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An Empirical Study on the Relationship between Scientific Collaboration and Knowledge Production of the Countries along the Belt and Road

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Abstract: The Belt and Road Initiative, proposed by the Chinese government in 2013, has exerted great influence, not only on geopolitics and the economy but also on scientific research. This paper investigates the relationship between scientific collaboration and knowledge production of the countries participating in the Belt and Road Initiative project. To this end, we used 314,678 co-authored papers and 6,226,577 paper publications in these countries from 2009 to 2018 to measure scientific collaboration and knowledge production, respectively. Additionally, we selected the country's economic level, the number of specialized disciplines, and political stability as influencing indicators. Methodologically, we established a dynamic panel model and used the generalised method of moments to empirically analyze the relationship between the two and the influencing factors. The results reveal that the scientific collaboration and knowledge production of the countries along the Belt and Road Initiative are mutually reinforcing and show accumulative effects. The number of specialized disciplines and political stability are major influencing factors for scientific collaboration and knowledge production. Knowledge production can facilitate scientific collaboration by increasing number of specialized disciplines, economic development and political stability. Scientific collaboration can weaken the promotion of knowledge production in a similar way, exclusive of economic development.

Keywords: scientific collaboration; knowledge production; dynamic panel model; belt and road initiative; generalised method of moments

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1. Introduction

Within the background of economic globalization, international scientific collaboration is considered as an effective and practical way for all countries to pool ideas and strengths in solving scientific puzzles. By lifting time and space limits, international scientific collaboration can facilitate data sharing within one and among many related disciplines, and greatly utilization efficiency. For countries and scientists themselves, research levels, academic influence, cooperation and communication will be enhanced and more research talents cultivated [1,2].

Some previous studies have proved that knowledge production is positively related to the influence of international scientific collaboration [3–6]. Expanded cooperation may reorganize the national innovation resources [7], and help increase research institutions and authors [8], thus elevating a country's level of creativity. For researchers and research institutions, participating in domestic and international scientific collaboration can improve their knowledge production and influencing factors [9,10]. It is also evidenced that the knowledge production in a region can be stimulated by enhanced centrality of the cooperative network, which is especially true for regions with relatively higher research levels [11]. However, studies have also proved that knowledge production is only enhanced by scientific collaboration under certain circumstances, and unideal collaboration may have no promoting effects [10]. Countries, therefore, need to encourage collaboration that is suitable for themselves in order to benefit from it [12].

In turn, knowledge production increases knowledge accumulation and thus expands countries' engagement in international scientific collaboration and boosts their position in the cooperation network. A large number of studies have revealed that countries with competitive research capabilities are more inclined to actively participate in international scientific collaboration and secure a dominant position in the cooperation network [13,14]. Some scholars have concluded through regression analysis that knowledge production drives scientific collaboration among countries [15]. Additionally, some empirical studies adopted a gravity model with knowledge production as a measurement for scientific research level and certified that countries with outstanding scientific research ability are more likely to engage in collaboration [16].

In 2013, the Belt and Road Initiative (BRI) was proposed which provides an opportunity and platform for scientific collaboration and has received wide attention and engagement from countries around the world, making the study of scientific collaboration among countries along the BRI a hot research topic in recent years. For example, the theoretical analyses conducted by Zhen [17] and Fang [18] elaborated and studied the mode, path, and innovation mechanism of international scientific collaboration under BRI. Additionally, some other scholars adopted network research to analyze the present situation and evolution process of the collaboration network by looking at the overall network structure, core countries, cooperation scope and spatial layout with a cooperation network constituted by papers and patents of countries along the Belt and Road [19–21].

However, a paucity of studies have investigated the two-way relationship between scientific collaboration and knowledge production in BRI countries instead of developed ones. To fill this gap, this study puts the relationship between international scientific collaboration and knowledge production in the background of the Belt and Road Initiative, and discusses the correlation between them and the influencing factors. To answer the following research questions with empirical evidence:

(a) Does a country's engagement in the BRI scientific collaboration promote its knowledge production?

(b) Does a certain amount of knowledge production promote a country's position in the BRI cooperation network?

To answer the above questions, we constructed a paper co-authoring network from 2009 to 2018 among scientists in these countries to measure scientific collaboration and used paper publications to measure knowledge production. Moreover, as the generalised method of moments (GMM) can satisfactorily solve the problem of the interrelationship between two variables and their endogeneity [22,23], we established a dynamic panel model and used GMM to analyze the relationship between scientific collaboration and knowledge production of the countries along the Belt and Road with time-series datasets retrieved from 2009 to 2018. The results of this paper are expected to provide policy references for China and countries along the Belt and Road.

2. Data and Variables

2.1. Data Sources

The identification of countries along the Belt and Road in this paper referred to the Belt and Road Portal (www.yidaiyilu.gov.cn, accessed on 19 September 2022), according to which there are 65 countries (Table 1) joining in the BRI. Among them, 63 were selected for this study (East Timor and Palestine were excluded because of incomplete time series data).

In order to explore the correlation between scientific collaboration and knowledge production, we selected two core variables, paper co-authorship and paper publication, as well as potential impact indicators, to build a regression model, and conducted empirical research with the panel data from 2009 to 2018.

Table 1. List of countries along the Belt and Road and their geographical areas.

Geographical Area	Country
Northeast Asia	Mongolia, and Russia
Southeast Asia	Singapore, Malaysia, Thailand, Vietnam, Indonesia, Philippines, Cambodia, Myanmar, Laos, Brunei, and East Timor
East Asia	China
South Asia	India, Pakistan, Sri Lanka, Bangladesh, Nepal, Maldives, Bhutan
West Asia and North Africa	United Arab Emirates, Kuwait, Turkey, Qatar, Oman, Lebanon, Saudi Arabia, Bahrain, Israel, Yemen, Egypt, Iran, Jordan, Syria, Iraq, Afghanistan, Palestine, Azerbaijan, Georgia and Armenia
Central East Asia	Poland, Albania, Romania, Lithuania, Slovenia, Bulgaria, Czech Republic, Slovakia, Hungary, Macedonia, Serbia, Estonia, Croatia, Latvia, Bosnia and Herzegovina, Montenegro, Ukraine, Belarus, and Moldova
Central Asia	Kazakhstan, Tajikistan, Uzbekistan, Kyrgyzstan, and Turkmenistan

Our dataset of paper was drawn from the Clarivate Analytics' Web of Science (WoS) database hosted and managed by the Observatoire des Sciences et des Technologies at the University of Montreal. We made a search query for co-authored papers in all disciplines from 2009 to 2018, limited to the 63 countries along the Belt and Road; as a result, a total of 314,678 papers were retrieved. Additionally, we made a search query for paper publications similarly, retrieving 6,226,577 papers. The data of the GDP per capita of the countries were extracted from the United Nations database (www.un.org, accessed on 19 September 2022). We extracted the Political Stability and Absence of Violence score in the World Governance Indicators (WGI).

2.2. Variable

In this paper, the variables characterizing scientific collaboration and knowledge production were taken as core variables, i.e., the centrality of nodes in a weighted collaboration network and the number of knowledge production.

The centrality of nodes in a weighted collaboration network (COOP): Taking paper co-authorship as a measurement for scientific collaboration [24], we built a BRI scientific collaboration network, in which each country selected is displayed as a node, and the centrality of each node not only reflects the frequency and closeness of its communication with others but also its position in the network [25–28]. We used Python to construct a collaboration network and sum up the number of papers jointly published by one country and another. The number of co-authored papers in each country refers to the centrality of a node in the network.

The number of knowledge production (PAPER): The paper publication is a standard index to measure knowledge production in bibliometrics and applied statistics [29,30]. We selected the data on the number of papers of all disciplines produced in the 63 countries from the WoS Core Collections, which is expected to reflect the country's high-quality knowledge production in a year. The following hypotheses were proposed:

H1. *A country's participation in the BRI scientific collaboration is beneficial to promoting its knowledge production;*

H2. *The increase in knowledge production will enhance a country's status in the collaboration network.*

Three variables that would affect scientific collaboration and knowledge production were taken as control variables, i.e., the economic level, the number of specialized disciplines, and political stability.

The economic level (GDP): The economic level is not only an important index for a country's economic conditions, but also a foundation of its scientific strength [31,32] and knowledge production [33]. According to Gu et al. [34], it is also one of the reference factors for scientific collaboration among the Belt and Road countries. Regarding many other studies, this paper selects the GDP per capita of the countries to reflect their economic level [35].

The number of specialized disciplines (DISCIPLINE): The more disciplines a country devotes itself to, the more opportunities will be opened for cooperation [36,37], and the more effectiveness will be exerted in publications. As Yang et al. [38] and Li [39] show that the activity index (AI) is commonly used for measuring the degree of discipline specialization, reflecting how professional a country's study is on a specific discipline. In this paper, the number of disciplines with $AI > 1$ was added to reflect the degree of discipline specialization in that year:

$$AI_{ij} = \frac{R_{ij}}{R_{iw}} = \left(P_{ij}/P_j\right)/\left(P_{iw}/P_w\right), \quad (1)$$

In Equation (1), i refers to a discipline; j refers to a country. The numerator R_{ij} reflects the degree of specialization of the discipline i in the country j, in which P_{ij} represents the number of papers published in the discipline i by country j, and P_j represents the total of papers published of the country j. The denominator R_{iw} reflects the professional degree of the discipline i in global academia, in which P_{iw} represents the total of papers published globally in the discipline i, and P_w represents the total of papers published throughout the year.

Political stability (POLITICS): The stability of a country's political environment can affect a country's overall development, including its involvement in scientific collaboration and paper publications [40,41]. In this paper, the scores of Political Stability and Absence of Violence are chosen to reflect the political stability of the countries, referring to the research of Kraay and Mastruzzi [42].

We then put forward the hypotheses:

H3a. *Higher economic level, number of specialized disciplines, and political stability will lead to richer knowledge production*;

H3b. *Higher economic level, specialized research disciplines, and political stability will bring broader participation in scientific collaboration*.

It is necessary to take each core variable both as the explanatory variable and the explanatory variable, to gauge the correlation between the two. Additionally, the above three control variables may exert influence not only on the two variables but also on their correlation. In this case, we considered the following hypotheses:

H4a. *The improvement in a country's economic level, the number of specialized disciplines, and political stability will adjust the positive promotion of its participation in scientific collaboration on knowledge production*;

H4b. *The improvement in a country's economic level, the number of specialized disciplines, and political stability will adjust the positive promotion effect of knowledge production on the status of the scientific collaboration network*.

We integrated the panel data of the above variables into the panel dataset in chronological order and applicable to STATA16 software, thus obtaining the descriptive statistics as shown in Table 2. As seen from the standard deviation of each variable, the values are found to be larger under their respective orders of magnitude, indicating more prominent numerical fluctuations. The minimum value reveals the values of each variable are greater than zero. It can be seen that all variable data need to be processed by a natural logarithm to reduce the influence of skewness and make the regression coefficient conform to the definition of elastic coefficient.

Table 2. Descriptive statistics of raw data of variables.

Variable	Mean	Standard Deviation	Minimum	Maximum
COOP	2781	3804	2.000	31,935
PAPER	9883	35,659	4.000	424,840
GDP	10,955	13,703	442.800	85,076
POLITICS	7.335	1.482	3.000	9.000
DISICIPLINE	41.600	11.170	4.000	71.000

3. Methodology

In order to analyze the correlation between scientific cooperation and knowledge production, we constructed a dynamic panel regression model. As China proposed the Belt and Road initiative in 2013, we used 314,678 co-authored papers and 6,226,577 paper publications in these countries from 2009 to 2018 to measure scientific collaboration and knowledge production, respectively.

(a) The model for the impact of scientific collaboration on knowledge production is built as in Equation (2):

$$\begin{aligned} lnPAPER_{i,t} = \alpha_0 + \alpha_1 lnPAPER_{i,t-1} + \alpha_2 lnCOOP_{i,t} + \alpha_3 lnGDP_{i,t} + \\ \alpha_4 lnDISICIPLINE_{i,t} + \alpha_5 lnPOLITICS_{i,t} + \mu_i + \varepsilon_{i,t}, \end{aligned} \quad (2)$$

in which: i represents the country, t the year; $lnPAPER_{i,t}$ denotes the knowledge production of the explained variable and $lnPAPER_{i,t-1}$ is its first-order lag; $lnCOOP_{i,t}$ denotes the centrality of the core explanatory variables; $lnGDP_{i,t}$, $lnDISICIPLINE_{i,t}$, and $lnPOLITICS_{i,t}$ are control variables, i.e., the economic level, the number of specialized disciplines, and political stability, respectively; α_0 is the intercept term; α_1~α_5 is the core explanatory variable and control variable regression coefficient; μ_i is the country fixed effect that does not change over time; and $\varepsilon_{i,t}$ denotes the random error term. This model contains all variables whose value will be denoted by Boolean attributes {0,1}, similarly hereinafter.

Considering the possible influence of control variables on the relationship between them, we added the interaction term between node centrality and each control variable based on Equation (3):

$$\begin{aligned} lnPAPER_{i,t} = \alpha'_0 + \alpha'_1 lnPAPER_{i,t-1} + \alpha'_2 lnCOOP_{i,t} + \alpha'_3 lnGDP_{i,t} + \\ \alpha'_4 lnDISICIPLINE_{i,t} + \alpha'_5 lnPOLITICS_{i,t} + \alpha_6 lnCOOP_{i,t} * lnGDP_{i,t} + \\ \alpha_7 lnCOOP_{i,t} * lnSUBJECT_{i,t} + \alpha_8 lnCOOP_{i,t} * lnPOLITICS_{i,t} + \mu_i + \varepsilon_{i,t}, \end{aligned} \quad (3)$$

in which $lnCOOP_{i,t} * lnGDP_{i,t}$, $lnCOOP_{i,t} * lnDISICIPLINE_{i,t}$, $lnCOOP_{i,t} * lnPOLITICS_{i,t}$ are interaction terms; $\alpha_0{}'$ is the intercept term; $\alpha_1{}' \sim \alpha_5{}'$ are the core explanatory variables' and control variables' regression coefficient; and $\alpha_6 \sim \alpha_8$ are the interaction regression coefficient.

(b) The model for the impact of knowledge production on scientific collaboration:

$$\begin{aligned} nCOOP_{i,t} = \beta_0 + \beta_1 lnCOOP_{i,t-1} + \beta_2 lnPAPER_{i,t} + \beta_3 lnGDP_{i,t} + \\ \beta_4 lnDISICIPLINE_{i,t} + \beta_5 lnPOLITICS_{i,t} + \mu_i + \varepsilon_{i,t}, \end{aligned} \quad (4)$$

in which $lnCOOP_{i,t}$ represents the node centrality of the explained variable, and $lnCOOP_{i,t-1}$ represents its first-order lag; $lnPAPER_{i,t}$ is the core explanatory variable of knowledge production; β_0 is the intercept term; and $\beta_1 \sim \beta_5$ are the regression coefficients of core explanatory variables and control variables.

In the same way as above, we added the interaction terms of knowledge production and each control variable based on Equation (5), thus obtaining the model as follows:

$$\begin{aligned} lnCOOP_{i,t} = \beta'_0 &+ \beta'_1 lnCOOP_{i,t-1} + \beta'_2 lnPAPER_{i,t} + \beta'_3 lnGDP_{i,t} \\ &+\beta'_4 lnDISICIPLINE_{i,t} + \beta'_5 lnPOLITICS_{i,t} + \beta_6 lnPAPER_{i,t} \\ &* lnGDP_{i,t} + \beta_7 lnPAPER_{i,t} * lnDISICIPLINE_{i,t} \\ &+\beta_8 lnPAPER_{i,t} * lnPOLITICS_{i,t} + \mu_i + \varepsilon_{i,t} \end{aligned} \quad (5)$$

The explanation of variables and coefficients is the same as above.

In order to estimate the model, considering the inclusion of the lag term of the explained variables and that the main explanatory variable and the explained variable are correlational to each other, there may exist endogenous problems, making it related to the error term. In this case, the ordinary least squares (OLS) estimation would not be optimal, for the result may not converge to the actual situation even with a large sample [43].

In econometrics, two estimation methods with instrumental variables are usually used to solve endogeneity problems, namely, two-stage least squares (2SLS) and the Generalised Method of Moments (GMM) [44,45]. GMM is a method to construct estimators. It is based on the assumption that random variables follow specific moments, which are called Moment Conditions. GMM estimation was used to resolve the problem of endogeneity according to time series data variation and controlled group-specific variables and permitted the inclusion of lagged dependent variables [23]. So GMM is more effective than 2SLS when the disturbance term has autocorrelation, and vice versa under the assumption of a spherical disturbance term. In this study, with a small sample of panel data from 63 countries, we chose the dynamic differential GMM model, for the autocorrelation of disturbance term is evidenced [46,47]. In addition, there is an endogenous high-order lag term of explanatory variables in the choice of tool variables, and the Hansen test is needed to verify the rationality of the choice of instrumental variables to ensure the validity of regression results.

4. Correlation Analysis

This paper preliminarily visualized the correlation between scientific collaboration and knowledge production by scatterplots and correlation analysis.

The scatterplot and fitting line of the relationship between scientific collaboration and knowledge production in the Belt and Road countries from 2009 to 2018 (Figure 1) show the distribution and aggregation of data and reflect the essential correlation and dynamic changes of the two core variables in this study.

As shown in Figure 1, most scattered points in each year are relatively densely distributed near the fitting line and tend to move closer year by year. The goodness of fit R^2 climbed from 0.18 in 2009 to 0.27 in 2018, with a peak at 0.28 in 2017, showing an overall upward trend. It can thus be concluded that there is a close relationship between scientific collaboration and knowledge production in BRI countries, which becomes more and more prominent year by year.

Correlation analysis examines two or more correlated variables to gauge the closeness of their correlation. By analyzing the results as shown in Table 3, we can test whether there is a correlation between independent and dependent variables.

The results in Table 3 show that the correlation coefficients among the variables are significant. Among them, the correlation coefficient between scientific collaboration and knowledge production is 0.493, indicating a moderately close correlation between the two core variables. The range of correlation coefficients between the core and the control variables is from 0.293 to 0.762; all indicators are related to the core variables to some extent.

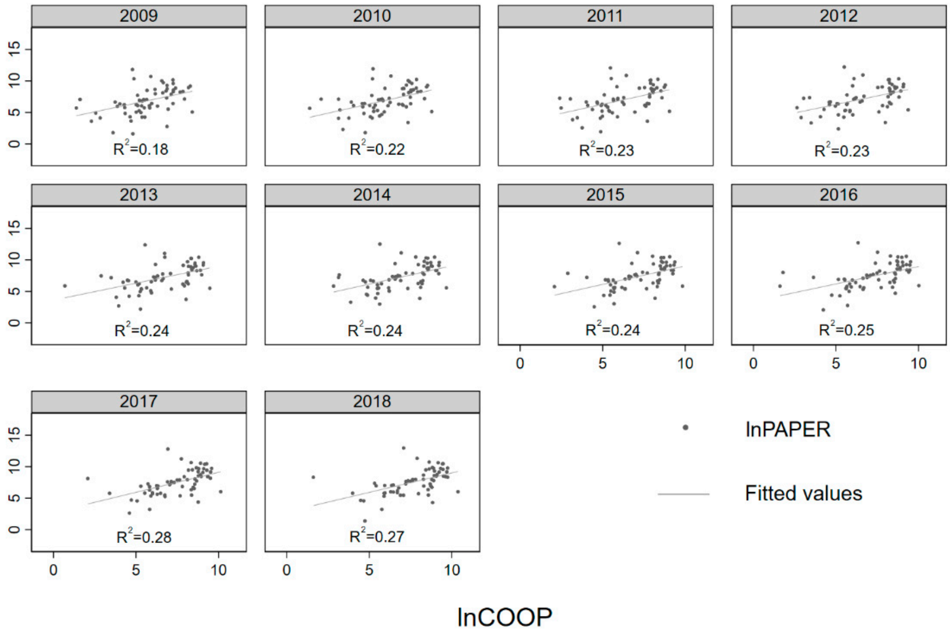

Figure 1. Scatterplots of the relationship between knowledge production and scientific collaboration in BRI countries from 2009 to 2018.

Table 3. Correlation analysis of variables.

	lnPAPER	*lnCOOP*	*lnGDP*	*lnPOLITICS*	*lnDISICIPLINE*
lnPAPER	1.000				
lnCOOP	0.493 ***	1.000			
lnGDP	0.360 ***	0.395 ***	1.000		
lnPOLITICS	0.429 ***	0.762 ***	0.287 ***	1.000	
lnDISICIPLINE	0.293 ***	0.589 ***	0.190 ***	0.677 ***	1.000

Note: *** means significance at 0.01 level.

5. Empirical Results

5.1. Regression Analysis of the Influence of Scientific Cooperation on Knowledge Production

Before regression, a series of tests are needed to substantiate the validity of the regression results. The specific tests and results are as follows:

(a) Multicollinearity test

If there is a high correlation between explanatory variables in the linear regression model, the model estimation will be distorted. Multicollinearity tests are, therefore, carried out for each index, as shown in Table 4.

Table 4. Multicollinearity test of the knowledge production model.

VARIABLES	VIF	1/VIF
lnPOLITICS	2.95	0.339368
lnCOOP	2.66	0.375899
lnDISICIPLINE	1.9	0.527109
lnGDP	1.19	0.841625
Mean VIF	2.17	

The test results show that the variance inflation factor value of each index and the overall average value are between 1.9 and 2.95, all less than 10. Combined with the results in Table 3, the correlation coefficients among all indexes are less than 0.8, indicating that the model is thus well constructed without multicollinearity problems assessed among the comprehensive reflection variables.

(b) Hausman test for explanatory variables

The non-existence of endogeneity in the model should be the premise of traditional OLS regression. However, now, it is inferred that due to the mutual influence between scientific collaboration and knowledge production, scientific collaboration as an explanatory variable is endogenous, which can be verified by the Hausman test. The test result is −79.95, and a negative value means that the original assumption is rejected. Hence, considering the node centrality of explanatory variables is endogenous, we phase out the option of OLS regression.

(c) Test for autocorrelation of disturbance items

H0: There is no autocorrelation in the disturbance term. The result is 12.798, and the p-value of 0.0007 indicates that the original hypothesis is rejected at a significance level of 0.01. In this case, the GMM method would be more effective.

Due to the limitation of the sample size, we chose to build a dynamic difference GMM model. As previously, the two-step method was used for robust regression of the model, and the results are shown in Tables 5 and 6. The models (1A) to (5A) in Table 5 manifest the influence of node centrality on knowledge production with different control variables and the impact of different control variables on knowledge production. The models (6A)~(8A) in Table 6 add the interaction terms between each control variable and the node centrality, which can reveal the moderating effect of each control variable on the influence of node centrality on knowledge production.

Table 5. Regression results of knowledge production GMM model 1.

MODELS VARIABLES	(1A) *lnPAPER*	(2A) *lnPAPER*	(3A) *lnPAPER*	(4A) *lnPAPER*	(5A) *lnPAPER*
L.lnPAPER	0.593 *** (−0.173)	0.706 *** (−0.144)	0.626 *** (−0.200)	0.709 *** (−0.135)	0.553 *** (0.174)
lnCOOP	0.123 ** (−0.058)	0.088 * (−0.046)	0.119 * (−0.068)	0.075 * (−0.043)	0.149 ** (0.0593)
lnGDP		0.024 (−0.058)			−0.002 (0.059)
lnDISICIPLINE			−0.119 (−0.101)		−0.179 * (0.091)
lnPOLITICS				0.199 (−0.121)	0.279 ** (0.139)
AR(1)	0.049	0.039	0.047	0.037	0.054
AR(2)	0.096	0.108	0.096	0.110	0.106
Hansen test	0.295	0.268	0.106	0.252	0.212

Note: In brackets are T statistics corresponding to the regression coefficient and *, **, *** mean significance at the significance levels of 0.1, 0.05 and 0.01, respectively; the same below.

In the regression results of Tables 5 and 6, AR(1) and AR(2) are the results of differential autocorrelation tests for disturbance terms. The Hansen test is for weak instrumental variables. The results of both of the above tests certified the assumption, indicating that the regression results are all valid.

As seen from the results of models (1A) to (5A), the regression coefficients of the lag items of knowledge production are all significant at the level of 0.01, demonstrating that a country's knowledge production has certain inertia and will be influenced by the accumulative effect. However, the regression coefficient of node centrality is significant and positive at the levels of 0.05 and 0.1, which means that the core explanatory variable also has a significant and positive influence on knowledge production, assuming H1 holds.

Models (2A) to (4A) add the level of economic development, the number of specialized disciplines, and political stability as control variables based on the model (1A). The regression coefficients of control variables were, respectively, not significant, indicating that the level of economic development and political stability had positive effects on knowledge production. In contrast, the number of specialized disciplines affected knowledge production in a negative but not significant manner. Presumably, there is an indirect influence caused by interaction between the control variables, or the control variables have no significant impact on the model. Model (5A) will verify this conjecture.

Table 6. Regression results of knowledge production GMM model 2.

MODELS VARIABLES	(6A) *lnPAPER*	(7A) *lnPAPER*	(8A) *lnPAPER*
L.lnPAPER	0.665 *** (0.136)	0.541 *** (0.195)	0.484 ** (0.210)
lnCOOP	0.090 * (0.046)	0.133 * (0.068)	0.161 ** (0.077)
lnGDP	0.011 (0.065)	−0.028 (0.051)	−0.0370 (0.055)
lnDISICIPLINE	−0.124 (0.088)	−0.0657 (0.089)	−0.097 (0.105)
lnPOLITICS	0.266 ** (0.133)	0.359 ** (0.137)	0.405 ** (0.161)
lnCOOP ∗ *lnGDP*	−0.0001 (0.0005)		
lnCOOP ∗ *lnDISICIPLINE*		−0.008 ** (0.003)	
lnCOOP ∗ *lnPOLITICS*			−0.012 * (0.006)
AR(1)	0.040	0.035	0.045
AR(2)	0.105	0.156	0.187
Hansen test	0.578	0.369	0.520

Note: *, **, *** mean significance at the significance levels of 0.1, 0.05 and 0.01, respectively.

Model (5A) adds all the control variables based on model (1A). Among them, the regression coefficient of the economic level is not significant and small in value, indicating that the improvement in the economic level has a slightly negative impact on a country's knowledge production. On the other hand, the regression coefficient of political stability is significant, indicating that the increase in political stability will promote knowledge production. This demonstrates that political stability is an essential prerequisite for the country to carry out scientific research activities.

The regression coefficient of the number of specialized disciplines is significant at the level of 0.1, indicating that the increase in the number of disciplines that the country focuses on research will hurt knowledge production. The inference for this would be that a country may eventually reach a bottleneck when it digs deeply enough in a certain field, making knowledge innovation more difficult and start to shrink. Studying specialized disciplines will also occupy more scientific research resources. If a country's scientific research power is certain, the more specialized disciplines there are, the more dispersed resources will be, resulting in a decline in knowledge production. So H3a is partially established.

The regression coefficient of economic level in the control variables is remarkably stable and does not float with the addition of other control variables. The regression coefficient between the number of disciplines and political stability has changed from insignificant to significant, with obvious fluctuation, implying that there is an interaction among the three control variables which has an impact on knowledge production. This interaction is, however, not obvious at the level of economic development, which substantiates the previous hypothesis.

Models (6A)~(8A) add the interaction terms between economic level, the number of specialized disciplines, political stability and node centrality based on model (5A), respectively. The regression coefficient of the model (6A) is insignificant and extremely small in value, which shows that the level of economic development barely has any influence on the promoting effect of scientific collaboration on knowledge production. It can be seen that the regression coefficients of the model (7A) and model (8A) are significantly negative, indicating that the increase in the number of specialized disciplines and political stability are negatively related to the promoting effect of scientific collaboration on knowledge production. H3a is partially established.

In order to more intuitively show the conditioning of the number of specialized disciplines and political stability to the relationship between knowledge production and scientific collaboration, a corresponding function diagram is drawn (Figure 2).

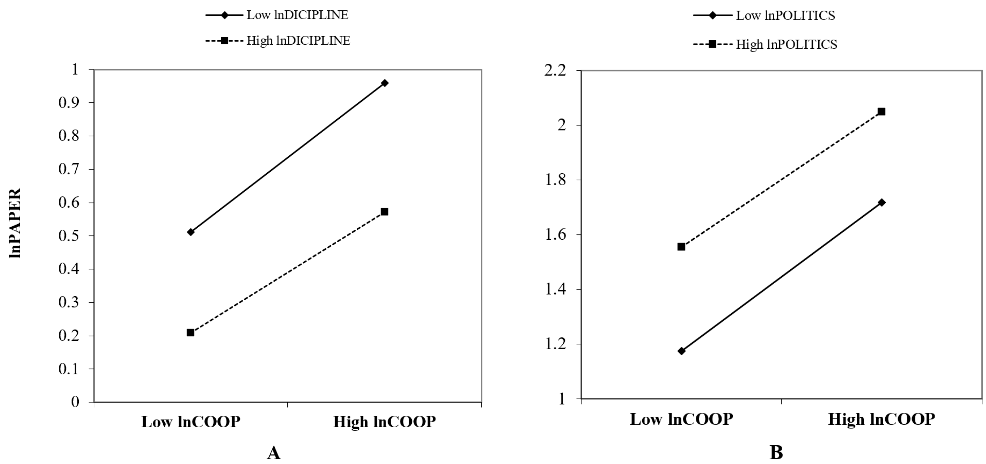

Figure 2. The moderating effects of the number of specialized disciplines and political stability on the influence of scientific collaboration on knowledge production. (**A**). The moderating effect of the number of specialized disciplines on the influence of scientific collaboration on knowledge production. The values of lnCOOP are divided into high value (dotted line) and low value (solid line) by adding and subtracting the standard deviation based on its average value. The other variables are processes in the same way. The slope of solid line indicates the negative regulation of the number of specialized disciplines. The slope of dotted line indicates the positive regulation of the number of specialized disciplines. The larger absolute value of the slope of the solid line or the slope of the dotted line indicates that its moderating effect is more significant. (**B**). The moderating effect of political stability on the influence of scientific collaboration on knowledge production. Its explanation is similar to that of Figure 2A.

The two straight lines in Figure 2A are at a similar slope, with the solid one slightly steeper than the dashed, indicating that when the number of specialized disciplines is small, the positive impact of scientific collaboration on knowledge production is more significant. In this sense, the number of specialized disciplines has a certain negative influence on the relationship. In Figure 2B, the lines have a similar slope, with the solid line slightly steeper than the dashed one. Similarly, the similar but subtly different slope shows that political stability is slightly negatively related to the relationship.

5.2. Regression Analysis of the Influence of Knowledge Production on Scientific Cooperation

It has been tested that no multicollinearity exists in the index related to this regression (Table 7), the knowledge production of explanatory variables is endogenous (the result is 203, the *p*-value is 0), and the disturbance term is autocorrelation (the result is 32.408, the *p*-value is 0). The testing process is the same as above.

Table 7. Multiple collinearity test of scientific collaboration model.

VARIABLES	VIF	1/VIF
lnPOLITICS	2.1	0.475335
lnDISICIPLINE	1.85	0.541032
lnPAPER	1.33	0.754599
lnGDP	1.18	0.848605
Mean VIF	1.61	

Similarly to above, the two-step method is used for a robust regression test of the dynamic difference GMM model with scientific collaboration and interaction terms. The results are shown in Tables 8 and 9. In both tables, the AR(1) p-value is less than 0.05, and the AR(2) and Hansen test p-values are greater than 0.05. This means the model stood the above two tests and is able to yield valid regression results. The following is the result analysis:

Table 8. Regression results of GMM model of scientific collaboration 1.

MODELS VARIABLES	**(1B) *lnCOOP***	**(2B) *lnCOOP***	**(3B) *lnCOOP***	**(4B) *lnCOOP***	**(5B) *lnCOOP***
L.lnCOOP	0.690 *** (−0.091)	0.720 *** (−0.078)	0.678 *** (−0.086)	0.771 *** (−0.064)	0.703 *** (−0.087)
lnPAPER	0.592 *** (−0.222)	0.410 ** (−0.179)	0.449 ** (−0.175)	0.288 ** (−0.123)	0.428 ** (0.190)
lnGDP		−0.013 (−0.121)			0.003 (−0.103)
lnDISICIPLINE			0.710 ** (−0.293)		0.727 ** (−0.302)
lnPOLITICS				−0.218 (−0.316)	−0.426 * (−0.238)
AR(1)	0.018	0.018	0.014	0.018	0.015
AR(2)	0.436	0.487	0.678	0.512	0.692
Hansen test	0.102	0.209	0.161	0.199	0.279

Note: *, **, *** mean significance at the significance levels of 0.1, 0.05 and 0.01, respectively.

Table 9. Regression results of GMM model of scientific collaboration 2.

MODELS VARIABLES	**(6B) *lnCOOP***	**(7B) *lnCOOP***	**(8B) *lnCOOP***
L.lnCOOP	0.699 *** (0.0754)	0.713 *** (0.0699)	0.618 *** (0.0923)
lnPAPER	−0.639 (0.501)	−0.413 (0.448)	−0.325 (0.372)
lnGDP	−0.786 * (0.405)	0.0491 (0.120)	0.00986 (0.114)
lnDISICIPLINE	0.730 *** (0.272)	−0.775 (0.850)	0.779 *** (0.278)
lnPOLITICS	−0.331 (0.302)	−0.382 (0.253)	−3.219 ** (1.321)
lnPAPER ∗ *lnGDP*	0.121 ** (0.0601)		
lnPAPER ∗ *lnDISICIPLINE*		0.212 * (0.126)	
lnPAPER ∗ *lnPOLITICS*			0.449 ** (0.207)
AR(1)	0.014	0.016	0.021
AR(2)	0.763	0.682	0.824
Hansen test	0.975	0.997	0.812

Note: *, **, *** mean significance at the significance levels of 0.1, 0.05 and 0.01, respectively.

From the models (1B) to (5B), the regression coefficients of the lag term of the node centrality are all significant at the level of 0.01, showing significant influences of lag terms on the node centrality. This implies that a country's participation in scientific collaboration activities is also influenced by the accumulative effect. However, the regression coefficient of knowledge production is significant and positive at the levels of 0.01 and 0.05, which means that knowledge production also has a significant positive influence on node centrality; H2 holds.

Models (2B)~(4B) involve the level of economic development, the number of specialized disciplines, and political stability as control variables based on the model (1B), respectively. Among them, the regression result of the number of specialized disciplines is significant, indicating that the number of specialized disciplines has a notable positive impact on node centrality. On the other hand, the regression results of the two control variables are not significant. Presumably, either there is an indirect influence caused by the interaction between the control variables, or the control variables have no significant impact on the model, which will be verified by Model (5B).

Model (5B) is the comprehensive model with all control variables included. Among them, the regression coefficient of the economic level is not significant and small in value, indicating that economic development only marginally promotes a country's knowledge production; on the other hand, the regression coefficient of the number of disciplines is significantly positive at a 0.05 level. It means that the increase in the number of national specialized disciplines will elevate network centrality.

The regression coefficient of political stability is significant at the 0.1 level. It means that the increase in political stability score will abate the node centrality. One possible reason is that countries with unstable political environments need to cooperate with other countries in certain specific disciplines. For example, the top three disciplines published by Syria in the core journal literature from 2009 to 2018 are agronomy, plant sciences and nuclear science technology. In recent years, Syrian agriculture has been on the verge of collapse because of the war. In order to restore agriculture, which is a pillar of its national economy, and enhance military strength, Syria has a solid demand to cooperate with other BRI countries in related papers to improve the scientific level of agriculture and military. Generally speaking, many of the BRI countries are in constant political turmoil, so the geopolitical factors may also be the reason why the actual results deviated. So, H3b is partially established.

The significance of the regression coefficient between the level of economic development and the number of specialized disciplines in the control variables remained stable and did not fluctuate despite the inclusion of other control variables. However, the regression coefficient of political stability changed from insignificant to significant, with obvious fluctuation. It shows interaction among the three control variables, and it impacts knowledge production. The interaction between variables is reflected in political stability but not the other two variables.

The models (6B)~(8B) include the interaction items of the economic level, the number of specialized disciplines, political stability and knowledge production based on model (5B), respectively, which can show the adjustment of the relationship between knowledge production and scientific collaboration through three control variables. It can be seen that the regression coefficients are all significantly positive, indicating that the increase in the three control variables will enhance the promotion of knowledge production to scientific collaboration, so H4b is established.

In order to more intuitively show the influence of the three control variables, a function diagram is drawn (Figure 3). The slope of the dotted line in Figure 3A is steeper than that of the solid line, which indicates that the positive influence of knowledge production on scientific collaboration is more significant when the economy is more developed, so the level of economic development plays a positive role. In Figure 3B, there are a negative-to-positive dotted line and a negative solid line, which indicate that when the number of specialized disciplines is higher, the positive influence of knowledge production on scientific collaboration is more significant. This is because the level of economic development plays a positive role. The slope of the dotted line in Figure 3C is steeper than that of the solid line, which indicates that the positive influence of knowledge production on scientific collaboration is positively related to political stability which plays a positive role in the relationship between the two.

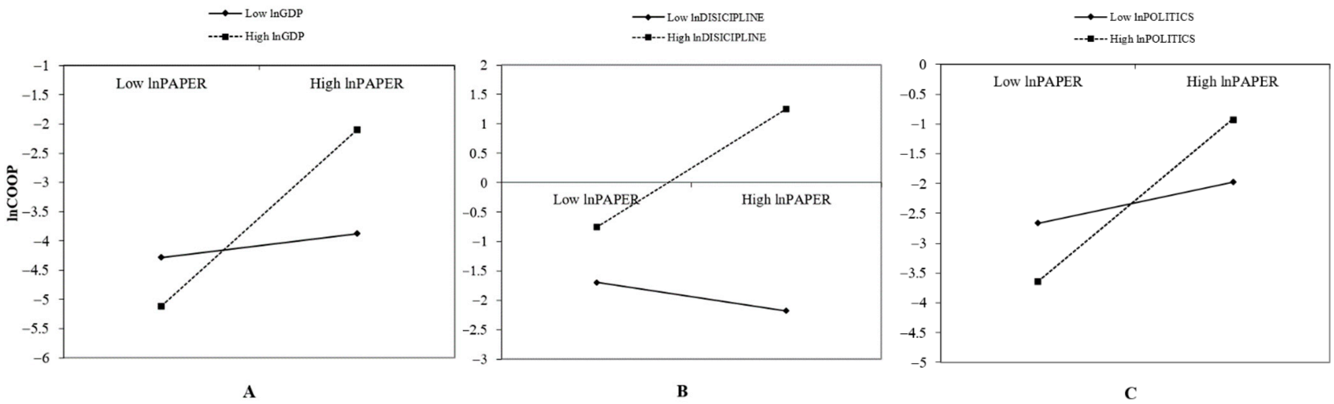

Figure 3. The moderating effects of the level of economic development, the number of specialized disciplines and political stability on the influence of knowledge production on scientific collaboration. (**A**). The moderating effect of the level of economic development on the influence of knowledge production on scientific collaboration. The values of lnPAPER are divided into high value (dotted line) and low value (solid line) by adding and subtracting the standard deviation based on its average value. The other variables are processes in the same way. The slope of solid line indicates the negative regulation of the level of economic development. The slope of dotted line indicates the positive regulation of the level of economic development. The larger absolute value of the slope of the solid line or the slope of the dotted line indicates that its moderating effect is more significant. (**B**). The moderating effect of the number of specialized disciplines on the influence of knowledge production on scientific collaboration. (**C**). The moderating effect of political stability on the influence of knowledge production on scientific collaboration.The explanation for Figure 3B,C is similar to that of Figure 3A.

5.3. Summary

We further refine and summarize the results, and visualize and the relationship between knowledge production and scientific collaboration and their influencing factors, as shown in Figure 4, in which "+" and "−" represent positive and negative influences, the solid and dotted lines refer to direct and indirect influences, the thickness of the lines represents the degree of influence, and the greyscale of the lines represent the magnitude of significance. We, therefore, have the following findings:

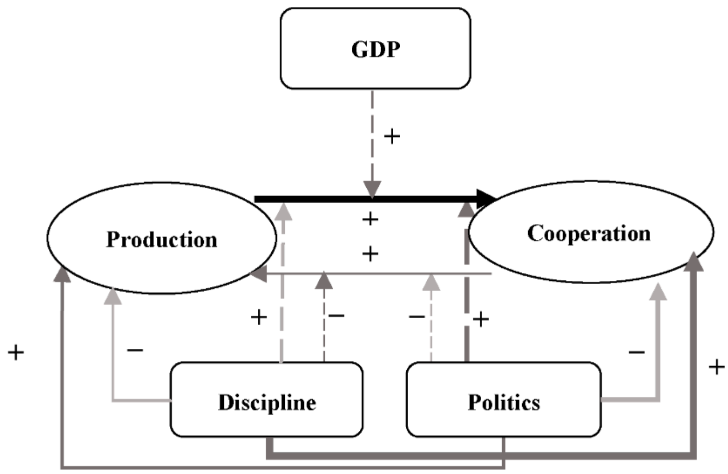

Figure 4. Relationship between knowledge production, scientific collaboration and influencing factors.

(a) Knowledge production and scientific collaboration have accumulative effects, meaning the current knowledge production or the node centrality in the network can be affected by what it accumulates in the past. The improvement in a country's knowledge production can promote scientific progress, which will in turn facilitate knowledge production. If a country's status in the BRI scientific collaboration network is constantly improving, its international influence and cooperation will be expanded.

(b) Knowledge production and scientific collaboration are mutually reinforcing. A country's participation in BRI scientific collaboration can raise its status in the network, and uplift its knowledge production and scientific level. Additionally, improved knowledge production represents enhanced research ability, which will in turn encourage a country's involvement in the scientific collaboration and status in the network. This mutually reinforcing relation helps all countries that participate in the BRI scientific collaboration continuously absorb nutrients from the cooperation, enhance their scientific strength and comprehensive strength, and at the same time vitalise the cooperation network.

(c) The number of disciplines and political stability are important factors of national knowledge production and scientific collaboration. The increase in the number of specialised disciplines will reduce a country's knowledge production but improve its status in the collaboration network. Improved political stability will increase knowledge production yet hinder scientific collaboration. The two influencing factors can affect the correlation between knowledge production and scientific collaboration by together weakening the promoting role of scientific collaboration to knowledge production but improving that of knowledge production to scientific collaboration. Hence, instead of having overabundant focuses, it is advisable to rationally allocate scientific research resources depending on a country's specialisation and actual needs. Political and social stability is an important prerequisite for national development, and countries with unstable political environment tend to depend more on cooperation.

(d) Economic development will enhance the positive impact of knowledge production on scientific cooperation. It shows that more prosper economy is conducive for a country to participate in BRI scientific collaboration, in which knowledge production serves as a bridge. As the premise of comprehensive development, the economy shall be the focal point of all countries.

6. Conclusions

In this study, 63 countries along the Belt and Road were taken as the research object. The co-authored paper network from 2009 to 2018 was constructed to measure scientific collaboration, and paper publication was used to measure knowledge production. On this basis, a dynamic panel model was established. The relationship between scientific collaboration and knowledge production and its influencing factors was empirically analyzed using the generalized method of moments.

Through empirical analysis, we have reached the following conclusions: knowledge production and scientific collaboration have accumulative effects, meaning the current knowledge production or the node centrality in the network can be affected by what it accumulates in the past; knowledge production and scientific collaboration are mutually reinforcing; the number of disciplines and political stability are important factors that simultaneously affect national knowledge production and scientific collaboration; and economic development will enhance the promoting role of knowledge production to scientific collaboration.

According to the research conclusion, we provided several policy recommendations for the development of countries along the Belt and Road and the promotion of the initiative.

(a) To strengthen the scientific collaboration along the Belt and Road and build a BRI scientific and technological innovation community. This study reveals the mutually reinforcing relationship between scientific collaboration and knowledge production, which emphasizes the significance of BRI. Countries should strengthen exchanges and cooperation under the BRI to improve their scientific research level and strength to raise their status in the cooperation network, thus forming a virtuous circle. Through this, the cooperation among BRI countries will be closer in an optimized network, and a BRI scientific innovation community will be thus built with the joint efforts of all countries.

(b) Countries need to distribute their scientific research resources in various disciplines in an appropriate manner, to balance discipline specialization and diversification. A country cannot afford to inappropriately allocate its limited scientific research resources in certain disciplines which leads to shrunk knowledge production. So, finding a balance between the depth and breadth of research is necessary.

(c) Countries with an unstable political environment can strengthen scientific collaboration and enhance their scientific strength through the BRI platform. For these countries, there may be a paucity of wonderful global collaboration opportunities, so BRI may become an ideal platform for scientific collaboration and a source of knowledge production.

In general, the Belt and Road Initiative has brought new opportunities for the development of countries along the route and even the whole world. The BRI countries are enjoying a win–win situation through scientific collaboration and innovation, which generates a steady stream of power for the countries' scientific development and injects vitality into the cooperation network. However, due to the limited time and space of this study and the complexity of influencing factors in scientific collaboration and knowledge production, there remains room for improvement in this study. Further research should be undertaken to provide a more objective theoretical reference for the implementation of BRI and the development of the collaborative innovation system.

This study has several limitations. First, owing to the difficulty of data acquisition and processing, this study only selects the research data from 2009 to 2018. Second, this study only reveals the relationship between scientific collaboration and knowledge production based on the paper publication data. Other data could be studied, such as patents or citations. Moreover, the impact mechanism could be tested in detail in future research.

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