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Measurement Methods and Application Research of Triple Helix Model in Collaborative Innovation Management

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Abstract: In the knowledge economy era, the innovation body is formed into Government-Industry -Academy collaborative innovation pattern, which can be described by triple helix model. What's more, triple helix model can better serve the scientific and technological innovation management. Although a variety of triple helix measurement methods have been applied into evaluation practice, these methods have their own drawbacks. In this paper, we conducted an in-depth analysis on the current principal methods based on mathematical characteristics. Combined with empirical analysis, we expect to form a comprehensive utilization pattern of different methods. This paper discusses the theory development of triple helix model with a focus on measurement methods, which are method based on mutual information and method cooperation similarity respectively. In this paper, we summarize the application scope of triple helix model by means of output of scientific papers, and bring technology transfer organization (TTO) into the triple helix innovation dimension, which can provide the triple helix model with exogenous motivation. Finally, we make a discussion on the future improvements of the triple helix model.
Keywords: Collaborative Innovation; Triple Helix Model; Government-Industry-Academy; Agency Cooperation

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1. Introduction

The Triple Helix innovation model of University-Industry-Government Relationship is first proposed by Etzkowitz from United States and Leydesdorff from Netherlands in 1995 (Leydesdorff and Etzkowitz 1996). The Triple Helix model mainly describes the cooperative relationship among research institutions, industry and government in promoting innovation in the era of knowledge economy. In the Triple Helix model, research institutions, industry and government are both independent and interacting. Researchers can become entrepreneurs by implementing technology developed by themselves, while entrepreneurs can also work in university labs or technology transfer agency; public sector researchers can spend time working for companies, and research institutions and industry researchers can manage regional institutions for technology transfer, and so on (Fang 2004). Countries or institutions with a high coordination degree can contribute to efficient innovation output, and facilitate the effective transfer and transformation of innovations to achieve a virtuous circle of innovation activities. Therefore, how to carry out a quantitative evaluation of collaborative innovation at the level of both nations and agencies, the degree of collaborative innovation and the trends of monitoring targets in terms of the triple helix model is significant to maintain high innovation efficiency for countries and institutions. Meanwhile, the monitoring of the collaborative innovation degree is significance in finding the shortages of innovation chains and cruxes of countries or agencies, and further improving or amending management systems and policies. In particular, it is significant in improving the low conversion rate of scientific research achievements.

Based on the theoretical analysis, this paper focuses on studying measurement methods and applicability of the existing triple helix collaborative model. Then combined with empirical analysis, we can get comprehensive and in-depth understanding of various methods. Then we can better utilize different methods to obtain a more objective measurement results and give recommendations related to the usage of the model.

2. The measurement and application of triple helix model

2.1 The theoretical research of triple helix collaborative innovation

The social background of triple Helix model proposed is the changing of innovative models and innovative bodies in the era of knowledge economy. Complex interactions among government, industry and research institutions have existed before the triple helix innovation model is proposed. And the triple helix model is just the fine expression for that phenomenon, which can capture the multiple linkages among main innovations in the process of knowledge capital. Both developed and developing countries can use this model to understand the interactions among universities, industries and governments of various levels and explain their developments and changes of innovation systems (Qi and Wu 2007). In the era of knowledge economy, there has been no doubt in technological innovation's irreplaceable role in promoting economic growth. In order to maintain a steady stream of creativity, the relevant countries or regions must form a virtuous cycle, in which the scientific and technological innovation can promote industrial upgrading, and industrial applications give feedback to research and innovation. Main innovations were previously led by businesses or research institutions, but now it is tripartite participation pattern composed by government, industry and research institutions. This forms an interactive collaborative innovation of University-Industry-Government.

Etzkowitz emphasizes that the changes of university functions are essential to the forming of triple helix model. In the era of knowledge economy, universities' function is far beyond teaching and research. Many universities have first-class laboratories and undertake important national scientific and technological projects, and these universities are indispensable to promote scientific and technological innovation. Etzkowitz also stressed that an entrepreneurial university is the development motivation of University-Industry-Government triple helix and university should take a proactive approach in the application of knowledge and increase investment in knowledge creation. Some scholars in our country also conducted theoretical studying on entrepreneurial universities' role and building ideas in the triple helix (Li, etc. 2010; Han 2010). But the enhancement of university's innovative role and the construction of entrepreneurial university are only a sufficient condition for the formation of the triple helix model. The successfully established sign of the triple helix model is the formation of a variety of (bilateral or trilateral) mixed organizations and institutions. The mixed organizations are also known as interface organizations, which are within the overlapping regions of the triple helix's bilateral or trilateral areas. Interface organizations can influence innovation activities because of many of their important roles such as coordinating, conflict resolution, cooperation program selection and stabilization through their carrier and centrality feature. (Pan and Yin 2009).

Liu describes the triple helix model as well as their role, arising problems and relationship of three elements, which is appropriate for China currently. Liu also analyzes the methods and effects in scientific and technological achievements transformation in Chinese Academy of Science based on the triple helix model (Liu 2011). Some scholars (Shi 2010; Zi, etc. 2009) consider the triple helix provides an ideal model for the cooperation among university, industry and government, which reflects the nature and requirements of their cooperation. The triple helix has division and crossover, making up for the deficiency of simple binding in original GUI modes. Chengjun Wang described researches as the triple helix of University-Industry- Government which has been quite thorough internationally, but in China study on this field is still in its infancy stage. Wang also introduced a normalized quantitative research, conducted a triple helix algorithm after the data mining from SCI2000, and carried out a comparative analysis of the corresponding countries (Wang 2007).

2.2 Measurement methods and empirical research of triple helix collaborative innovation

It has aroused the interest of many researchers since the triple helix collaborative innovation proposed. Those researchers continue to interpret and improve the theory and apply it to innovation management research in different countries, institutions and fields. Park et al. elaborated on the Triple Helix model for measuring the emergence of a knowledge base of socio-economic systems. The knowledge infrastructure was measured using multiple indicators: webometric, scientometric, and technometric. They employed this triangulation strategy to examine the current state of the innovation systems of South Korea and the Netherlands. These indicators were thereafter used for the evaluation of the systemness in configurations of university-industry-government relations (Park et al. 2005). The interaction among the three sub-dynamics of economic exchange, technological innovation, and institutional control could be captured with a generalized Triple Helix model. Leydesdorff et al. proposed to use the information contained in the configuration among the three sub-dynamics as an indicator of the synergy in a configuration (Leydesdorff, etc. 2006). Using the University–Industry–Government relations and the International Co-authorship Relations, Leydesdorff et al. studied the National and International Dimensions of the Triple Helix in Japan (Leydesdorff, etc. 2009). Shin et al. analyzed the research productivity of Saudi academics using the triple-helix model. In the analysis, they combined domestic and international collaboration by three sectors—university, industry, and government—according to the model of the triple-helix (Shin, etc. 2012). Kwon et al. traced the structural patterns of co-authorship between Korean researchers at three institutional types (university, government, and industry) and their international partners in terms of the mutual information generated in these relations (Kwon, etc. 2012). The agricultural innovation systems of two Northeast Asian countries—Korea and China—were investigated and compared from the perspective of triple helix innovation (Kim, etc. 2012). Hossain et al. mapped the emergence dynamics of the knowledge base of innovations of Research & Development (R&D) by exploring the longitudinal trend of systemness within the university-industry-government relations in Bangladesh on the TH model (Hossain, etc. 2012). Swar et al. investigated the IT outsourcing knowledge infrastructure from a network point of view by using triple helix indicators and social network analysis techniques (Swar, etc. 2013).With the theme class clusters, technology roadmap and semantic Triz method, Zhang, etc. analyze the research cooperation of dye solar cell field in China (Zhang, etc. 2014).

Yimin Zou Preliminarily summarized indicators used to measure the collaborative innovation of triple helix model (Zou and Zhang 2013), which include mutual information (Leydesdorff 2003), ψ coefficient and partial correlation coefficient (Sun and Negishi 2010) and indicators based on vector space model, etc. (Priego 2003). In addition, the relevant indicators of social network analysis and patent analysis have also been used in the scientometric analysis of the triple helix.

We think Mutual information, the correlation coefficient/partial correlation coefficient and vector space model can measure the collaborative innovation degree of the triple helix, but their principle is different. Measure ways of ψ coefficient, partial correlation coefficient and social network analysis are all similar to vector space model. They all are based on government, industry and academia collaboration ratio, in other words, these measurement method are all based on cooperation similarity. However, the mutual information indicates the relationship of two random variables, which is the information amount one random variable contained by another, which also can be expressed as one the uncertainty reduction of one random variable since the information known another. Therefore, from this perspective, the mutual information expresses a correlation or synergistic relationships from another point of view with the cooperation similarity way. Therefore, this article will divides the existing measures of the triple helix into two categories: indicators based on the mutual information and cooperation similarity respectively.

2.2.1 Measurable indicators of the triple helix based on the mutual information
Innovation system consisting of Government - Industry - Academy is a typical complex system with uncertainties. Leydesdorff believes that uncertainty and integrity of the system can be displayed by the mutual information of three subsystems. The mutual relationship of the three subsystems can be seen as a relative frequency distribution, while the mutual information can be calculated by entropy proposed by Shannon. Shannon entropy and its use in the measure of the triple helix will be made a brief introduction in the following text.

Shannon defines entropy as the occurrence probability of discrete random events. The bigger the uncertainty of events, the bigger the entropy value is. That is to say the more orderly the system, the lower the entropy is. The evolution model of the triple helix system has brought negative entropy for the entire system, and negative entropy's generation can explain the network's self-organization due to lack of central coordination. Therefore, the system can be better self-updated, self-driven in the triple helix evolution model (Wang, etc. 2006). In the case of one variable, the entropy is calculated as follows:

$$H_i = -\sum_i p_i \log p_i \qquad (1)$$

Among them, H_i is the value of entropy, and the unit is bit. p_i is the probability distribution of the i event.

In the case of two variables, entropy is calculated as follows:

$$H_{ij} = -\sum_i \sum_j p_{ij} \log p_{ij} \qquad (2)$$

Among them, p_{ij} is the joint probability distribution of *i* and *j*.

Abramson indicated that T_{ij} is the uncertainty of information transmission between two interactive subsystems, which can be calculated by Formula (3) and called Abramson and Theil decomposition algorithm (Abramson 1963). The decomposition method takes advantage of mutual information calculation of subsystem variables. Formula is as follows:

$$T_{ij} = H_i + H_j - H_{ij} \quad (3)$$

It can be seen that, when two subsystems interact, its uncertainty will increase as the uncertainty（$H_i + H_j$） of each variable increases. Meanwhile, it will decrease as the uncertainty（H_{ij}） of the interaction between the two increases. Uncertainty of information transmission（T_{ij}） between the two variables is non-negative, if and only if both variables are identical to zero.

When three subsystems interact, Abramson also gives its calculation methods of mutual information:

$$T_{ijk} = H_i + H_j + H_k - H_{ij} - H_{ik} - H_{jk} + H_{ijk} \quad (4)$$

It can be seen that the bilateral relationship can reduce uncertainty of system, while the trilateral relationship increases uncertainty of the system. Specific to the Government-Industry-Academy (GIA) relations in the triple helix, the collaborative information could be expressed as:

$$T_{uig} = H_u + H_i + H_g - H_{ui} - H_{ig} - H_{ug} + H_{uig} \quad (5)$$

The formula (5) can measure the degree of collaborative innovation based on triple helix model. Obviously, when there is no intersection of three subsystems, their collaborative information is zero.

Data analysis needed for mutual information index calculation can be obtained through various ways. It can be simply GIA's cooperation data, or it could be cooperation fact reflected through co-authored scientific papers or jointly applications patents. Since either co-authored paper or jointly application patent is important manifestation of institutional collaboration innovation, what's more, the data is readily available, so they often are used as sources of analysis data. Yu Shan (Yu 2013) and Ye (Ye, etc. 2013) retrieved data from Web of Science database and analyzed the institution's cooperation feature respectively. However, the search queries have some defects, for the government agencies usually do not appear in the column of the author affiliation, but mostly appear in the form of government funding. Thus, by retrieval the co-occurrence of GIA three subsystems to get the basic analysis data, there certainly will lead to deviation. In addition, in the current analysis of the triple helix model, the research institutes generally seen as government sector, which is unreasonable. In the triple helix model, with organization and control functions, government should ensure stable contractual relationship of tripartite interactions and exchanges. The main function of the industry is wealth production, while the university's function is to create new knowledge and technology. Seen from the relationship between government, industry and research institutions, the institutions' commitment is mainly knowledge creation and technology development, which is similar as a university.

Therefore, Academy dimension in this paper include both university and research institution. In actual measurement operation, Web of Science database contains papers from universities or research institutes, enterprises and government. We use the statistic value of different cooperation papers as basic data, and further make a calculation to indicators of collaborative innovation of the triple helix (see details in the next section). The calculation results could be used as the reference to the collaborative innovation of the triple helix.

2.2.2 Measurable indicators of the triple helix based on the cooperation similarity

Measurable indicators of the triple helix based on the cooperation similarity include a variety of specific forms of manifestation, such as ψ coefficient and partial correlation coefficient, vector space model and the social network model. The common ground of these models is that all these indicators are calculated based on cooperation rate of Government - Industry - Academy.

Sun and Neiishi proposed that using ψ coefficient and partial correlation coefficients to measure status of the triple helix innovation system is easier to calculate and expand. Ψ coefficient is used to analyze bilateral relations, and is calculated by Pearson product-moment correlation coefficient. The formula is as follows:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - Y)}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \tag{6}$$

The range of ψ coefficient unlike mutual information, whose range is limited to [-1, 1], it also makes it reflect more detailed information of bilateral relations (Martynovich 2011).

Vector Space Model (VSM) is a binary matrix, and a record can have several variables. VSM describes features of an object by a general form with a number of vectors and uses multiple co-occurrence relationships vector to calculate their similarity. Therefore, we consider synthesizing multiple variables, and then calculate the distance or similarity (various correlation coefficients) to obtain clusters between subjects. Priego proposed a new index using vector space model measure the relationship of the triple helix model. VSM takes a variable as a vector. The similarity of the two vectors are calculated by cosine functions, and range is within [0, 1].

3. Comprehensive measurement

3.1 Measurement methods

The principles of measurable indicators of the triple helix based on the mutual information and cooperation similarity is different, so there is discrepancy between the two results. This paper proposed a comprehensive evaluating method of combination multi-indicators, which can find the features while the single index cannot and also avoid errors evaluating only by single one indicator. Then, it is possible to obtain more comprehensive and accurate information. The analysis procedure can mainly be divided into two steps. Firstly, according to the measurable indicators of the triple helix based on the mutual information and cooperation similarity, we calculate the collaborative innovation degree of the triple helix, and analyze their results respectively. Secondly, we conduct a contrastive analysis, and compare the results of two measurement types, including similarity and difference, strong and weak correlation and also other aspects of the data to be evaluated on the collaborative innovation degree, in order to get a comprehensive assessment.

3.2 Measurement indicators

This paper uses papers recorded retrieved from Web of Science as our analysis data. Therefore, in the measurement of the degree of collaboration in this article, papers participated by government mean papers funded by government. In the process of measurement of collaborative innovation degree, the critical step is the extraction of intermediate variables and conversion of measure variables.

- Intermediate variables are those can be directly extracted from bibliographic data.
- Measure variables are those can be directly used to calculate the degree of collaborative innovation.

Through Thomson Data Analyzer data processing software, we write regular matches scripts and extract seven intermediate variables (Table 1).

Table1 Intermediate variables and extraction methods

Variables	Meaning	Extraction methods
A0	Number of papers published by academy	Author Affiliation includes UNIV*、COLL*、ACAD* or NIH*. Create a data subset: A0.
I0	Number of papers published by industry	Author Affiliation includes GMBH*、CORP*、LTD*、AG* or INC*. Create a data subset: I0.
G0	Number of papers funded by government	The dataset includes mark of Funding Organization. Create a data subset: G0.
AI0	Number of papers co-published by academy and industry	Author Affiliation includes both A0 and I0. Create a data subset: AI0.
G0A	Number of papers	Extracts subset involved academy

	funded by government and published by academy	from G0. Create a data subset: G0A.
G0I	Number of papers funded by government and published by industry	Extracts subset involved industry from G0. Create a data subset: G0I.
G0IA	Number of papers funded by government and co-published by academy and industry	Extracts subset involved industry from AG0, or extracts subset involved academy from IG0. Create a data subset: G0IA.

We obtain calculation variables on the basis of intermediate variables (Table 2).

Table2 calculation variables and extraction methods

Variables	Meaning	Calculation formulas
A	Number of papers published only by academy	A=U0-UI0-UG0+UIG0
I	Number of papers published only by industry	I=I0-UI0-IG0+UIG0
G	Number of papers published only by government organization	G=G0-IG0-UG0+UIG0
AI	Number of papers co-published only by academy and industry	AI=Ul0-UIG0
GI	Number of papers funded by government and published only by industry	GI=IG0-UIG0
GA	Number of papers funded by government and published only by academy	GA=UG0-UIG0
GIA	Number of papers funded by government and co-published only by academy and industry	GIA=UIG0

Now we already obtain several calculation variables listed in Table 2. Combined with formulas (1) - (5), we can write a procedure, or we can also select the triple helix model software tool developed by Leydesdorff to achieve (Leydesdorff 2014).

4. The empirical analysis

4.1 Data sources and analysis tools

In recent years, biomedicine has become the world's most dynamic and fastest growing industries. Biopharmaceuticals is a large class of drugs obtained by using organisms, biological tissue or organ and other ingredients, and it integrated use principles and methods of biology, biochemistry, microbiology, immunology, physical chemistry and pharmacy. Research and industry information services related to biomedical have also become a hot area with rapid growth. Biological drugs can be divided into four sub-categories: genetic engineering drugs, antibody engineering drugs, blood products drugs and vaccines. Among them, vaccine is formulations for prevention, diagnosis and treatment produced by microorganisms or their toxins and enzymes, human or animal's serum and cells, etc. Vaccines can be divided into: inactivated vaccine, live attenuated vaccines, toxoids and vaccines (including subunit vaccines, combination vaccines, synthetic peptide vaccines, genetically engineered vaccines, etc.).

We select the core collection of Web of Science, index database includes: SCI-EXPANDED, SSCI, CPCI-S, CCR-EXPANDED and IC。The type of document is article, and the time span is from 2000 to 2014. Retrieval strategy is: (TS = vaccin *). We retrieved a total of 111,060 scholarly research papers. Among them, there are 7 countries published over 5,000 papers: United States, Britain, China, Germany, France, Canada and Japan.

4.2 Statistical description

Figure 1 shows the number of papers published by the top 7 countries in the field of vaccine from 2000 to 2014. Clearly, the United States' biomedical research output occupies the high ground in vaccine research field, and there is wide margin with the remaining six countries. The second is China, and then followed by the UK, Germany, France, Canada and Japan.

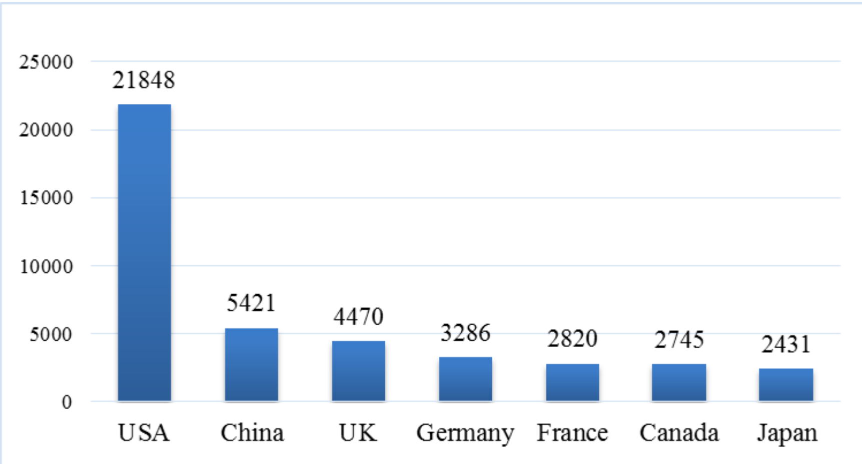

Fig.1 The number of papers published by the top 7 countries（Recorded by web of science）

Through the analysis of the raw data, we find that seven countries have had significant tripartite cooperation since 2008. Maybe it comes from the collect content of Web of science database, but the specific reasons temporarily can't be determined. Since this is not the important job, we don't have more deep investigation about this. However, measurement methods of mutual information and correlation coefficients can't accept excessive zero value. Therefore, in order to better verify the applicability and differences of mutual information and correlation coefficients, this paper selects sub dataset from 2008 to 2013 to analyze the average annual growth rate and calculate the T (gia) of collaborative innovation of top 7 countries.

Figure 2 is the annual growth rate of papers published by the top 7 countries in the field of vaccine research from 2009 to 2013. It is obvious the seven major innovative countries all have a negative growth rate in 2012 in the field of vaccine research, briefly into the doldrums. In 2013, apart from the United Kingdom and Canada still remaining negative growth, China has maintained a steady growth rate; the remaining four countries began to grow, especially France and Japan grow a lot.

Fig.2 The annual growth rate of papers published by the top 7 countries

4.3 The measurement of the triple helix collaborative innovation

4.3.1 The measurement of the degree of collaboration based on mutual information

By the triple helix measurable indicators of mutual information, we measure the degree of collaborative innovation in seven countries from 2008 to 2013. Figure 3 is the degree of collaborative innovation, and figure 4 is the five-year average value of collaborative innovation radar chart. As can be seen from figure 3, the time series analysis result of seven countries can be basically divided into turmoil type and steady type. Germany and Japan belong to the turmoil type in vaccine research field, but they have maintained a high degree of synergy. United States has remained relatively stable and high degree of coordination, not only locates in the leading position in the field of vaccine research output, while maintains a good cooperation between GIA. This also explains from another aspect why the United States has a higher technology transfer rate, because higher collaborative degree of Government- University-Industry is beneficial to technology transfer and transformation.

The degree of collaborative innovation in Canada and the United Kingdom lie at a low level in seven countries, but remain stable. France’s has greater volatility; it greatly improved from 2009 to 2010, but they began to fall after 2011. The degree of collaborative innovation in China is the lowest in seven countries, and remains relatively stable, even occur positive value in 2009.

Fig.3 The T(gia）of the top 7 countries in the field of vaccine

In this paper, five-year average value of collaborative innovation is divided into three gradients according to the numerical size. Germany, Japan and the United States are among the top three, belong to the first gradient (triangle logo), and they are countries with the highest degree of collaborative innovation. France and Britain are in the second gradient (square logo), their collaborative innovation degree rank in the median. Canada and China are in the third gradient (round logo), belong to weaker countries.

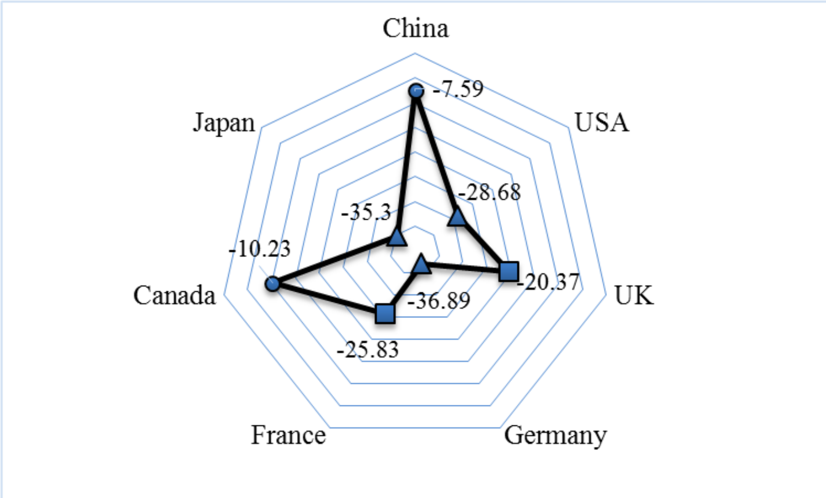

Fig.4 The average of T(gia）of the top 7 countries in the field of vaccine

In conjunction with figure 1 to figure 4, we can conclude that, although the Chinese scientific papers in the field of biological vaccine grow rapidly, and average annual growth rate takes the leading position, China has not yet reached a good level of coordination among the GIA. This low level of collaborative degree goes against to the spread of the new theory, the conversion and implementation of new technologies, and research results are usually difficult to reach the level of market applications. So technology is difficult to truly serve the economy and innovative development. This requires attention and improvement from policies and government institutions.

4.3.2 The measurement of the degree of collaboration based on cooperation similarity

To illustrate the different mechanisms of the measurement of collaborative innovation based on mutual information and cooperation similarity, we draw the top 7 countries' radar chart of R_{GAI} averages (figure 5).

Comparing Figure 4 and 5, the results have significant differences. This is because the calculation of collaborative similarity based on mutual information contains seven cooperation ratios, while R_{AIG} average is only the ratio of University-Industry- Government cooperation. So R_{AIG} average can't accurately characterize the degree of collaborative innovation. We should integrate using seven kinds of ratios to measure the degree of collaborative innovation.

We do a survey of different cooperation ratios of seven countries, and make a comparative analysis (Table 3). According to the meaning of each variable in Table 2, R_A, R_I, R_G, R_{AI}, R_{GI}, R_{GA} and R_{GIA} constrain each other. In particular, the higher the value of R_A, R_I and R_G, the lower the degree of collaborative innovation. National research institutions (R_A) possess a higher independent scientific output ratio, and have a higher funding ratio (A_G) by government. Compared to other countries, research output rate of China's industry is significantly lower, and its funding rate by the government is also lower, while its cooperation with research institutions is not high. In contrast, German companies not only have a high ratio of government funding, but also has a high proportion of independent research output.

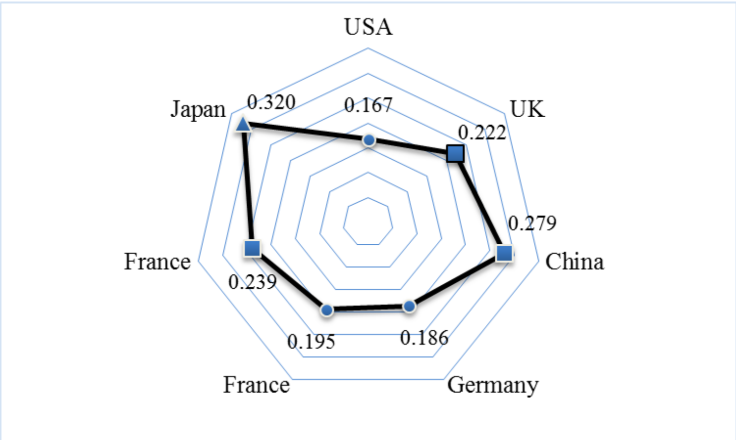

Fig. 5 The average of R_{GIA} of the top 7 countries in the field of vaccine

Table 3 The cooperation ratio of top 7 countries in the field of vaccine

Ratio	United States	UK	China	Germany	France	Canada	Japan
R_A	0.2184	0.1793	0.1389	0.2503	0.2405	0.2049	0.1591
R_I	0.0204	0.0229	0.0030	0.0381	0.0202	0.0202	0.0458
R_G	0.0538	0.0424	0.0337	0.0373	0.0403	0.0131	0.0284
R_{AI}	0.0680	0.0876	0.0673	0.0962	0.1007	0.1019	0.1303
R_{GA}	0.4509	0.4126	0.4732	0.3701	0.3833	0.4088	0.2973
R_{GI}	0.0212	0.0330	0.0049	0.0217	0.0203	0.0123	0.0192
R_{GIA}	0.1672	0.2223	0.2790	0.1863	0.1948	0.2389	0.3198

In order to further get the numerical relationship of cooperation ratio and collaborative degree T (gia) of mutual information, we chose the Pearson correlation coefficient to characterize their relationship (Table 4). By Pearson correlation, we find that the relationship between the various collaborative evaluation indicators is complex. Indicators with high degree of correlation are less, so each index can be used as complementary measurement elements. Meanwhile, the multi-index evaluation can find characteristics that cannot be found by single indicator. Thus, the indicators should be cross-referenced and integrated used.

Table4 The correlation between cooperation ratio and collaborative degree T (gia)

	R_A	R_I	R_G	R_{IA}	R_{GA}	R_{GI}	R_{GIA}	T(gia)
R_A	1.000	.256	.244	.040	-.121	.349	-.831	-.004
R_I	.256	1.000	-.092	.787	-.909	.465	.143	-.633
R_G	.244	-.092	1.000	-.524	.294	.487	-.575	.001
R_{IA}	.040	.787	-.524	1.000	-.955	.175	.473	-.554
R_{GA}	-.121	-.909	.294	-.955	1.000	-.309	-.370	.691
R_{GI}	.349	.465	.487	.175	-.309	1.000	-.402	-.353
R_{GIA}	-.831	.143	-.575	.473	-.370	-.402	1.000	-.288
T(gia)	-.004	-.633	.001	-.554	.691	-.353	-.288	1.000

Integrated R_A, R_I, R_G, R_{AI}, R_{GA}, R_{GI} and R_{GIA}, we make multidimensional scaling analysis of collaborative innovation degree of the seven countries (Figure 6). According to national layout in Figure 6, this is only the comparison between ratios, and it cannot represent the absolute number. United States, France and Japan are similar in the status of Government, industry and Academy. Germany, Canada, UK and China have large differences with other countries, and thus they are on the edge of the image.

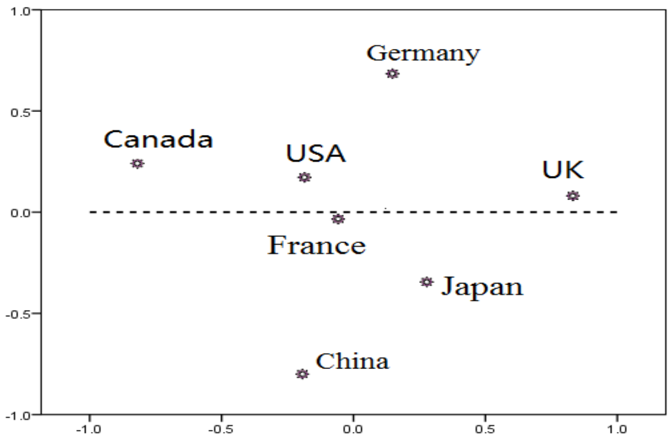

Fig. 6 The multidimensional scaling cluster analysis of top 7 countries in the field of vaccine

5. The role of technology transfer Organizations in University -Industry-Government collaborative innovation

The traditional triple helix model considers that continuous spiral development of Government-Industry-Academy comes from the internal mechanisms power. Zhou and Heng (Zhou and Heng 2008) think that the triple helix's result of the interaction achieves along with the triple helix's longitudinal evolution and horizontal circulation. In the longitudinal direction, each spiral constantly improves and forms the vertical evolutionary characteristics. In the transverse direction, the triple helix forms flow and circulation including personnel, information and products and other factors to promote their own progress.

We believe that in the era of scientific and technological achievements emerge one after another, we should pay attention to the role of technology transfer organizations (TTO) in collaborative innovation. Xiaoli Li (Li 2011) has analyzed the dynamic evolution of American university's patented technology transfer mechanisms in the triple helix model. Each participant forms interactive and reflexive close relationship, and promotes the further development of innovation activities. Thereafter, the further development of relations between the triple helix is inseparable from the promoting of universities' TTOs. TTO can be used as effective external impetus supplement to the triple helix internal impetus. With the accelerated pace of development of science and technology, as well as refined specialization, external impetus perhaps become the main driving force to the collaborative innovation in GIA triple helix(Figure 7).

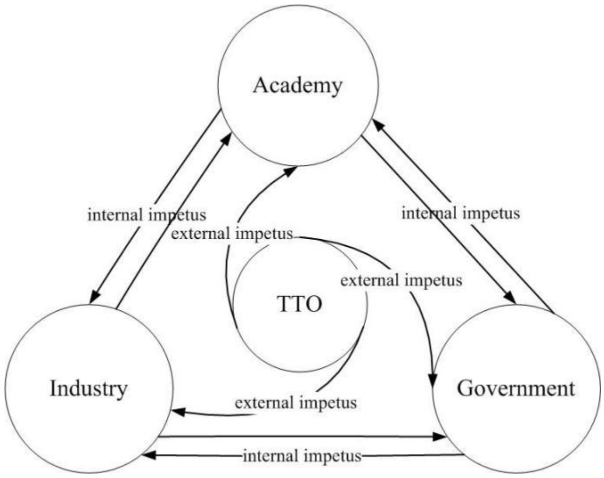

Fig. 7 The role of technology transfer intermediaries in collaborative innovation

We believe that technology transfer intermediaries are the effective force to solve information island phenomenon and technical distance difference in the current technology transfer process. Information Island comes from the supply and demand imbalance due to lack of communication between technologies' supply-side and demand-side. Technical distance difference comes from the business put excessive attention on profit, while the new technologies generally involved higher technology level than the current ones, leading to the new technology difficult to be applied. According to the analysis of collaborative degree above, we find that China's current technological support funding comes mainly from government financial. Therefore, R&D staffs actually do not care about the transfer and transformation. Meanwhile, researchers pay more attention to their own research work, rather than spending time and effort to contribute to make an effort to results transformation.

As a result, a large number of scientific and technological achievements require specialized TTO to eliminate information silos. To eliminate transformation resistance caused by technical distance difference, we need TTO to provide the technique's value prospects map which including technology valuation and industrial potential assessment and prediction. Thus it can promote the transformation of scientific and technological achievements. At present there are many problems existing in TTOs services, such as the single function (Wu 2014). Meanwhile, the intermediary service of patent transfer and transformation is a high value-added work, not a simply sale. In addition to institutional issues, it also need appropriate talents at present.

6. Conclusions

This paper discusses the theoretical development of the triple helix model, and analyzes the current triple helix measure model, including mutual information and correlation coefficient. Vaccine research of biomedicine is selected as the empirical analysis area. We use the information entropy and the correlation coefficient indicator respectively to calculate the top 7 countries' collaborative innovation of triple helix. We think that there are differences between mutual information and correlation coefficient. On the application of the triple helix model based on mutual information and cooperative similarity, we should pay attention to the following three points.

First, although the research papers are important manifestation of the results of Government-Industry-Academy cooperation, they represent only one part of it. These collaborative innovation projects also include established labs by the three parties, product R&D centers and personnel training. Therefore, we must recognize the scope of the Triple Helix collaborative degree indexes. Secondly, there is no association between the value of T (gia) and national comprehensive scientific research strength for innovation, because the value of T (gia) can only represent collaborative innovation capacity of a country from the perspective of domestic cooperation. Thirdly, the Triple Helix can not only measure the degree of domestic collaborative innovation, but also the collaborative innovation degree of foreign countries, the two of which are not necessarily linked. We need to distinguish between the two. That means the country with a relatively small absolute value of T (gai) has a lower domestic collaborative innovation degree, but the concrete international coordination degree requires further analysis.

Measurement method of collaborative innovation in this paper is research at the national level, which belongs to macroeconomic scope of coordination mechanism study. In the future, research on microscopic perspective is more important, such as tracking collaborative features from the scientific output of research papers to application for patent protection. By this way, we can know the situation and influencing factors of collaborative innovation, and then find the weak links to solve the crux and ills hindering innovation. Therefore, in the future we will increase monitoring to the collaborative innovation of the GIA in the process of patented technology transfer and transformation. We expect to form the collaborative innovation monitoring mechanism covering the entire innovation chain of technology incubation and industrialization from basic research to patent protection and technical implementation, so as to further support collaborative innovation decision, improve the technology implementation rate in China and promote the efficiency of technological innovation.

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References

Leydesdorff, L.,Etzkowitz, H. Emergence of a Triple Helix of university-industry-government relations[J]. Science and public policy, 1996,23(5): 279-286.

Fang, Weihua. The Triple Helix model of innovation research: concepts, structure, and public policy implications [J]. Dialectics of Nature, 2004,19(11): 69-72.

Qi, Hongshan, & Wu, Si. The analysis of innovation strategy evolution and trend in China - Architecture based on the Triple Helix model [J]. Liaoning Science and Technology Reference, 2007, (8): 9-12.

Li, Xueqin, &Zhou, Huaiying, & Cai, Xiang. The construction of "entrepreneurial" university based on the "Triple Helix" theory [J]. Technoeconomics & Management Research, 2010,(4): 46-49.

Han, Gaojun. Entrepreneurial universities from the perspective of Triple Helix theory [J]. Education Research Monthly, 2010,(6): 41-43.

Pan, Donghua, & Yin, Dawei. The Triple Helix interface organization and innovation mechanism [J]. Research Management, 2009,(1): 15-21.

Liu, An. Study on the triple helix model of the transformation of scientific and technological achievements in China- take CAS as an example [J]. Studies in Science of Science, 2011,29(8): 1129-1134.

Shi, Huaxue. The triple helix model: Ideal model of combination of university- industry- government [J]. Chinese University Technology Transfer, 2010,(10):30-31.

Zi, Wucheng, & Luo, Xinxing, & Lu, Xiaocheng. Study of university-industry-government innovation cluster model based on the Triple Helix theory [J]. Science & Technology Progress and Policy, 2009,26(6): 6-7.

Wang, Chengjun. Comparative study of the Triple Helix measurement at home and abroad [J]. Research Management, 2007,27(6): 19-27.

Park, H. W., Hong, H. D.,Leydesdorff, L. A comparison of the knowledge-based innovation systems in the economies of South Korea and the Netherlands using Triple Helix indicators[J]. Scientometrics, 2005,65(1): 3-27.

Leydesdorff, L.,Fritsch, M. Measuring the knowledge base of regional innovation systems in Germany in terms of a Triple Helix dynamics[J]. Research Policy, 2006,35(10): 1538-1553.

Leydesdorff, L.,Sun, Y. National and international dimensions of the Triple Helix in Japan: University–industry–government versus international coauthorship relations[J]. Journal of the American Society for Information Science and Technology, 2009,60(4): 778-788.

Shin, J., Lee, S.,Kim, Y. Knowledge-based innovation and collaboration: a triple-helix approach in Saudi Arabia[J]. Scientometrics, 2012,90(1): 311-326.

Kwon, K.-S., Park, H., So, M.,Leydesdorff, L. Has globalization strengthened South Korea's national research system? National and international dynamics of the Triple Helix of scientific co-authorship relationships in South Korea[J]. Scientometrics, 2012,90(1): 163-176.

Kim, H. *et al*. Triple helix in the agricultural sector of Northeast Asian countries: a comparative study between Korea and China[J]. Scientometrics, 2012,90(1): 101-120.

Hossain, M. D., Moon, J., Kang, H., Lee, S.,Choe, Y. Mapping the dynamics of knowledge base of innovations of R&D in Bangladesh: triple helix perspective[J]. Scientometrics, 2012,90(1): 57-83.

Bobby, S.,Gohar Feroz, K. An analysis of the information technology outsourcing domain: A social network and Triple helix approach[J]. Journal of the American Society for Information Science and Technology, 2013,64(11): 2366-2378.

Zhang, Y., Zhou, X., Porter, A., Gomila, J. V.,Yan, A. Triple Helix innovation in China's dye-sensitized solar cell industry: hybrid methods with semantic TRIZ and technology roadmapping[J]. Scientometrics, 2014,99(1): 55-75.

Zou, Yimin, & Zhang, Zhixiong. A review of measuring the Triple Helix using quantitative approach [J]. Journal of Intelligence, 2013,32(4): 85-90.

Leydesdorff, L. The mutual information of university-industry-government relations: An indicator of the Triple Helix dynamics[J]. Scientometrics, 2003,58(2): 445-467.

Sun, Y.,Negishi, M. Measuring the relationships among university, industry and other sectors in Japan's national innovation system: a comparison of new approaches with mutual information indicators[J]. Scientometrics, 2010,82(3): 677-685.

Priego, J. L. O. A Vector Space Model as a methodological approach to the Triple Helix dimensionality: A comparative study of Biology and Biomedicine Centres of two European National Research Councils from a Webometric view[J]. Scientometrics, 2003,58(2): 429-443.

Wang, Chengjun, & Huang, baodong, & Qiu, Yu. Comparative researches onweb metrics- based Triple Helix of university- industry- government partnerships [J]. Technology and Innovation Management, 2006,27(3): 48-53.

Abramson, N. Information theory and coding[M].1963.

Yu, Shan. An Empirical Study of Measurement Science of the Triple Helix model [D]. Zhejiang University, 2013.

Ye, F. Y., Yu, S. S.,Leydesdorff, L. The Triple Helix of university-industry-government relations at the country level and its dynamic evolution under the pressures of globalization[J]. Journal of the American Society for Information Science and Technology, 2013 64(11): 2317-2325.

Martynovich, M. On the Way to Developing the Triple Helix Indicator[D].Lund, Sweden: Lund University, 2011.

Leydesdorff, L., Park, H. W.,Lengyel, B. A routine for measuring synergy in university–industry–government relations: mutual information as a Triple-Helix and Quadruple-Helix indicator[J]. Scientometrics, 2014,99(1): 27-35.

Zhou, Chunyan, & Heng, Li. The theoretical discussion of the Triple Helix innovation model [J]. Journal of Northeastern University(Social Science), 2008,10(4): 300-304.

Li, Xiaoli. Dynamic evolution of university technology transfer organization in U.S.A based on the model of Triple Helix [J]. Library and Information Service, 2011,(14): 36-41.

Wu, Weiguang. How to facilitate the transfer of university technology outcomes to market [EB/OL].http://academic.law.tsinghua.edu.cn/homepage/index.php?r=show/index&id=2220.[2014-07-12].

Xu, Haiyun. Important points and difficult points of analysis and appraisal of intellectual property rights (patents) and the transfer & conversion services [EB/OL]. http://blog.sciencenet.cn/home.php?mod=space&uid=535291&do=blog&id=793382.[2014-05-11].

Lin, Geng. The spring of technology market is upcoming [EB/OL]. http://blog.sciencenet.cn/blog-473911-770840.html.[2014-06-25].