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Research on the structural features and influencing factors of the scientific exchange network of countries along " the belt and road"

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ABSTRACT

"The Belt and Road" is an initiative proposed by China in recent years to cooperate and develop to build a community with a shared future for mankind. Analyzing the academic exchanges of countries along the "The Belt and Road" can provide a quantitative reference for future international scientific and technological exchanges, collaborative innovation development and related research. We carry out matrix construction and network structure analysis on the citation and cooperation of highly cited papers among countries along the "Belt and Road" included in China from 2013 to 2018 included in Web of Science Core Collection, and explore the current status of scientific exchanges in countries along "the Belt and Road". The Quadratic Assignment Procedure analysis method verifies the influence of five variables, including geographic proximity, differences in economic levels, scientific productivity, similarity of research content, and economic and trade cooperation, on scientific exchange networks. The research results show that the countries along the "the Belt and Road" have relatively close academic exchanges; Geographical proximity, similarity of research content, differences in economic level between countries, and differences in scientific productivity are significantly correlated with each other; the similarity of scientific and technological level and research content and the closeness of economic and trade cooperation have a positive effect on scientific exchanges as a whole.

KEYWORDS

The Belt and Road; Scientific exchange; Highly cited papers; Proximity

1 Introduction

The Belt and Road (B&R) originated from the cooperation initiative of the "New Silk Road E-conomic Belt" and the "21st Century Maritime Silk Road" proposed by President Xi Jinping in 2013. As of April 2020, China National Knowledge Infrastructure (CNKI) has included more than 12,000 papers in core journals and CSSCI journals, and there are about 1,000 papers in Web of Science Core Collection (WoS) database. Research on the Belt and Road Initiative is mainly focused on economics and trade (Du & Zhang, 2018; Wang et al., 2017; Cheng, 2016; Liu et al., 2018) international relations (Ferdinand, 2016; Clarke, 2017; Rimmer, 2018), global-

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ization (Liu & Dunford, 2016; Huang, 2019). In addition, many scholars have reviewed and summarized the B&R related papers through the methods of bibliometrics and knowledge visualization. Gui et al. (2019) constructed a dynamic scientific cooperation network of countries along the B&R route based on the WOS database and used social network analysis methods to analyze the structure of the national scientific cooperation network of the Belt and Road Initiative. Shahriar (2019) conducted a systematic literature review, bibliometric citation analysis and contents analysis on 210 B&R related papers in databases such as WOS, Scopus, and Science Direct, and concluded that the world's research on the "Belt and Road" Academic interest is getting higher and higher. Zhao and Wang (2018) conducted a quantitative analysis of the "Belt and Road" theme literature based on the CNKI database, revealing the structure and characteristics of the research results of Chinese scholars: the hot spots are concentrated in the "Silk Road Economic Belt" and "Marine On the Silk Road" and other related issues, there is relatively little research on scientific exchanges in countries along the Belt and Road.

1.1 Research on the structural characteristics of the scientific exchange network

Most of the papers related to B&R scientific exchange focus on the level of collaborative papers. There are some researches show that China has significantly more cooperation with developed countries than B&R countries, and China prefers to cooperate with countries along the route with close geographic location and high level of economic and scientific development (Wu et al., 2016; Jin & Yang, 2017; Zhou et al., 2016). In addition to cooperative papers, the citation of highly cited papers provides a good way to detect scientific exchange from the perspective of metrology (Wang, 2014). Based on the WoS database, the Thomson Reuters Technology Group in the United States developed the ESI database in 2001, which can be used to determine the top 1% of papers cited in the last 10 years, that is, highly cited papers (Thomson, 2012). Qiu (2010) studied the literature in the field of materials science collected by ESI from 1998 to 2008 from the perspective of citation and found that highly cited papers can fully reflect the quality of the paper. The "formal process" and "informal process" theories put forward by the sociologist Giuliani (2007) are sorted into the "scientific exchange theory", in which the formal process is a process of scientific information exchange based on literature. Scholars such as Li (2012) believe that the scientific exchange model based on literature is an important subject of the overall scientific exchange model research, and the Internet provides great convenience for scientific exchange. Therefore, studying the formal process of scientific exchange between countries from the level of paper cooperation and citation has high theoretical value.

1.2 Research on the factors of the scientific exchange network

Many scholars around the world have conducted in-depth research on the influencing factors of scientific exchange and have achieved certain results. Boschma and Frenken (2009) divide proximity into five categories: geographic proximity, technical proximity, social proximity, institutional proximity, and organizational proximity, and believe that the proximity of each category has an impact on the performance of cooperative innovation. Balland et al. (2015) and others proposed the dynamic extension of proximity architecture to illustrate the dynamic co-evolution between the establishment of knowledge network and proximity. In addition, scientific exchanges between countries are also affected by factors such as differences in economic levels and trade cooperation levels.

Wal (2013) believes that geographic location can directly affect the formation of inter-organizational partnerships, which in turn will form an innovation network, promote resource sharing, and improve innovation performance. Liang et al. (2006) found that as the geographical distance increases and the degree of language diversity increases, the intensity of scientific cooperation among EU countries will decrease. Giuliani (2007) believes that geographic location is not a sufficient and necessary condition for knowledge dissemination. However, most related studies have shown that geographical proximity has a decisive influence on cooperative R&D and innovation, and the geographical distance between countries is an important factor in scientific research exchanges and cooperation.

Diao et al. (2014) first used methods such as overall description, Gini coefficient, σ convergence, and β convergence, and found that the activity of regional industry-university research cooperation is affected by various factors such as regional social capital, technical capabilities, and economic environment. Cao and Song (2017) believe that when the differences in economic levels of innovation entities are small, they are more likely to encounter similar problems, and they are more likely to cooperate to solve similar problems they face. Therefore, the national economic level also has a certain impact on its scientific research exchanges and cooperation.

Schubert and Braun (1990) and Haustein et al. (2011) believe that countries with high scientific research capabilities have more opportunities to obtain partners, and scientific productivity is an important factor affecting innovation cooperation. The research of Huamaní et al. (2012) shows that the scientific productivity of most countries in Latin America is positively correlated with the level of national scientific cooperation. Therefore, the scientific productivity of various countries is also an important factor in scientific research exchanges and cooperation.

Nooteboom (1999) puts forward the concept of research content compatibility, which is defined as the similarity in the way individuals perceive, interpret, understand and evaluate the world. Giuliani (2007) defines cognitive proximity, which refers to the degree to which two participants share the same knowledge base. Li and Wang (2014) believe that the compatibility of research content covers the language, goals, technical level and knowledge base of different subjects, using the number of the same leading industries in 56 sub-regions of the country as the index of research content compatibility, and explored the impact of similarity of research content on innovation. Wang et al. (2011) found that when the network enters a mature stage, the degree of knowledge similarity is particularly important.

Some scholars have explored the relationship between academic exchanges and Economic and trade cooperation between countries. Scholars such as Grossman and Helpmanz (1991) proved that international trade has an important impact on national technological progress; Zhang (2009) found that trade imports between countries, foreign investment and the number of foreign invention patents in China have promoted technological progress to a certain extent. Jiang (2017) analyzed the characteristics of economic and trade exchanges and scientific and technological cooperation between China and the countries along the B&R from the perspective of geographical divisions and found that scientific and technological innovation cooperation has greatly contributed to the economic and trade ties between China and other B&R countries. Continuous development of economic and trade ties will further strengthen China's scientific and technological innovation cooperation with these countries.

Through literature review, scholars have carried out a series of studies on the network structure characteristics and influencing factors of scientific exchanges between countries and achieved a large number of excellent results, but there are still some problems. (1) Domestic and foreign researches on the scientific exchanges of countries along the B&R route mostly focus on the level of cooperative papers and seldom conduct an in-depth analysis of the network structure characteristics of scientific exchanges between countries from the citation level of papers. (2) At present, many studies are exploring the impact of multi-dimensional factors on innovation synergy, but there are few studies on the influencing factors of scientific exchange networks between countries. Most of them focus on a specific region, such as Southeast Asia, Europe, or a specific type of company. From the perspective of B&R, with the country as a research scale, few documents are analyzing the influencing factors of the national science exchange network.

1.3 QAP related research

Therefore, this article constructs the scientific exchange network of countries along the B&R route from the perspective of the citation and cooperation of highly cited papers, analyzes the scientific exchanges of the countries along the B&R route, and reveals the academic influence of the core countries (Figure 1). In addition, according to the characteristics of the measured variables, this article uses the Quadratic Assignment Procedure (QAP) method to conduct an empirical analysis of the influencing factors of the B&R national science exchange network, and analyze the differences in these influencing factors, to provide certain facts for the in-depth development of scientific exchanges between China and countries along with the route Basis and reference enlightenment (Liu, 2007).

2 Data Sources and Research Methods

The main research objects of this paper are 65 countries along the B&R, including China (https://www.yidaiyilu.gov.cn). In the WoS database, the highly cited papers from 2013 to 2018 years in 65 countries were searched. After deduplication, identification, and sorting, a total of 45,478 highly cited papers were obtained. And data on paper citations and collaborations between 65 countries were obtained. Among them, the number of highly cited papers published in China far exceeds the search results of 10,000 records limited by the WoS citation report, which means that the citation analysis cannot be performed directly. Therefore, this paper changes the time to download the citation report in batches and delete the citations of the same DOI to perform de-duplication.

VBA is used to construct a reference matrix, a cooperation matrix and a scientific exchange matrix. The elements of the citation matrix are the citation frequency of highly cited papers among 65 countries, and the mutual citations of highly cited papers between countries constitute a directed matrix. The cooperation of highly cited papers between countries constitutes a cooperation matrix. After normalizing and processing the citation matrix and the cooperation matrix, respectively, a scientific exchange matrix can be constructed to represent the scientific exchange relationship of highly cited papers among 65 countries.

Combining the advantages of each software, this paper selects a variety of software to assist the research. From the perspective of highly cited papers citation and cooperation, use Excel, Gephi, python and other software to analyze the network structure of the citation, cooperation and scientific exchanges between countries along the B&R route, including China included in WoS from 2013 to 2018 years. VOSviewer draws a national high-cited paper scientific communication network map. In addition, VBA is used to construct the GDP difference matrix, geographic distance matrix, scientific research capability matrix, and import and export matrix, respectively. And Python is used to construct similarity of research content matrix, and QAP correlation analysis and regression methods are used to explore the factors affecting the scientific exchange network of countries along the "Belt and Road".

3 Analysis of the Structural Features of National Science Exchange Networks along the B&R

3.1 Analysis of overall scientific exchange network characteristics

If all nodes in a network are connected, the density of the network is 1. Divide the number of edges connected by all nodes in the network by the maximum number of edges that the network can have, which is the network density. The result is between 0 and 1. The closer to 1 means that the nodes are connected more closely. This study calculates that the citation network density of countries along the B&R route is 0.864, the cooperation network density is 0.798, and the scientific exchange network density is 0.89. Therefore, the scientific exchange network of the countries along the B&R is complete and closely connected (Table 1).

For a node, its clustering coefficient is the number of edges connected to it divided by the maximum possible number of edges. And clustering coefficient plus the average path length can show the small-world phenomenon (Liu et al., 2005). The average clustering coefficient of a scientific exchange directed network is 0.936, and the average clustering coefficient of citation network and cooperation network is 0.909 and 0.905. By further calculating the average path length of the network, it is found that the average number of steps reached between nodes in the scientific exchange network is 1.099, and the average path lengths of highly cited papers and cooperative networks are 1.107 and 1.167, respectively. The larger average clustering coefficient and the smaller average path length indicate that the scientific exchange network of the countries along the B&R route is a small-world network.

Table 1 Analysis of the overall structure of the scientific exchange network

	citation network	cooperation network	scientific exchange network
Number of nodes	65	65	65
Number of edges	3544	3321	3702
Graph density	0.852	0.798	0.89
Average clustering coefficient	0.909	0.905	0.936
Average path length	1.107	1.167	1.099

3.2 Network node analysis

If a paper comes from country A, the paper cited m papers, and the address of m papers is in n countries or regions, it means that the country to which the paper belongs has cited papers from n-1 countries, which means this country has input knowledge to n-1 countries; similarly, these n-1 countries have exported knowledge to country A, and the country to which the paper belongs is the knowledge exporting country of country n-1. If a paper is co-authored by scholars from different countries and regions in the world, then the paper is a co-authored paper of multiple countries.

The mutual citations of highly cited papers from countries along the B&R route constitute a directed network, which is called the "citation network" in this article. The cooperation of highly cited papers in these countries constitutes a "cooperative network". Normalize the rows and columns of the directed matrix of the citation network. The network formed by all the knowledge input countries citing highly cited papers from countries along the B&R route is the knowledge input network. The network that the paper is cited by countries along the B&R route is a knowledge output network, and both of these networks are one-way networks.

Select the 6 countries with the highest number of highly cited papers from 2013 to 2018 , and use Gephi to quantitatively analyze the structural characteristics of the citation network and cooperation network, and the results are shown in Tables 2 and 3. According to Gephi's analysis of the weights of out and in degrees of B&R citation network nodes, it can be seen that China, Singapore, Saudi Arabia and other countries have the highest weighted in degrees, while China, Russia, Poland and other countries have higher weighted out degrees, indicating that countries along the B&R route is not balanced in terms of academic input and output. In addition, China's weighted out-degree is about three times the weighted in-degree, indicating that China has a greater influence on B&R countries in scientific research. The weighted in-degrees of Singapore, Saudi Arabia and other countries are much higher than the weighted-out degrees, indicating that the above-mentioned countries are more affected by the B&R countries in scientific research.

Table 2 Analysis of Nodes in Top 6 B&R Citation Networks

	In–degree	Weighted in–degree	Out–degree	Weighted out–degree	Betweenness centrality
China	64	236656	61	615454	19.859387
Singapore	64	137954	60	50451	16.675458
Iran	63	69933	59	84525	10.895107
Saudi Arabia	64	122407	61	54675	19.859387
Poland	63	88633	61	94980	12.86653
Russia	64	100763	61	92756	19.859387

It can be seen from Table 3 that China has the highest weighting degree in the cooperation network of countries along the B&R route, indicating that China has a great influence in the cooperation network. Among the countries along the B&R route, Russia, which ranks sixth in the number of highly cited papers, is weighted almost twice that of Singapore, the country with the highest number of highly cited papers, indicating that there is a large gap in the influence of these countries in B&R cooperation network. The analysis shows that compared to countries with similar scientific research capabilities, Russia is more inclined to collaborate with countries along the B&R route, while countries such as Singapore are more inclined to "North-South cooperation", that is, to cooperate more closely with developed regions such as North America or prefer to cooperate with domestic researchers. In addition, the six countries that have published the most highly cited papers have little difference in proximity to centrality, indicating that these countries are all influenced by other countries on the cooperation network. However, the intermediary centrality of these countries is significantly different: China and Iran have higher intermediary centrality, while other countries have low intermediary centrality. It shows that China and Iran are at the center of the B&R cooperation network and play a pivotal role in the operation of the entire cooperation network.

Table 3 Analysis of Nodes in Top 6 B&R Cooperation Networks

	degree	Weighted degree	proximity centrality	intermediary centrality
China	61	15166	0.984	57.47
Singapore	59	5042	0.954	13.65
Iran	60	6070	0.969	69.627
Saudi Arabia	60	6574	0.969	15.803
Poland	57	9212	0.925	6.027
Russia	59	9398	0.954	13.205

According to the results of Gephi's analysis, the six countries that published the most highly cited papers from 2013 to 2018 have an uneven position in the scientific exchange network of countries along the B&R route. It can be seen from Table 4 that compared with countries with similar scientific research capabilities, Russia's weighted in-degree is twice that of other countries, indicating that Russia is more willing to input knowledge from countries along the B&R route. China has the highest weighted out-degree, far surpassing other B&R countries along the route, and China's weighted out-degree is 6 times the weighted in-degree. This shows that China has output a lot of knowledge to the countries along the B&R route, and China has a great influence on the countries along the B&R route in terms of scientific and technological research. In terms of centrality, the six countries that have published the most highly cited papers have little difference in proximity to centrality, indicating that these countries are all influenced by other countries on the network. However, the intermediary centrality of these countries is significantly different: China, Singapore, and Iran have high intermediary centrality, while the other three countries have extremely low intermediary centrality. It shows that China is at the center of the B&R scientific network and plays an important pivotal role in the operation of the entire network. In addition, China's proximity centrality and intermediary centrality are both in a leading position, which shows that China has great influence in the national scientific exchange network along the B&R line and plays an important "bridge" role in the network.

Table 4 Analysis of Nodes in Top 6 B&R Science Exchange Networks

	in–degree	weighted in–degree	out–degree	weighted out–degree	proximity centrality	intermediary centrality
China	62	5.682	63	35.469	1.000	27.904
Singapore	62	5.016	62	10.321	0.984	6.702
Iran	62	4.098	62	8.043	0.984	6.702
Saudi Arabia	62	5.591	62	9.056	0.992	0.131
Poland	61	4.529	61	7.286	0.984	0.129
Russia	62	9.449	62	14.299	0.992	0.131

3.3 Community division

Newman (2003) divides the closely connected nodes into a community according to the characteristics of the network. The nodes within the community are closely connected, and the nodes between the communities are relatively loose. The research of Van and Waltman (2010) found that the association strength method is used to show the correlation between nodes in the network graph, and it is more appropriate to analyze the clustering distribution of scientific communication networks. Therefore, this paper uses the correlation strength method to analyze the scientific exchanges of countries along the B&R from 2013 to 2018, and the results are shown in Figure 2.

The scientific exchange network is divided into 10 communities, of which 57 countries occupy 4 communities. There are 65 nodes and 1801 connections in the network. Nodes are represented by their labels and circles. The size of the node depends on the degree of the node, the strength of the connection, the number of connections, and so on. The higher the weight of the node, the larger the label and circle of the node. Some nodes may not display labels due to avoiding overlapping (Newman, 2003). In addition, the closer the two nodes are, the closer the connection is. The distance between two countries in the visual map roughly indicates the relevance of the country in scientific exchanges. The closer two countries are to each other, the stronger their correlation.

The vast majority of B&R countries in Figure 1 are divided into four communities: red, green, blue, and yellow. The red is the first community, and it is composed of 25 countries including China, India, Thailand and Singapore. Some countries in the first community have larger nodes, while others have smaller nodes, and the size of the nodes varies greatly. In most countries, the nodes are relatively small and the nodes are generally close, and the distribution is relatively close, indicating that the countries in the red community are more relevant in scientific exchanges.

The green community is the second community, including countries such as Russia, Turkey, Poland, and the Czech Republic. The nodes in the second community are generally larger, indicating that these countries have played a significant role in the scientific exchanges of countries along the B&R route. Compared with the first community, the second community has a looser distribution of nodes. Therefore, the relevance of academic exchanges between countries in this association is weaker than that of academic exchanges between countries in the first association.

Blue represents the third community, including Serbia, Ukraine, Bulgaria, Croatia and other countries. The distance between the nodes of the third community and the first community is farther, which indicates that the scientific exchanges between the countries of this community are relatively loose. However, the third community node is relatively large, indicating that these countries play an important role in the scientific exchange of countries along the B&R route.

The fourth community represented by yellow includes seven countries, including Saudi Arabia, UAE, Pakistan, and Iran. Among the four societies, the yellow societies are the most loosely distributed, indicating that these countries are relatively weak in scientific exchanges. However, compared with the first community, the nodes of the yellow community are larger, indicating that the countries of the fourth community have made important contributions to the scientific communication of the overall network.

China has the largest weight among the 65 countries along the B&R route, indicating that China is at the core of the academic exchanges in these 65 countries. In addition, China is located at the junction of red, green, blue, and yellow societies, which shows that China is a bridge and link between these societies in terms of scientific exchange.

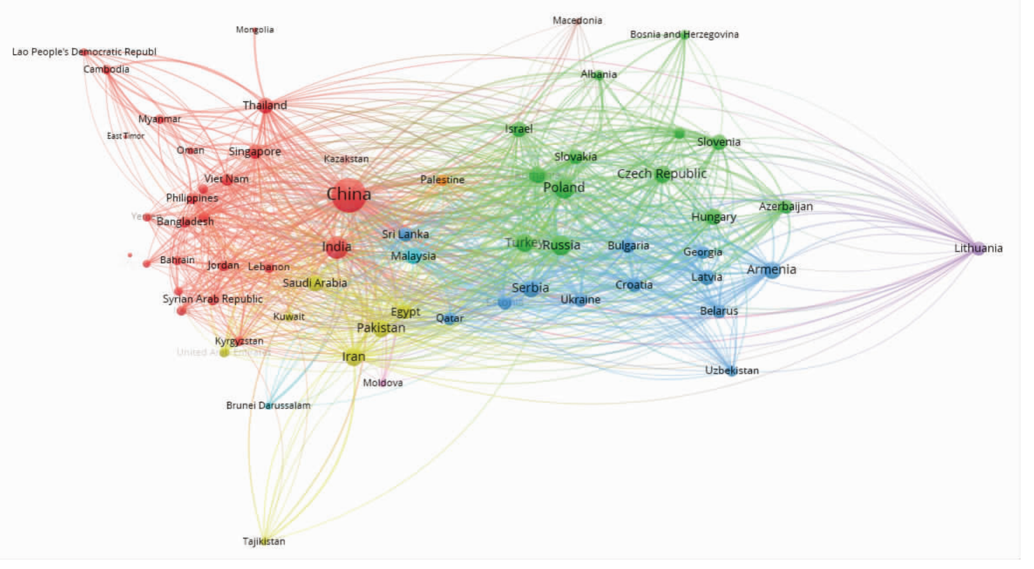

Figure 2 Results of the division of science exchange network along the B&R

4 Analysis of Influencing Factors of Science Exchange Network along the B&R

4.1 Research hypothesis

For different research subjects and dimensions, the degree of proximity to the innovation cooperation network varies greatly. This article focuses on the influencing factors of the scientific exchange network of countries along the B&R, therefore expounds the mechanism of geographic proximity, differences in economic levels, scientific productivity differences, technological proximity, and Economic and trade cooperation, and proposes research hypotheses.

4.1.1 The impact of geographic proximity on the network

The current excellent research on the mechanism of geographic proximity mainly includes: proximity in geographic space leads to shortening of interaction time, thereby reducing information interaction and transaction costs; Geographical proximity effectively increases opportunities for face-to-face contact, broadens communication channels, increases communication frequency, accelerates knowledge dissemination, and promotes scientific exchanges between countries. Therefore, geographical proximity has a positive effect on innovation cooperation. The smaller the geographical distance, the closer the scientific exchanges. Therefore, the hypothesis is as follows:

H1: Geographical proximity has a positive role in promoting scientific exchanges among countries along the B&R.

4.1.2 The impact of differences in economic levels on the network

The higher the economic level of a country, the greater the amount of funds and resources the country invests in scientific research, which enhances the ability of scientific researchers to innovate, and the academic output is more abundant, and it is easier to obtain citations and references to papers. Collaboration of papers in other countries enhances scientific exchanges between countries. Based on this, the following hypotheses are proposed:

H2: Higher differences in economic levels have a positive effect on scientific exchanges among countries along the B&R.

4.1.3 The impact of scientific productivity differences on the network

Scientific productivity is an important factor affecting innovation cooperation. The stronger the country's scientific productivity, the more likely it is to achieve breakthroughs in innovation and the more likely it is to overcome geographic distance to cooperate and obtain more partners. Therefore, scientific productivity capabilities have a certain impact on scientific exchanges, and countries with lower scientific productivity are more willing to conduct scientific exchanges with countries with high scientific productivity. Based on this, the following hypotheses are proposed:

H3: Higher differences in scientific productivity have a positive role in promoting scientific exchanges among countries along the B&R.

4.1.4 Research on the impact of content similarity on the network

Researchers need a similar knowledge base to cite and collaborate on papers. The higher the degree of similarity in research content between countries, the easier it is for scientific exchanges; if there is a lower technical distance between researchers and the closer the scientific research capabilities, the easier it is to publish Co-authored papers. Based on the above influence mechanism of cognitive proximity, the following hypotheses are proposed:

H4: The similarity of research content has a positive role in promoting scientific exchanges among countries along the B&R.

4.1.5 The impact of economic and trade cooperation on the network

Economic and trade cooperation has an important impact on national technological progress. Import and export trade between countries is conducive to the flow of funds of scientific research institutions between countries and helps to enhance the cross-border communication and exchanges of scientific researchers. Therefore, the import and export trade of countries along the B&R route will promote scientific exchanges between countries. Based on the above influence mechanism, the following hypotheses are proposed:

H5: Economic and trade cooperation has a positive role in promoting scientific exchanges among countries along the B&R route.

4.2 Data and variables

The independent variable of this article is the national science exchange network along the B&R. The citations and cooperation data of highly cited papers published by the countries along the B&R of the WOS database from 2013 to 2018 are selected to construct a national science exchange network. And research the factors that affect scientific exchanges among countries along the B&R.

The data of influencing factors obtained in this paper are sorted into multiple N*N matrices, which are GDP difference matrix, geographic distance matrix, scientific research capability matrix, import and export matrix and similarity of research content matrix, and each matrix is not independent of each other. Therefore, this article uses QAP correlation and regression methods to analyze the influencing factors of the national science exchange network along the B&R.

4.2.1 Geographical proximity measurement index

Scholars have a variety of indicators for measuring geographic proximity between countries. Taking into account the scientific nature and easy access of the data, this article selects the GeoDist indicator of the CEPII database to measure the geographic distance between countries, constructs a 65*65 symmetric matrix, and normalizes it. The larger the value, the higher the geographical proximity between countries.

4.2.2 Economic level difference measurement index

There are many indicators to measure the difference in economic levels between countries. Taking into account the availability of data, this article selects the GDP data of the countries along the B&R route of the World Bank or the National Bureau of Statistics in 2018 and uses the EXCEL function to calculate the difference in GDP between each country. After normalization, a GDP asymmetric difference matrix of 65*65 mapping between 0-1 is obtained. The larger the value, the larger the GDP difference between countries.

4.2.3 Scientific productivity measurement index

Highly cited papers have strong influence and high academic value, and the output of the country's highly cited papers can be used as an indicator to measure the country's scientific productivity. Therefore, this paper selects the difference in the number of high-cited papers published by the countries along the B&R from 2013 to 2018 as the scientific capability measurement index and normalizes it. The closer the value is to 1, the closer the scientific research capabilities of the two countries are.

4.2.4 Similarity of research content measurement index

The similarity of research content is considered to be part of cognitive proximity (Boschma, 2005). The proximity of research content is conducive to the citation and collaboration of papers by researchers. Drawing lessons from scholars at home and abroad to measure the similarity of research content between regions, this article refers to the similarity index to construct a structured distribution vector space of different countries in different disciplines (Li et al., 2012). And calculate the cosine similarity, which is used to measure the similarity of the discipline structure of the countries along the B&R route from 2013 to 2018, as shown in formula (1)

$$S_{ij} = \frac{\sum_{k=1}^{n} R_{ik} \times R_{jk}}{\sqrt{\sum_{k=1}^{n} (R_{ik})^2} \times \sqrt{\sum_{k=1}^{n} (R_{jk})^2}} \tag{1}$$

Among them, R_{ik} is the structured index of country i in k disciplines, $R_{ik} = P_{ik} / P_i$; P_{ik} is the number of published highly cited papers by country i in k disciplines, and P_i is the total number of published highly cited papers by country i.

4.2.5 Economic and trade cooperation measurement index

The import and export trade measurement data selected in this paper comes from the UN Director of the Statistics Division (UNSD), using VB to sort the import and export data between countries into a 65*65 matrix and normalize it to get the import and export matrix. The larger the value, the larger the country's import and export balance.

4.3 Analysis of the overall influencing factors of the science exchange network

4.3.1 Correlation analysis of overall influencing factors

Use the QAP correlation analysis of UCINET software to analyze the correlation matrix and scientific exchange matrix of geographical proximity, differences in economic levels, differences in scientific productivity, the similarity of research content, economic and trade cooperation, etc., to support regression analysis. The results are shown in Table 5.

It can be seen from Table 5 that there is a very significant positive correlation between differences in economic levels and differences in scientific productivity, which indicates that countries with similar economic environments tend to have similar scientific research productivity. In addition, the similarity of research content has a positive and significant relationship with geographical proximity and differences in scientific productivity; Economic and trade cooperation has a positive and significant relationship with differences in economic levels and differences in scientific productivity; Except for differences in economic levels, there is a very significant positive correlation between scientific exchanges and other indicators.

Table 5 QAP correlation coefficient analysis results

	Geographical proximity	Differences in economic levels	Differences in scientific productivity	The similarity of research content	Economic and trade cooperation
Geographical	1				
Differences in economic levels	0.000 (0.285)	1			
Differences in scientific productivity	0.000 (0.305)	0.980*** (0.000)	1		
Similarity of research content	0.182*** (0.007)	0.000 (1.000)	0.000*** (0.000)	1	
Economic and trade cooperation	−0.017 (0.206)	0.023** (0.028)	0.020** (0.038)	0.021 (0.193)	1
Scientific Exchange	0.104*** (0.009)	0.026 (0.256)	0.508*** (0.000)	0.295*** (0.000)	0.063*** (0.001)

Note: The regression coefficients in the table are standardized; ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively

4.3.2 Regression analysis of overall influencing factors

Use QAP multiple regression to establish models 1-4, and gradually increase the influencing factors. The results are shown in Table 6. With the gradual addition of variables, the R^2 of the model continues to increase. After all the independent variables are added, the model determination coefficient is 0.351. In terms of significance, all variables except geographic proximity are significant at the 10% level, among which differences in scientific productivity, the similarity of research content, and economic and trade cooperation are significant at the

5% level; from the point of view of the coefficients, All variables play a positive role in promoting scientific exchanges between B&R countries.

It can be seen from Model 1 that geographical proximity and differences in economic levels have a positive impact on scientific exchanges between countries. Among them, the coefficient of geographic distance is 0.103, which is significant at the 1% level, indicating that the closer the distance between countries, the closer the academic exchanges of scientific researchers, which initially verified the hypothesis H1. The coefficient of differences in economic levels is 0.506, indicating that B&R countries are more inclined to conduct scientific exchanges with countries with higher differences in economic levels, which validates hypothesis H2.

After the introduction of the differences in scientific productivity measurement index, the R^2 of the model has improved slightly. The coefficient of differences in scientific productivity is 0.313, which is more significant, which is consistent with our perception. Countries with high scientific research levels have published more highly cited papers, so countries with lower scientific research capabilities are more likely to cite papers published by countries with high scientific research levels. In addition, countries with lower scientific research capabilities are more inclined to cooperate with countries with higher scientific research levels when conducting paper cooperation. The above verifies hypothesis H3.

After introducing the similarity of research content indicator, the R^2 of Model 3 has been significantly improved. The similarity of research content between countries also has a positive effect on scientific communication, with a coefficient of 0.286 and a significance of $0.000<0.01$. It shows that the higher the similarity of research content, the more fields for scientific exchanges between the two countries, which in turn promotes the citation and cooperation of papers between countries, and validates hypothesis H4. But in terms of geographic proximity, the coefficient is 0.051, and the significance is $0.134>0.1$, which overturns the hypothesis H1.

Model 4 shows that after the introduction of economic and trade cooperation measurement indicators, the R^2 of the model has a small increase. The coefficient of Economic and trade cooperation is 0.047, and the significance is $0.016<0.05$. This shows that with the increase in trade between the two countries, the resources in science and technology have increased. Therefore, trade lays the foundation for scientific exchanges between the two countries, and the degree of scientific exchanges between countries will also deepen, verifying hypothesis H5.

In summary, differences in economic levels, differences in scientific productivity, similarity of research content, and economic and trade cooperation all have a positive effect on scientific exchanges, and scientific research capabilities have the greatest impact. For countries, Economic and trade cooperation has a small positive impact on scientific exchanges. The impact of differences in economic levels on scientific exchanges is not significant for other variables, but it also has a certain promoting effect. Geographical proximity has a positive effect on scientific exchanges. There is no obvious impact on scientific exchanges. Before the introduction of similarity of research content and economic and trade cooperation measurement indicators, geographic proximity has a positive and significant impact on scientific exchange networks.

Table 6 QAP multiple regression results

Variables	Model 1	Model 2	Model 3	Model 4
Geographical proximity	0.103***	0.103***	0.051	0.052
	(0.007)	(0.008)	(0.134)	(0.137)
Differences in economic levels	0.506***	0.199*	0.199*	0.195*
	(0.000)	(0.074)	(0.063)	(0.073)
Differences in scientific productivity		0.313**	0.313*	0.315***
		(0.013)	0.063)	(0.007)
The similarity of research content			0.286***	0.284***
			(0.000)	(0.000)
Economic and trade cooperation				0.047**
				(0.016)
R^2	0.266	0.270	0.349	0.351
Observations	4160	4160	4160	4160

Note: The regression coefficients in the table are standardized; ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively

4.4 Analysis of influencing factors of internal scientific communication in community

4.4.1 Correlation analysis of influencing factors for community

It can be seen from the results of the division of communities above that the 1 includes 25 countries, including China, India, Thailand and Singapore. These countries are mainly distributed in East Asia and Southeast Asia, and they are highly relevant in scientific exchanges; Community 2 includes 13 countries such as Russia, Turkey, Poland, and the Czech Republic, and is mainly located in Central and Eastern Europe. Most of the community 2 countries have played a significant role in the scientific exchanges of countries along the B&R, but compared with the community 1 countries, their scientific exchanges are less relevant. According to the results of the division of the national science exchange network associations along the B&R line, the QAP correlation analysis is carried out.

From Tables 7 and 8, it can be seen that for community 1, there is a positive and

Table 7 QAP correlation coefficient analysis results (model 5)

	Geographical proximity	Differences in economic levels	Differences in scientific productivity	The similarity of research content	Economic and trade cooperation
Geographical proximity	1				
Differences in economic levels	0	1			
	–0.501				
Differences in scientific productivity	0.000***	0.1	1		
	0	–0.123			
Similarity of research content	0.138*	0	0.000***	1	
	–0.059	–0.345	0		
Economic and trade cooperation	0.093**	0.037	0.045	0.007	1
	–0.019	–0.175	–0.14	–0.458	

Note: The regression coefficients in the table are standardized; ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively significant relationship between geographic proximity, similarity of research content, and economic and trade cooperation; for community 2, the difference in scientific research productivity and differences in economic levels are strong. The similarity of research content has a positive correlation with geographic proximity.

Table 8 QAP correlation coefficient analysis results (model 6)

	Geographical proximity	Differences in economic levels	Differences in scientific productivity	The similarity of research content	Economic and trade cooperation
Geographical proximity	1				
Differences in economic levels	0 −0.65	1			
Differences in scientific productivity	0.000*** 0	0.718*** −0.007	1		
The similarity of research content	0.387** −0.048	0 −0.92	0 −1	1	
Economic and trade cooperation	0.049 −0.3	0.002 −0.442	−0.014 −0.467	0.086 −0.141	1

Note: The regression coefficients in the table are standardized; ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively

4.4.2 Regression analysis of influencing factors for community

It can be seen from Table 9 that the determination coefficients of community 1 and community 2 are 0.382 and 0.251, respectively, and the adjustment coefficients are 0.378 and 0.231. For the 25 countries in the community 1, including China, from the point of view of significance, differences in scientific productivity, the similarity of research content, and economic and trade cooperation are all significant at the level of 1%; from the point of view of coefficients, all variables play a positive role in the national science exchange network along the B&R. Among them, the coefficient of scientific productivity is 0.564, which is significant at the level of 1%, indicating that scientific productivity has a strong positive role in promoting scientific exchanges between the countries of the organization 1. The countries of the first organization pay more attention to differences in scientific productivity in scientific communication, prefer scientific exchanges with countries with strong scientific research capabilities. The similarity of research content and the coefficient of Economic and trade cooperation are 0.188 and 1.131, respectively, which are also significant at the level of 1%, indicating that the similarity of research content and economic and trade cooperation will promote scientific exchanges between organizations and countries. The coefficients of geographic proximity and differences in economic levels are both greater than 10%, indicating that these two variables have no significant impact on the scientific communication network of community 1.

Analyzing the regression results of community 2 shows that from the point of view of significance, differences in scientific productivity and similarity of research content are both significant at the level of one percent, while geographic proximity is significant at the level of 5%; from the point of view of the coefficients, all variables except geographic proximity play a positive role in the national science exchange network along the B&R. The similarity coefficient of the research content is 0.367, which is significant at the 1% level, indicating that the scientific exchange network of community 2 is strongly and positively affected by the scientific productivity between countries. The coefficient of scientific productivity is 0.003, which is significant at the level of 1%, which means that scientific productivity affects the scientific exchanges among the 13 countries in the organization 2 to a certain extent.

By comparing the regression results of community 1 and community 2, it can be seen that the differences in scientific productivity and the similarity of research content have a positive impact on their respective scientific communication networks, indicating that the countries of these two communities prefer to conduct scientific exchanges within the community. Look for countries with strong scientific research capabilities and similar research disciplines as exchange partners. The difference between the regression results of the overall scientific communication network and the regression results of the scientific communication network of community 1 is that the coefficient of the geographic proximity of the community 2 is -0. 239, which is significant at the level of 5%, indicating that the geographic proximity affects the country of the community 2 Scientific exchanges have a negative impact. Through analysis, it can be seen that the community 2 countries distributed in Central and Eastern Europe are more inclined to conduct scientific exchanges with countries with high research content, and do not pay attention to scientific exchanges with countries that are geographically close. The difference from community 1 is that economic and trade cooperation does not have a significant impact on the scientific exchange network of community 2, which shows that the countries of community 2 do not consider the impact of import and export trade when looking for scientific exchange partners.

Table 9 Results of multivariate regression of community QAP

	Geographical proximity	Differences in economic levels	Differences in scientific productivity	Similarity of research content	Economic and trade cooperation	R^2	Adjusted R^2	Observations
Model 5	0.033	0.008	0.564***	0.188***	0.131***	0.382	0.378	600
	(0.378)	(0.351)	(0.000)	(0.003)	(0.009)			
Model 6	–0.239**	0.321	0.003***	0.367***	0.100	0.251	0.231	156
	(0.026)	(0.738)	(0.000)	(0.002)	(0.114)			

Note: The regression coefficients in the table are standardized; ***, **, * represent significance at the level of 1%, 5%, and 10%, respectively

5 Conclusion and Outlook

Based on the WoS database and the official website of "BELT AND ROAD PORTAL[1]", this paper constructs a high-cited paper citation network, a cooperation network and a scientific exchange network of countries along the B&R from 2013 to 2018, and uses UCINET 6.0 and GEPHI 0.8.2 to conduct an overall and node analysis. In addition, this article also analyzes and summarizes the influence mechanism of geographical proximity, economic level differences, scientific productivity, similarity of research content, economic and trade cooperation and other factors on the "Belt and Road" scientific exchange network and the division of associations, and puts forward five hypotheses. Besides, this paper used QAP

1 https://www.yidaiyilu.gov.cn/

regression to verify these hypotheses, and finally came to the following conclusions:

(1) The countries along the B&R route have relatively close overall scientific exchange networks. China, Singapore, and Iran have relatively high intermediary centralities and are at the center of the B&R scientific network, playing a pivotal role in the operation of the entire scientific network.

(2) The knowledge input and output of the core countries to the science exchange network is not balanced, and China has carried out a large amount of knowledge output to the countries along the B&R route; Compared with countries with similar scientific research capabilities, Russia is more inclined to import knowledge from countries along the B&R.

(3) Differences in economic levels, scientific productivity, similarities in research content, and economic and trade cooperation among countries all have a positive effect on scientific exchanges, and scientific productivity has the greatest impact. The impact of differences in economic levels on scientific exchanges between countries is not significant for other variables, but it also has a certain promoting effect. Geographical proximity has no obvious impact on scientific exchanges between countries. But before the introduction of similarity of research content and economic and trade cooperation measurement indicators, geographic proximity has a high impact on scientific exchange networks.

(4) The variables that affect the science exchange network after the division of communities are quite different. The scientific exchange networks between the communities located in Asia and the European communities countries are both affected by differences in scientific productivity and similarity of research content between countries, while there are big differences in factors such as geographic proximity and economic and trade cooperation.

Through the above conclusions, the author has the following enlightenment:

(1) Countries occupying an important position in the scientific exchange network have played a leading and promoting role in the entire network. Countries such as China, Singapore, and Iran should increase their investment in academic research to increase high-quality innovations, strengthen the knowledge flow of the overall network and help improve the scientific level of the overall B&R countries.

(2) Countries such as China, Singapore, and Iran that are at the hub of scientific exchange networks should strengthen cooperation with other countries. Through the establishment of international scientific research forums and the creation of shared databases, the scientific research capabilities of B&R countries will be improved under the impetus of these "bridge" countries.

(3) Improving the economic level of B&R countries and increasing import and export trade will help to improve the level of scientific communication in the overall network to a certain extent. By strengthening the diversified financing system for countries along the B&R line, supporting construction projects in countries with lower economic levels, and expanding the import and export trade of countries, the national economic level is improved. The exchange of scientific and technological resources between countries is brought about through trade, which ultimately acts on the overall scientific exchange network.

(4) For the community of Asian countries, increasing economic and trade cooperation between countries will help improve the level of scientific exchanges between countries. Asian countries can increase the economic and trade exchanges between countries, promote the flow of resources and talents, and improve the level of scientific exchanges among Asian countries by participating in international import expos and conducting economic and trade

consultations to promote multilateral and bilateral cooperation.

This article starts with the number of highly cited papers published by the country, and studies the structural characteristics and influencing factors of the national science exchange network along the B&R route, but does not consider factors such as time-series changes, the number of national scientific researchers, and national investment funds. Therefore, in future research, research perspectives can be further expanded, influencing factors can be increased, and more in-depth and complete research can be formed.

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