	0.04	1.42
UK	25,623	60.71	0.68	2.03	5.94	25.15	0.2	5.29
Australia	16,319	64.85	0.15	1.65	3.65	25.31	0.06	4.32
Germany	18,622	59.47	0.59	1.67	4.43	28.32	0.15	5.37
Canada	15,219	57.68	0.24	4.23	3.11	30.1	0.24	4.4
France	12,190	42.3	0.29	4.61	2.66	43.43	0.28	6.44
Spain	10,382	54.79	0.16	2.85	3.71	33	0.16	5.33

Table 1. Publications Co-authored by Various Categories in Eight Countries.

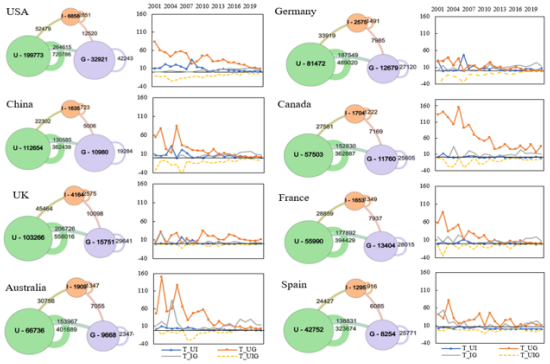

Figure 5. The triple helix cooperation network and the longitudinal trends of T values for eight countries.

In terms of cross-organizational border cooperation, the publications of UG in France, Finland, Norway, Switzerland, and Japan account for over 35%, indicating the close relationships between the governments and universities in these countries. There are relatively few cooperations between industries and governments, which shows the cooperation mechanisms are not yet mature (0.02%-0.41%). The proportions of trilateral cooperative publications in different countries do not beyond 10%. The proportions of UI publications in the United States, China, and the UK are higher than the UIG category. The proportion of UI publications (5.9%) in the UK ranks the first in the country list.

Figure 5 allows us to focus on the different dynamics in different countries. In the United States, the dynamics changed profoundly during 2016-2021 is compared with 2001-2015. Universities were encouraged to conduct in-depth and broaden cooperation with governments, strategic alliances were established, and the synergic effect of the triple helix relationships was promoted gradually. In recent years, UG, UI and UIG relations became less synergetic. Canada and Austria presented strongly integrated systems in terms of UG co-authorship relations in 2002 and 2005, but rapidly decreased afterward. Germany presents greater volatility in terms of T_{IG}, with the lowest degree of trilateral synergic effect. China has not yet reached a good level of coordination, even occurred positive in the early stage.

CONCLUSION

Faced with the global challenge of climate change, it is crucial for the governments, industries, and universities to form a collaborative innovation system, which can help to promote sustainable development of global scientific and technological innovation. Based on the Triple Helix theory, this study analyzed the fundamental characteristics of scientific research cooperation in the field of climate change, as well as the situations of scientific research the bilateral and trilateral collaboration. On the one hand, the trends of triple helix interactions among them are presented clearly by the longitudinal time-series analysis. On the other hand, we compared the synergic effects of the Triple Helix relationships from the perspectives of country and topic, respectively. The following results can be obtained:

First, in terms of individual output, universities are the most vital innovation units, thereby reflecting their importance as the main source of scientific knowledge production. Although independent knowledge innovation in the governments has developed rapidly, they are still at a disadvantage in terms of publications compared with the universities. Industries are more likely to focus on the application and protection of innovative outputs, resulting in insufficient attention on basic research. In terms of cross-organizational collaboration, the publications co-authored by different units have been stably increasing. The collaboration between the governments and universities is the most frequent, followed by UI and UIG. The number of collaborative publications co-authored by industries and governments is relatively few in recent two decades. Both T_{UI} and T_{UIG} represent the same trends of fluctuating decline, while T_{UG} and T_{IG} remain stable.

Second, after comparing the UIG bilateral and trilateral collaborative networks of eight topics, we find industries are more focused on Climate technology, while universities pay more attention to Paleoclimatology. UIG scientific collaboration system is pay more attention to Climate policy and Biodiversity. In terms of vertical time series analysis, the T_{UG} values of almost all topics show the trends of climbing in the early stage and descending subsequently, except for Physical science basis. T_{UIG} values have not yet reached a good level, even occurred positive in the early stage.

Third, the synergic effect of most countries shows a long-term trend of weakening. Specifically, the United States has the highest number of publications and frequency of collaborations in the field of climate change, with a high level of the university-government relationship, which is resulted from the encouragements about conducting in-depth and broaden cooperation among different institutions (Kang et al., 2019). Canada and Austria presented strongly integrated systems in terms of UG co-authorship relations in the early stage, but rapidly decreased afterward.

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