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Spatial-temporal Evolution and Determinants of the Belt and Road Initiative: A Maximum Entropy Gravity Model Approach

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Abstract: The spatial interaction model is an effective way to explore the geographical disparities inherent in the Belt and Road Initiative (BRI) by simulating spatial flows. The traditional gravity model implies the hypothesis of equilibrium points without any reference to when or how to achieve it. In this paper, a dynamic gravity model was established based on the Maximum Entropy (MaxEnt) theory to estimate and monitor the interconnection intensity and dynamic characters of bilateral relations. In order to detect the determinants of interconnection intensity, a Geodetector method was applied to identify and evaluate the determinants of spatial networks in five dimensions. The empirical study clearly demonstrates a heterogeneous and non-circular spatial structure. The main driving forces of spatial-temporal evolution are foreign direct investment, tourism and railway infrastructure construction, while determinants in different sub-regions show obvious spatial differentiation. Southeast Asian countries are typically multi-island area where aviation infrastructure plays a more important role. North and Central Asian countries regard oil as a pillar industry where power and port facilities have a greater impact on the interconnection. While Western Asian countries are mostly influenced by the railway infrastructure, Eastern European countries already have relatively robust infrastructure where tariff policies provide a greater impetus.

Keywords: spatial interaction model; the Belt and Road Initiative (BRI); Maximum Entropy (MaxEnt) gravity model; spatial pattern; China

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1 Introduction

The spatial paradigms inherent in the Belt and Road Initiative (BRI) reveal the vision of common value and multilateral collaboration through joint consultation, contribution, and sharing (Huang, 2016; Summers, 2016). From the geographical and regional perspectives, the BRI is a comprehensive project of trans-regional and multilateral connectivity expected to connect vibrant East Asia and developed Europe, which will significantly reduce the cost of trade, contribute to overall regional economic integration, and foster regional stability and prosperity (Liu, 2015; Kolosov et al., 2017). Since the BRI was proposed by China in 2013, an increasing number of countries across Eurasia have shown great interest in joining this initiative to promote bilateral relations and mutually beneficial cooperation (Godement, 2015). However, the implementation of the BRI also

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faces a number of challenges and constraints (Tekdal, 2018), including environmental degradation (Tracy et al., 2017), China's intentions of addressing its own dilemmas, and capacity deficits in dealing with the complex situations in Central Asia, South Asia, and the Middle East (Wang, 2016; Pavlićević and Kratz, 2018; Shen and Chan, 2018). The development of BRI is regarded as a part of the global sustainable development. It embodies the principles of the Charter of the United Nations and gradually becomes the common responsibility of all countries (Jing, 2005; Hong, 2016; Ramasamy et al., 2017). The formulation of regional development based on spatial analysis is an effective way to optimize regional cooperation and sustainable development (Tong and Murray, 2012), despite little research has been done concerning spatial-temporal evolution and determinants in the BRI regions.

Spatial interaction models describe and predict spatial flows of people, commodities, capital, and information, which are appropriate for modeling data that are associated with a link or pair of locations in geographic space (Smith and Slater, 1981; Roy and Thill, 2003). Original models rested on analogies with the physical world of interacting particles and gravitational force based on the causal multiple regression models following the Newtonian paradigm (Ravenstein, 1885; Zipf, 1946; Timmermans, 1981). However, the analogy-type gravity model has been criticized for its lack of a theoretical basis, implying the hypothesis of equilibrium points and does not considering when or how to achieve it (Sayer, 1976; Fotheringham, 1983; Matyas, 1997). Contemporary models have progressed from comparative static models to dynamic models (Casetti, 1981; Griffith, 1982; Black, 1983; Nijkamp and Reggiani, 1988). Wilson provided a theoretical background for spatial interaction models based on entropy maximization (Wilson, 1971; 1975), extended by many others (Clarke et al., 1998; Pooler, 1994), which significantly shifted the analogy paradigm to Boltzmann statistical mechanics (Gordon, 2010; O'Kelly, 2010). Statistical procedures, such as linear or Poisson regression have been utilized for parameter estimation (LeSage and Pace, 2008), the neural network approach (Black, 1995; Fischer and Reismunn, 2002; Fischer and Reggiani, 2005), DEA window analysis (Cuccia et al., 2017), percolation theory (Piovani et al., 2017), weighted ego network (Liu et al., 2018a; 2018b), and many other methods have also been applied in modeling spatial interaction (Chun and Griffith, 2011; Alamá-Sabater et al., 2015). Theoretically, there is a tendency to apply new methods in measuring the complexity and systematicity of geographical systems, but many empirical studies still use an analogy-type gravity model.

Existing literature has studied the investment environment (Li et al., 2019a), scientific collaboration network (Gui et al., 2019), trade efficiency (Fan et al., 2016), traffic patterns (Wang et al., 2015), flow distribution (Sheu and Kundu, 2018), agricultural development (Li et al., 2018; Liu et al., 2019), environmental degradation (Hafeez et al., 2018), nomadic ecology (Frachetti et al., 2017; Hermes et al., 2018), and resource cooperation (Dong et al., 2015; Yu et al., 2015) within the framework of BRI. By constructing the integration index, the existing literature analyses the impact of cultural integration, tariff reduction and trade facilitation on inter-regional trade relations (Wang, 2017; Chung, 2018). An empirical study conducted a multidimensional survey of BRI's national structure, including trade networks and core-peripheries (Zou and Liu, 2016), demographic and urbanization evolution (Liu et al., 2018c), electric power consumption (Shi et al., 2018), and using night-time light date as the substitute for GDP (Li et al., 2019b). Frequent trade and exchanges between East Asia and Europe confirm that Eurasia cooperation has brought prospects for development in different regions and commodity types. The heterogeneity of resources endowment, geographical location, history, culture, customs and habits of BRI countries determines the differences of their development characteristics (Rodemann and Templar, 2014; Dąbrowski et al., 2018; Liao et al., 2018). Therefore, spatial interaction in BRI requires more detailed analysis of connectivity strength and its determinants at regional scale (Clinch and O'Neill, 2009).

The primary purpose of this paper is to explore the interconnection intensity, spatial difference, and dynamic mechanism, taking BRI-relevant countries as an example, and it includes the following activities: 1) estimating and monitoring the interconnection intensity and dynamic character of bilateral relations; 2) assessing and analyzing the determinants and mechanisms of spatial evolution, which transmit and reflect heterogeneous distribution; and 3) identifying the existing barriers and opportunities for developing and promoting regional relations.

2 Materials and Methods

2.1 Study area

The BRI is an open-ended network system without official map or fixed geographical scope. Since the BRI was proposed in 2013, the participating countries has gradually expanded from 65 countries in Eastern Europe and Asia to Africa, Latin America, and other regions, forming a strategic regional belt for the economic integration of Asia, Europe, and Africa. According to United Nations M49 geographical divisions, this paper takes the original 65 countries as the research objects and divides them into five sub-regions: 11 countries in Southeast Asia, 9 countries in South Asia, 5 countries in Central Asia, 19 countries in West Asia and North Africa, and 21 countries in East Europe (Table 1). Still, the visions and actions identifies six land corridors: the New Eurasian Land Bridge; the China–Mongolia–Russia Economic Corridor; the China–Central Asia–West Asia Economic Corridor; the China–Indochina Peninsula Economic Corridor; the China–Pakistan Economic Corridor; and the Bangladesh–China–India–Myanmar Economic Corridor. Along with these corridors, the Maritime Silk Road specifies two more routes: one running through the South China Sea and the Indian Ocean to ports in the Mediterranean, and the other through the South China Sea to the South Pacific (Fig. 1).

2.2 Methodology

Agglomeration of economic activity and uneven allocation of resources are common features of regional development (Zobler, 1958; Parr, 2014). Spatial interaction models offer an opportunity to explore the significance of these spatial disparities (Miller and Wentz, 2003; Murphy and O'Loughlin, 2009; Curran, 2012). Although spatial interaction models originated at the end of the nineteenth century following the Newtonian paradigm (Curry, 1972), they now have solid theoretical economic foundations grounded in probabilistic theory, discrete choice modeling, and entropy maximization. Entropy is a measure of the uncertainty of random variables. Maximum Entropy (MaxEnt) is the case where the distribution is the most uniform after a random event satisfies all known constraint functions, namely, the approximate solution of the maximum possible state of a random event (Gordon, 2010). Entropy in urban and regional modelling introduced a new framework for constructing spatial interaction and associated location models. The MaxEnt gravity approach makes spatial interaction models not just mechanical tools for empirical analysis, but also a framework for theoretical and structural analyses (Baltagi and Egger, 2016).

The MaxEnt gravity model regards the spatial interconnection intensity of two countries as a complex system of particle movement. This application of the method reveals a general idea. A disorganized complexity system can be define as an entropy function. Then under a set of constraint equations we can find the most probable state, which then becomes the model equations by maximizing the entropy subject to these constraints. For example, the transport model can be taken as production-attraction constrained. Similarly, the MaxEnt gravity model of geo-economic spatial interconnection is constructed by constraining functions of supply power of exporting country, demand power of importing country and generalized transportation cost. Then we constructed the MaxEnt gravity model of interconnection based on Boltzmann's standard formula:

Table 1 The group of countries along the Belt and Road Initiative

Sub-region	Country
Southeast Asia 11	Brunei Darussalam, Indonesia, Cambodia, Laos, Myanmar, Malaysia, Philippines, Singapore, Thailand, Timor-Leste, Vietnam
South Asia 9	China, India, Bangladesh, Pakistan, Sri Lanka, Nepal, Afghanistan, Maldives, Bhutan
Central Asia 5	Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan, Tajikistan
West Asia and North Africa 19	UAE, Saudi Arabia, Turkey, Israel, Qatar, Egypt, Kuwait, Iraq, Iran, Oman, Bahrain, Jordan, Azerbaijan, Lebanon, Georgia, Yemen, Armenia, Syria, Palestine
East Europe 21	Mongolia, Russia, Poland, Czech Republic, Hungary, Slovakia, Romania, Ukraine, Slovenia, Lithuania, Belarus, Bulgaria, Serbia, Croatia, Estonia, Latvia, Bosnia and Herzegovina, Macedonia, Albania, Moldova, Montenegro

Note: The classification of sub-region is based on the United Nations M49 geographical divisions

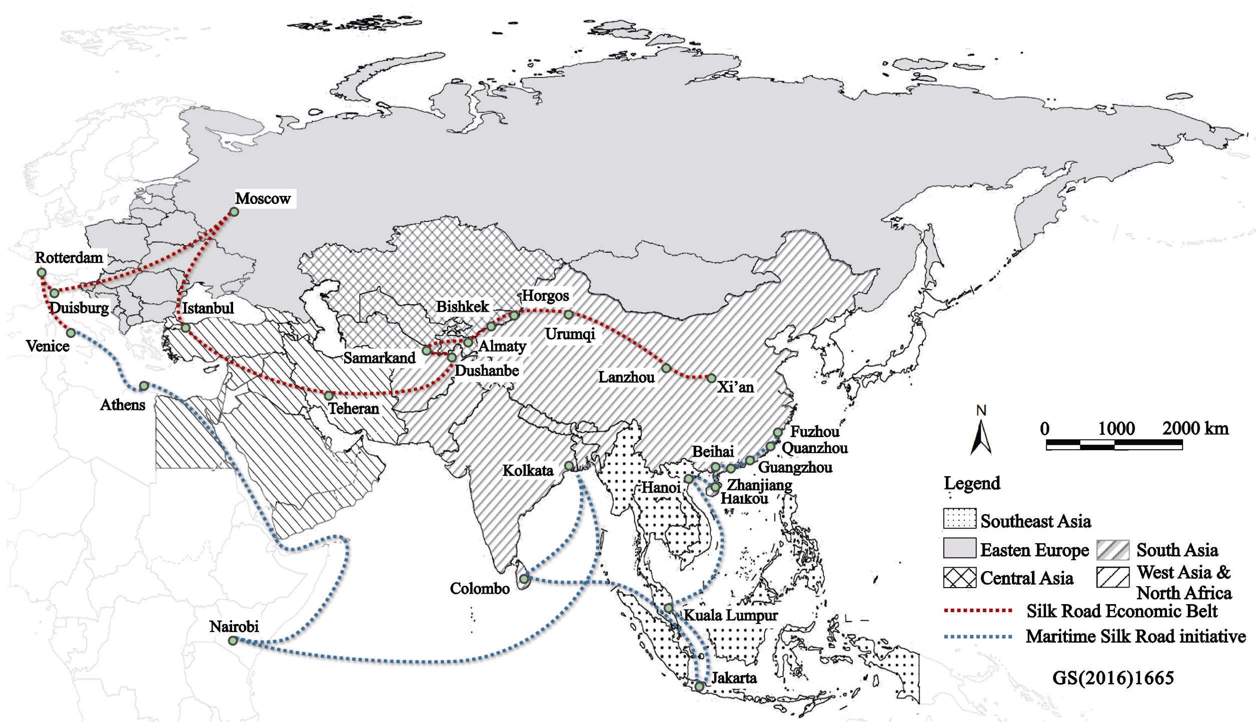

Fig. 1 The group of countries along the Belt and Road Initiative

$$\mathrm{Max}T = -\sum_{ij} T_{ij} \log(T_{ij}) \tag{1}$$

$$T_{ij} = A_i E_i P_j W_j^{\alpha} \exp(-\beta r_{ij}) \tag{2}$$

And $$A_i = 1/[\sum_k W_k^{\alpha} \exp(-\beta r_{ik})] \tag{3}$$

where Formula (2) is the classical form of the MaxEnt gravity model, T_{ij} is the trade flow moving from country i to country j, Max$T$ is the entropy maximization of T_{ij}, E_i is the total export supply of i, P_j is the population of country j, W_k^{α} is the import demand of j, r_{ij} is the surface distance of the capital between i and j, β is the spatial deterrence coefficient, and A_i is the proportionality coefficient. $P_j W_j^{\alpha}$ represents the import demand force of the importing country, $\exp(-\beta r_{ik})$ represents the distance attenuation function of the two countries, $1/A_i$ represents the economic interconnection intensity F_i of country i, and T_i is the regional gravity intensity of country i:

$$F_i = \sum_k W_k^{\alpha} \exp(-\beta r_{ik}) \tag{4}$$

$$T_i = \sum_j T_{ij} \tag{5}$$

In order to monitor the spatial heterogeneity and evolution trend of interconnection intensity, this paper uses space-time pattern mining to analyze the spatial patterns and development trends of sequence evolution in different periods. Studies on scalar independence and scale effect have shown that the smaller the scale, the more significant the scale-dependent will be (Ord and Getis, 1995). Therefore, this paper uses local spatial analysis to study the spatial and temporal evolution pattern of interconnection intensity among the BRI countries from 2000 to 2016. Optimized hot-spot analysis was used to analyze cold and hot spots with interconnection intensity based on a 90% significance level, and an false discovery rate (FDR) correction method was used to correct multiple tests and spatial dependence based on the Geti-Ord G_i^* index. Spatial-temporal cubes were created by space-time pattern mining. Hot-spot analysis was done for each column of the cube based on spatial distance and the time-step of the domain. The Mann-Kendall method was used to identify the trends of hot and cold spots.

$$G_i^*(d) = \sum_{i=1}^{n} w_{ij}(d)T_i / \sum_{i=1}^{n} T_i \tag{6}$$

$$q(i) = b(i) \times \text{lenth}(b) / \text{rank}(b) \tag{7}$$

where w_{ij} is the spatial weight matrix. In this paper, the Rook matrix is used to establish the weight relation of space. The adjacent space is 1 and the non-adjacent space is 0. If the G^* value is significantly positive, it indicates that the value around region i is high and belongs to the hot-spot region; otherwise, it is a cold-spot region. b represents the probability of a random distribution of spatial mode, q is the corrected b, length(b) is the total number, and rank(b) is the queue number.

Geodetector is a new statistical method to detect spatial stratified heterogeneity and reveal the driving factors behind it (Wang and Xu, 2017). In order to understand the factors that contribute to explaining these relations, the Geodetector method was applied to detect the influence and determinants. By using this approach, the interaction among multiple factors is identified and the influence factors of regional economic competitiveness are analyzed. The model is as follows:

$$V_{D,U} = 1 - \frac{1}{n\delta_U^2} \sum_{i=1}^{m} n_{Di} \delta_{U_{ni}}^2 \tag{8}$$

where $V_{D,U}$ is the detection index of influence factors of the interconnection intensity, n is the number of samples, m is the number of secondary regions, n_{Di} is the number of sub-regional samples, δ_U^2 is the variance of interconnection intensity, and $\delta_{U_{ni}}^2$ is the variance of the interconnection intensity of secondary regions. If $\delta_{U_{ni}}^2 \neq 0$, the model stands and the value range of $V_{D,U}$ is [0, 1]. When $V_{D,U} = 0$, the interconnection intensity is randomly distributed. The larger the value of $V_{D,U}$, the greater the influence of this factor on the interconnection intensity.

2.3 Date sources

In this paper, the basic data sources are Integrated Network for Societal Conflict Research (INSCR, http://www.systemicpeace.org/inscrdata.html), Global Competitiveness Index (GCI, https://www.weforum.org/), World Development Indicators (WDI, https://data.worldbank.org.cn/indicator), International Statistics Yearbook (ISY, https://www.chinayearbooks.com/tags/international-statistical-yearbook), and Coordinated Energy-related PPIs actions for cities (CEPPI, https://ceppi.eu/home/), covering 65 BRI countries and the time span is from 2000 to 2016. The data for GDP, population, per capita income, total import and export volume, net inflow of foreign direct investment, and international tourism revenue of various countries are from the WDI database. Data for distance and language similarity between two countries were obtained from the CEPII database. Other influence factors are derived from INSCR and GCI. Due to the large difference in dimensions of the national economic indicators, this paper uses the extremum data method for standardization. Considering the possible non-stationary characteristics of time series, this paper used Eviews 8.0 to carry out the AFD test on the variables. The test results showed that all variables met the stationarity requirements after the first-order difference.

ArcGIS was used to grade the indicators by natural clustering, among which the vulnerability of countries and trade tariffs were scored in reverse. Due to the large amount of missing data caused by wars, social unrests, and statistical cycles, this paper excluded the data for Afghanistan, Iraq, Bahrain, Belarus, Bhutan, Cambodia, Laos, Maldives, Macedonia, Lebanon, Moldova, Burma, Oman, Palestine, East Timor, Syria, Turkmenistan, Uzbekistan, and Yemen, because of the large amount of missing data. In fact, these countries have relative small trade flows and have little influence when estimating the determinants of regional spatial interaction intensity.

According to the no linear hypothesis of the Geodetector model, any missing data will be automatically removed during data processing. To ensure the integrity of the database, the following data are supplemented as follows: the data for four indicators including the efficiency of the legal framework, railway infrastructure, burden of customs formalities, and affordability of financial services were missing from 2006 to 2008. Data from 2009 are substituted for this missing data to ensure data integrity. There are no railways in the United Arab Emirates and Kuwait, so the data for railway infrastructure quality indicators are missing. Highways are the main transportation infrastructure for these two countries, and the value of road infrastructure quality was used as a substitute.

3 Determinant Factors and Parameters

3.1 Determinant factors of BIR

The spatial-temporal evolution of BIR is influenced by policy communication, road connectivity, unimpeded trade, currency circulation and people-to-people connectivity, spaning across diverse fields such as tourism, education, culture and healthcare. According to the Five Links index proposed by Zhai (Zhai et al., 2017), this paper establishes an index system including 20 influencing factors in five dimensions: policy, facilities, trade, finance and culture, considering the systematicness and accessibility of data (Table 2). Among them, policy coordination is an important guarantee for strengthening regional cooperation and political mutual trust, which depends on the stability of the policy environment and the efficiency of the legal framework and administration. It's measured by the national vulnerability index (x_1), the efficiency of the legal framework for dispute resolution (x_2), and the transparency of government decisions (x_3). Facility connectivity is a priority area for the formation of regional connectivity, including transport facilities, energy facilities, and communications facilities. It's measured by the quality of roads (x_4), railways (x_5), ports (x_6), air transport (x_7), and power supply (x_8), as well as the number of mobile phone (x_9) and internet users (x_{10}). Trade facilitation is a key component to remove trade barriers and expand trade, mainly affected by the ease of cross-border trade and the intensity of investment. It is measured using trade tariffs (x_{11}), net inflow of foreign investment (x_{12}), burden of customs formalities (x_{13}), and the percentage of imports in the GDP (x_{14}). Financial integration is an important support for deepening financial cooperation and promoting the stability of monetary system, which requires a sound financial environment and credit system. It is measured by the affordability of financial services (x_{15}), the total national savings (x_{16}), the robustness of banks (x_{17}), and the availability of loans (x_{18}). Culture bonds are the social foundation for deepening multilateral cooperation, reflected in tourism activities and culture exchanges. It is measured by using language similarity (x_{19}) and international tourism income (x_{20}). Strengthening the Five Links calls for the orderly and free flow of economic factors, efficient allocation of resources and deep integration of markets among all countries so as to build an open, inclusive, balanced and inclusive regional economic cooperation framework.

3.2 The elasticity of import demand income

The model involves two core parameters, namely the elasticity of import demand income α and the damping coefficient β. Referring to previous studies, we used regression analysis and continuous integration to estimate core parameters (Li et al., 2012). According to the destination in Formula (2), W_k^{α}, the import demand of importing country j, is restricted by population size and per capita income constraints. Therefore, $W_j \propto P_j C_j$, and for the per capita market demand EW_j, there is:

$$EW_j = kC_j^{\alpha} \tag{9}$$

When the per capita import consumption is used to measure the per capita market demand EW_j, the income-level parameter in Formula (10) can be a representation of the elasticity of import demand income.

Table 2 The dimensions and indexes system of determinants

Dimensions	Indexes
1 Policy	x_1 National vulnerability index (INSCR), x_2 The efficiency of the legal framework for dispute resolution (GCI), x_3 Transparency of government decisions (GCI)
2 Facilities	x_4 Quality of the road (GCI), x_5 Quality of railway infrastructure (GCI), x_6 Quality of port infrastructure (GCI), x_7 Quality of air transport infrastructure (GCI), x_8 Quality of power supply (GCI), x_9 Mobile phones (GCI), x_{10} Internet users (GCI)
3 Trade	x_{11} Trade tariffs (GCI), x_{12} Net inflows of foreign direct investment (WDI), x_{13} Customs burden (GCI), x_{14} The percentage of import out of GDP (GCI)
4 Financial	x_{15} Affordability of financial services (GCI), x_{16} Gross national saving (GCI), x_{17} The robustness of Banks (GCI), x_{18} Easy access to credit (GCI)
5 Culture	x_{19} Language similarity (CEPPI), x_{20} International tourism revenue (WDI)

Notes: INSCR, Integrated network for societal conflict research; GCI, Global Competitiveness Index; WID, World Development Indicator; CEPPI, Coordinated Energy-related PPIs actions for cities

According to the relevant statistics of 65 BRI countries from 2000 to 2016 (Table 3), if we perform fitting using Formula (10), a regression equation can be obtained:

$$EW_j = 0.335C_j^{1.038} \tag{10}$$

Formula (10) passed the F-test, parameter α passed the t-test, and the complex correlation coefficient $R^2 = 0.67$. Therefore, it can be assumed that in the 21st century, the elasticity of import demand income of the BRI countries is as high as 1.038, which is elastic on the whole. At present, the prices of most imported commodities are slightly higher than that of similar domestic commodities, for medium and high-end consumption. The demand has a certain relationship with per capita income and a certain elasticity. That is, with the increase in income level, the import demand increases pro rata.

3.2 The damping coefficient

The damping coefficient is a measure of the attenuation rate for the strength of the spatial interaction, and it is the core parameter of the gravity model. In this paper, the total amount of foreign trade of importing country j in different distance scales is divided and integrated to estimate the spatial damping coefficient of the exporting country. According to the distance decay law and the MaxEnt principle, this paper assumes that the import force from different importing countries at any distance r_x ($0 \le r_x \le R$) from the exporting country k is equal. At the same time, assuming that the exporting country is continuously distributed in homogeneous space, all the

Table 3 The per capita income and per capita consumption of imported commodities of 65 BRI countries (US dollar)

Country	Income	Import	Country	Income	Import	Country	Income	Import
CHN	3756.56	808.01	SAU	14199.20	3536.54	KAZ	5397.60	1584.65
VNM	1008.41	871.56	SRB	3812.19	1849.00	GEO	2562.85	1193.65
JOR	2991.08	1924.13	NPL	511.85	152.26	PHL	2212.33	606.44
IDN	2133.49	445.49	MDA	1520.37	919.56	RUS	7730.07	1341.38
IND	1046.94	211.35	MMR	826.05	129.25	TLS	1518.41	315.02
ISR	25043.37	7543.31	BGD	695.78	156.69	BTN	1640.80	847.95
IRN	4337.96	563.34	MNG	1661.68	1056.54	BIH	3561.32	2167.08
IRQ	3504.31	1032.04	MKD	3276.27	2352.83	POL	9795.61	3827.41
YEM	1185.30	322.01	MYS	6563.11	5105.72	BGR	5133.82	3146.73
ARM	2579.58	966.50	MDV	4889.85	3090.84	BLR	4593.96	2825.12
HUN	10062.31	7746.66	ROU	5864.55	2614.47	BHR	16025.74	9121.18
SGP	35426.79	51935.50	LTU	9891.24	6900.85	PAK	968.44	184.73
UZB	1064.72	259.44	LBN	6171.53	3163.06	EST	12128.98	9339.54
UKR	2269.19	1028.01	LAO	781.49	309.63	AZE	2505.50	687.56
BRN	21262.36	6039.24	LVA	8749.75	5434.35	OMN	5069.91	5501.68
TKM	3486.97	1048.03	HRV	10594.82	4418.20	SYR	10085.11	486.77
TUR	8833.54	2145.13	KWT	32393.05	6860.14	ARE	36182.72	20176.40
THA	3696.27	2277.68	QAT	42161.30	12427.95	EGY	31447.81	472.82
TJK	623.28	315.37	CZE	13926.50	9985.72	AFG	410.89	152.70
SVN	17898.88	12361.92	KHM	621.32	451.23	ALB	3282.09	1233.64
SVK	11746.58	9819.92	KGZ	692.82	517.42	PSE	2292.47	732.88
LKA	2398.77	632.66	MNE	5090.77	3108.37			

Notes: 1) Country code is 3 capital letters code in UN ISO 3166–2, http://www.unece.org/cefact/locode/ subdivisions.html; 2) Units: dollars per year, calculation based on the unchangeable price of 2010; 3) Data Sources: World Development Index (WDI), International Statistics Yearbook (ISY); 4) Per capita income and per capita consumption of imported commodities are the average of per capita income between 2000 and 2016 importing countries j can be linearized according to their spherical distance from the exporting country k; that is, the exporting country is continuously distributed on a line segment. According to Formula (11), the total import and export volume T of the exporting country k can be converted from discrete summation to continuous integral form:

$$T_k = \sum_j T_{kj} = \int_0^R T_{kx} dr_x = \int_0^R A_k E_k W_j^{\alpha} \exp(-\beta r_x) dr_x = A\int_0^R \exp(-\beta r_x) dr_x \quad (11)$$

In the equation $A = A_x E_x W_j^{\alpha}$, at the given distance r_x, the export force $A_x E_x W_j^{\alpha}$ of any exporting country is equal. So, A is a fixed value. Assuming that the total external economy of the exporting country j within the spatial range of radius r_x is T, and the proportion of T out of the total export volume in the area of j is P_x, then according to Formula (11), when the trade radius is r_1 and r_2 respectively, there is:

$$\begin{cases} T_1 = A\int_0^{r_1} \exp(-\beta r_x) dr_x = p_1 T_k \\ T_2 = A\int_0^{r_2} \exp(-\beta r_x) dr_x = p_2 T_k \end{cases} \quad (12)$$

Substitute one of the original functions of the integrand into Formula (12) and the corresponding solution is:

$$p_2 \exp(-\beta r_1) - p_1 \exp(-\beta r_2) - (p_2 - p_1) = 0 \quad (13)$$

The spatial damping coefficient can be calculated from the aggregate trade proportion data of any two-trade radius. Regarding the straight-line distance between two of the BRI countries as the spatial distance, this paper selected the aggregate trade proportion data for a trade radius of 1000 km and 5000 km to calculate the spatial damping coefficient. The economic connection spatial damping coefficient along BRI is determined in the real number range using MATLAB software. The results show that in the 21st century, with the development of transportation systems and the Internet, international trade has become significantly more convenient, and the influence of spatial distance on international trade volume has gradually decreased. The spatial damping coefficient is decreasing on a yearly basis, from 0.00037 in 2000 to 0.00013 in 2016, and has a stable trend since 2013. In this paper, the spatial damping coefficient is estimated to be 0.00015, which is the average of the spatial damping coefficient for the last five years (Table 4).

4 Results

4.1 Interconnection intensity and evolution of BRI

As the BRI enters the period of comprehensive construction, the dynamic characteristics of regional connectivity and spatial-temporal evolution have become one of the important topics of geographical research. Substituting α, β, and related data into Formula (2), this paper measured the 65 countries' interconnection intensity based on the MaxEnt gravity model (Fig. 2): 1) From 2000 to 2004, the first three countries for interconnection intensity are Singapore (0.9946), China (0.7770), and Russia (0.5217); the level of other interconnection intensity is relatively low; and the pattern of the regional spatial structure is single center. 2) From 2005 to 2008, China (1.000), India (0.2205), Poland (0.1272), and other countries significantly enhanced interconnection intensity, and the regional spatial structure showed a multi-center network pattern. 3) From 2009 to 2012, affected by the financial crisis and the security situation of countries in the Middle East, the interconnection intensity in West Asia and North Africa, including Syria (22 places down) and Yemen (7 places down), decreased significantly. 4) From 2013 to 2016, Bangladesh (15 places up), Laos (11 places up), and other countries achieved the fastest growth rate, sharing the benefits of China's reforms and development, as neighbors of China had prominent advantages. Many major projects have taken place in the four countries surrounding the Bay of Bengal region. For example, Laos is a mountainous country where railway was difficult to build before the BRI was proposed. The construction and implementation of the China–Laos railway has provided Laos with infrastructure to connect with the outside world. In addition, Vietnam's 'Two Corridors and One Economic Circle' Plan has become a model of regional cooperation among ASEAN countries. This paper uses space–time pattern mining to create a space-time cube to analyze the spatial pattern and development trend of sequence evolution at any time.

Table 4 The spatial damping coefficients corresponding to the segmentation data of different spatial distances from 2000 to 2016

Distance	2000	2001	2002	2003	2004	2005	2006	2007	2008
<1000 km	0.29675	0.29627	0.29430	0.27412	0.26458	0.25574	0.25335	0.24074	0.23673
<5000 km	0.80576	0.79231	0.79428	0.78927	0.79482	0.78529	0.78861	0.78038	0.77317
β	0.00037	0.00037	0.00037	0.00031	0.00029	0.00029	0.00026	0.00025	0.00021

Distance	2009	2010	2011	2012	2013	2014	2015	2016
<1000 km	0.22937	0.21244	0.21197	0.19659	0.19996	0.19647	0.18898	0.18916
<5000 km	0.77543	0.75541	0.74506	0.73988	0.73456	0.72674	0.74544	0.74559
β	0.00022	0.00022	0.00022	0.00016	0.00017	0.00017	0.00013	0.00013

Note: β, damping coefficient

The results show that the spatial and temporal evolution patterns of the BRI countries' interconnection intensity from 2000 to 2016 can be divided into a non-significant pattern, four hot-spot patterns, and four cold-spot patterns, for a total of 3 classes and 9 patterns (Fig. 2f): 1) 14 countries including Afghanistan and Bhutan, as a non-significant pattern, shows no significance in local spatial statistics. 2) The hot-spot patterns include the following: Russia is a continuous hot-spot, and about 95% of the time-step interval is a statistically significant hot-spot; China, Laos, and another 7 countries are enhanced hot spots. At least 90% of time-step intervals are statistically significant hot spots.

The clustering intensity of each time step increases overall. Singapore, Malaysia, and 5 other countries are historical hot spots. At least 90% of time-step intervals are statistically significant hot spots, while the most recent period is not. Mongolia and East Timor are newly added hot spots, and the last time step has become a statistically significant hot spot, which has never been statistically significant before. 3) The cold-spot patterns include: Armenia and three other countries are constant cold-spot regions, and about 95% of time-step intervals are statistically significant cold spots; Syria, Iraq, and 7 other countries are strengthened cold-spot regions. At least 90% of the time-step intervals are statistically significant cold spots, and the clustering intensity of each time step increases overall. Ukraine, Estonia, and 22 other countries are historical cold spots. At least 90% of the time-step interval has become statistically significant cold–spots. The most recent period is not a cold spot. The Czech Republic, Slovenia, and 4 other countries are newly added cold spots, and the final time step becomes a statistically significant cold spot, which has never been statistically significant before.

In general, the evolution of the temporal pattern of the intensity of geopolitical and economic connections in the BRI region has a significant non-circular cluster structure, and the developing cold-spots are distributed in a concentrated and continuous pattern. The West Asia and North Africa belt has always been the 'snow belt' of the BRI economic development. The persistent hot spots are distributed in Russia, Singapore, Malaysia, the Philippines, and other Southeast Asian regions, which used to be the historical hot spots in the Asia-Pacific region but have declined in recent years. The enhanced hot spots are concentrated in East Asia and Southeast Asia, while the newly added hot spots are scattered across East Asia and South Asia. Since the BRI was proposed, China and its neighbors have continuously strengthened their spatial effect.

4.2 Determinant factors of BRI from 2006 to 2016

The spatial detection of interconnection intensity was carried out by using the Geodetector model, and the influence values $P_{D,U}$ of each index on interconnection intensity was calculated. The result shows that over the past decade, railway infrastructure, international tourism, and the foreign direct investment have been the persistent and powerful driving forces of spatial-temporal evolution. In 2016, the rail infrastructure impact value was 0.388, the international tourism impact value was 0.572 and the foreign direct investment impact value was 0.667 (Table 5).

Among them, the foreign direct investment is a direct driving force for deepening regional cooperation, international tourism is an effective way to promote mutual cooperation, and highly interconnected railway network is an important driving force for revitalizing regional economic development. The Belt and Road is committed to creating a sound investment environment, enhancing the distinctive features and facilitation of regional international tourism, and establishing a bridging mechanism and facilitation conducive to international customs clearance, reloading and multimodal transport to promote inter-regional connection.

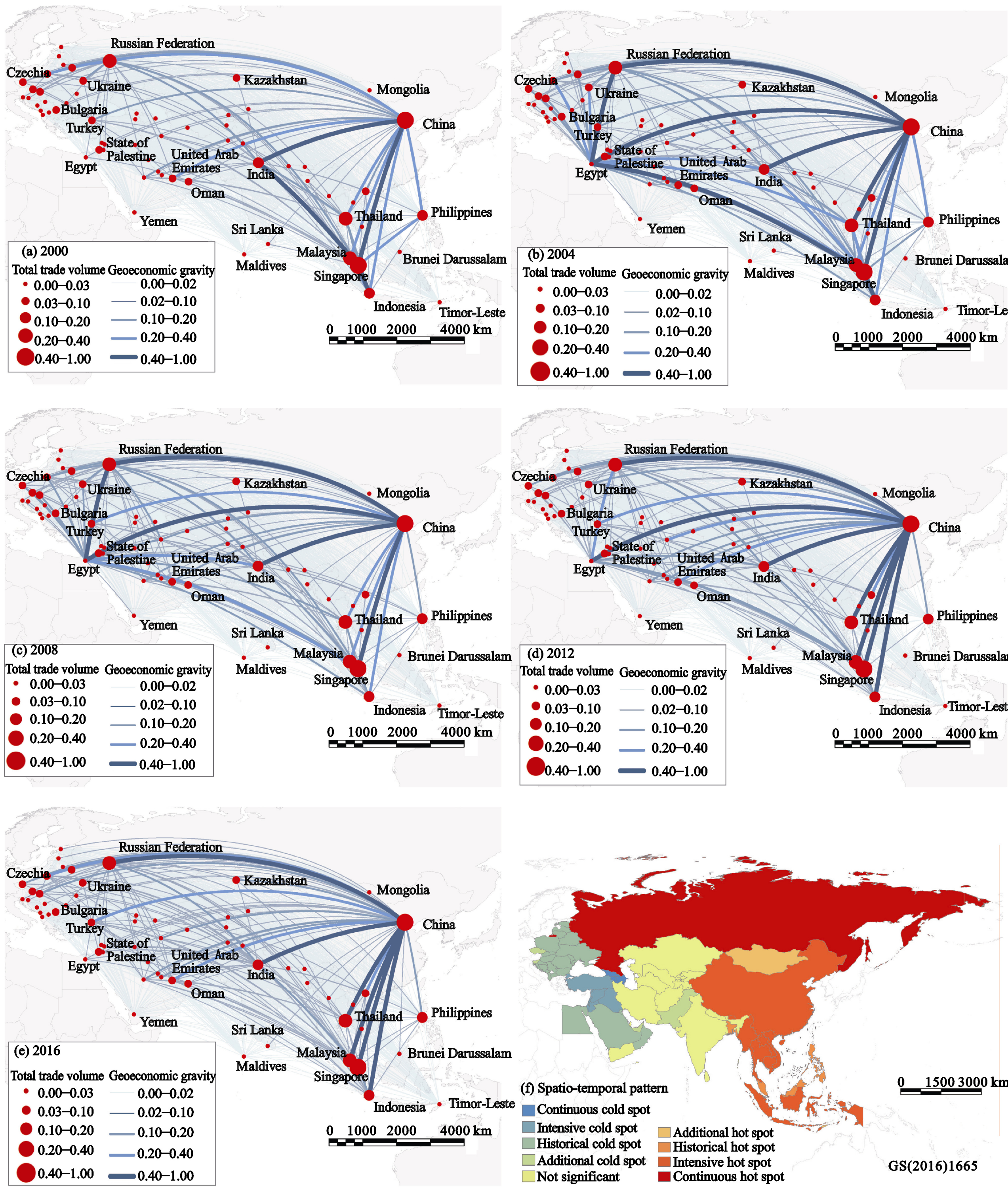

Fig. 2 The interconnection intensity and the spatial-temporal evolution pattern of the the Belt and Road Initiative countries

Table 5 Determinant factors of regional connectivity intensity along the Belt and Road Initiative from 2006 to 2016

Index	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
x_1 National vulnerability	0.055(0.722)	0.022(0.932)	0.022(0.926)	0.081(0.499)	0.101(0.378)	0.117(0.300)	0.039(0.814)	0.125(0.307)	0.092(0.454)	0.053(0.701)	0.055(0.684)
x_2 Legal framework	0.196(0.292)	0.175(0.372)	0.228(0.212)	0.108(0.483)	0.181(0.333)	0.148(0.394)	0.197(0.242)	0.167(0.201)	0.143(0.279)	0.180(0.208)	0.197(0.186)
x_3 Government decisions	0.616*(0.035)	0.274*(0.095)	0.253*(0.087)	0.091(0.517)	0.093(0.555)	0.226(0.649)	0.127(0.563)	0.060(0.694)	0.135(0.377)	0.163(0.269)	0.118(0.400)
x_4 Quality of road	0.361*(0.057)	0.354*(0.065)	0.437*(0.017)	0.178(0.287)	0.193(0.263)	0.124(0.403)	0.099(0.584)	0.132(0.405)	0.131(0.374)	0.105(0.44)	0.147(0.330)
x_5 Quality of railway	0.425*(0.037)	0.424*(0.037)	0.443*(0.027)	0.574***(0)	0.300*(0.02)	0.293*(0.023)	0.349*(0.011)	0.286*(0.023)	0.318*(0.012)	0.433**(0.005)	0.388**(0.004)
x_6 Quality of port	0.392*(0.034)	0.29*(0.071)	0.265(0.112)	0.113(0.444)	0.097(0.447)	0.167(0.205)	0.094(0.463)	0.084(0.496)	0.205(0.291)	0.172(0.204)	0.150(0.271)
x_7 Quality of aviation	0.388*(0.036)	0.241*(0.090)	0.305*(0.067)	0.126(0.334)	0.097(0.503)	0.114(0.406)	0.158(0.271)	0.155(0.210)	0.173(0.261)	0.163(0.270)	0.166(0.285)
x_8 Power supply	0.113(0.403)	0.123(0.315)	0.150(0.243)	0.061(0.646)	0.058(0.67)	0.067(0.609)	0.063(0.650)	0.040(0.804)	0.072(0.572)	0.086(0.484)	0.068(0.604)
x_9 Mobile phones	0.11(0.384)	0.083(0.539)	0.075(0.604)	0.027(0.888)	0.013(0.971)	0.056(0.694)	0.044(0.785)	0.057(0.695)	0.088(0.521)	0.020(0.934)	0.012(0.976)
x_{10} Internet users	0.155(0.239)	0.126(0.331)	0.074(0.599)	0.121(0.34)	0.037(0.839)	0.023(0.917)	0.047(0.761)	0.025(0.902)	0.016(0.957)	0.037(0.827)	0.107(0.411)
x_{11} Trade tariffs	0.607*(0.045)	0.558(0.104)	0.027(0.928)	0.064(0.63)	0.081(0.534)	0.092(0.462)	0.103(0.459)	0.121(0.314)	0.086(0.502)	0.116(0.396)	0.046(0.785)
x_{12} Direct investment	0.803***(0)	0.590***(0.000)	0.295*(0.034)	0.441**(0.009)	0.762***(0.000)	0.738***(0.000)	0.816***(0.000)	0.788***(0.000)	0.843***(0.000)	0.705***(0.000)	0.572***(0.000)
x_{13} Customs burden	0.13(0.321)	0.126(0.342)	0.114(0.472)	0.079(0.579)	0.096(0.495)	0.063(0.651)	0.206(0.122)	0.055(0.720)	0.077(0.57)	0.134(0.298)	0.077(0.575)
x_{14} Import percentage	0.603*(0.047)	0.538(0.14)	0.503(0.163)	0.279(0.397)	0.285(0.494)	0.312(0.343)	0.246(0.553)	0.274(0.416)	0.255(0.474)	0.262(0.456)	0.209(0.107)
x_{15} Financial services	0.25(0.125)	0.242(0.142)	0.307*(0.061)	0.223(0.115)	0.255*(0.077)	0.192(0.172)	0.220(0.124)	0.295*(0.058)	0.146(0.347)	0.159(0.286)	0.280*(0.039)
x_{16} National saving	0.143(0.176)	0.139(0.311)	0.167(0.252)	0.204(0.112)	0.195*(0.085)	0.191*(0.094)	0.259*(0.047)	0.247*(0.067)	0.213(0.102)	0.379*(0.019)	0.501**(0.003)
x_{17} Robustness of banks	0.105(0.44)	0.066(0.661)	0.035(0.850)	0.079(0.576)	0.207(0.107)	0.126(0.333)	0.128(0.375)	0.069(0.635)	0.035(0.843)	0.032(0.861)	0.026(0.900
x_{18} Easy access to credit	0.205(0.112)	0.101(0.452)	0.207(0.14)	0.086(0.512)	0.125(0.336)	0.099(0.481)	0.175(0.189)	0.226(0.119)	0.225(0.117)	0.238*(0.092)	0.249*(0.093)
x_{19} Language similarity	0.111(0.462)	0.086(0.588)	0.073(0.652)	0.212(0.149)	0.230(0.118)	0.208(0.155)	0.185(0.213)	0.196(0.181)	0.205(0.162)	0.217(0.139)	0.199(0.173)
x_{20} Tourism revenue	0.43**(0.004)	0.461**(0.004)	0.483**(0.003)	0.479**(0.002)	0.518***(0.000)	0.635***(0.000)	0.642***(0.000)	0.637***(0.000)	0.605***(0.000)	0.527***(0.000)	0.667***(0.000)

Notes: *** Statistically significant at the 0.001 significance level; ** Statistically significant at the 0.01 significance level; *Statistically significant at the 0.1 significance level

The BRI aims to promote the common development and prosperity of all countries, and gradually develop into a new driving force for globalization. Specifically, the main determinants of BRI over the past decade can be divided into three phases: 1) From 2006 to 2008, traditional factors such as infrastructure and policy transparency were the most important influencing factors. The results show that transparency of government decisions (0.616), the quality of road (0.361), railway (0.425), port (0.392) and air transport (0.388) factors had a greater impact in 2006. 2) From 2009 to 2012, before the BRI was proposed, the world economy slowed because of the financial crisis. At this stage, there are relatively fewer factors that influence the regional geographical connection, including railway, foreign direct investment, affordability of financial services and international tourism which show strong influence. 3) Since 2013, and in particular since the establishment of the AIIB in 2015, some emerging determinants, such as the affordability of financial services (0.28), gross national saving (0.501) and easy access to credit (0.249) has strengthened and effectively promoted regional linkages. Overall, foreign direct investment, international tourism and railway infrastructure, as well as policy communication and capital financing, have been important factors that have continued to influence the geopolitical and economic linkages of countries over the past decade.

4.3 Determinant factors of BRI in sub-region

The results of the Geodetector analysis show that the determinants in different sub-regions show obvious spatial differentiation, and the formulation of regional pertinence policies is the key to improving the efficiency of regional cooperation: In Southeast Asia, frequent cultural exchanges make the influence of culture bond (0.331) the smallest, while unimpeded trade (0.665) has the highest influence. Of these, influence of aviation infrastructure (0.613) is relatively higher because this region has more islands than the other regions. In East Europe, the relatively robust infrastructure makes the impact of infrastructure connectivity (0.096) the least, while trade connectivity factors such as tariffs (0.566) have a greater impact on spatial interconnection intensity. In South Asia, because of language differences, the culture bond (0.908) has the greatest influence, and cultural exchange has a major influence on spatial interconnection intensity. There are significant differences in the interconnection intensity among different cultural backgrounds in socio-economic context and ways of thinking. In West Asia and North Africa, the capital factor (0.267) and infrastructure factor (0.362) have greater impact on the spatial interconnection intensity due to limited infrastructure construction. In Central Asia, factors closely related to the oil industry, such as electric power (0.708) and ports (0.666) have a greater impact on the spatial interconnection intensity (Fig. 3 and Table 6). In general, Southeast Asian countries are typically multi-island area where aviation infrastructure plays a more important role. North and Central Asian countries regard oil as a pillar industry where power and port facilities have a greater impact on the interconnection. While Western Asian countries are mostly affected by railway infrastructure, Eastern European countries already have relatively robust infrastructure where tariff policies provide a greater impetus.

5 Discussion and Conclusions

This paper contributes to the existing literature in several ways. Firstly, in contrast to the analogy model, this paper applies a new framework that constructs spatial

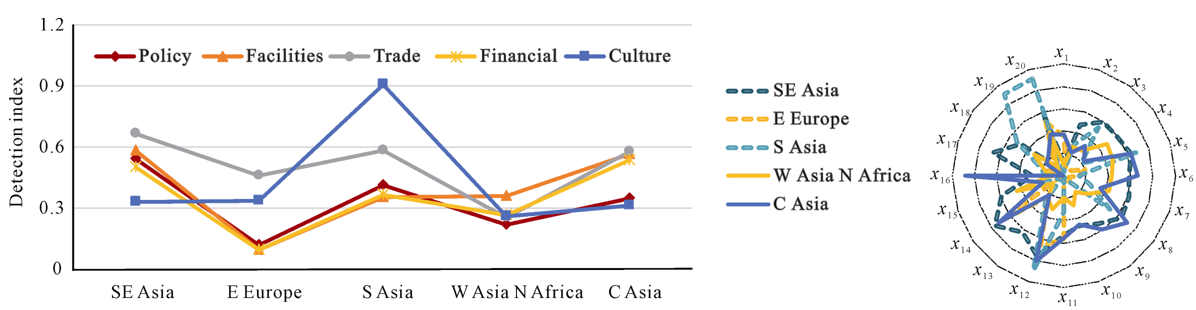

Fig. 3 Determinant factors of interconnection intensity in different sub-regions. SE Asia, Southeast Asia; E Europe, East Europe; S Asia, South Asia; W Asia N Africa, West Asia North Africa; C Asia, Central Asia

Table 6 Determinant factors of regional connectivity intensity along the Belt and Road Initiative from 2006 to 2016

Index	SE Asia	E Europe	S Asia	W Asia N Africa	C Asia	Index	SE Asia	E Europe	S Asia	W Asia N Africa	C Asia
x_1	0.114	0.356***	0.038	0.099*	0.368**	x_{11}	0.528***	0.564***	0.325	0.195***	0.555
x_2	0.479***	0.074**	0.291***	0.271***	0.221	x_{12}	0.760***	0.656***	0.889***	0.313***	0.805***
x_3	0.601***	0.091**	0.531***	0.278***	0.327*	x_{13}	0.630***	0.237***	0.275**	0.247***	0.214
x_4	0.594***	0.077**	0.196**	0.482***	0.221	x_{14}	0.757***	0.687***	0.020	0.110	0.714***
x_5	0.640***	0.213***	0.677***	0.465***	0.632	x_{15}	0.583***	0.023	0.218**	0.438***	0.194*
x_6	0.589***	0.119***	0.142*	0.432***	0.666***	x_{16}	0.277***	0.196***	0.170*	0.128**	0.882***
x_7	0.613***	0.042	0.251**	0.426***	0.347**	x_{17}	0.669***	0.151***	0.201*	0.178***	0.011
x_8	0.642***	0.095***	0.515***	0.269***	0.708***	x_{18}	0.479***	0.044*	0.514***	0.323***	0.184
x_9	0.530***	0.048*	0.038	0.180***	0.596*	x_{19}	0.085**	0.148***	0.908***	0.105**	0.234*
x_{10}	0.468***	0.021	0.005	0.282***	0.458*	x_{20}	0.577***	0.508***	0.911***	0.412***	0.391*

Notes: 1) *** Statistically significant at the 0.001 significance level; ** Statistically significant at the 0.01 significance level; *Statistically significant at the 0.1 significance level. 2) SE Asia, Southeast Asia; E Europe, East Europe; S Asia, South Asia; W Asia N Africa, West Asia North Africa; C Asia, Central Asia

interaction based on the MaxEnt gravity model. Secondly, empirical analysis of BRI countries predominantly focuses on a national scale. There are substantial differences in economic performance between countries, which require more detailed analysis at a sub-regional scale. Thirdly, this paper examines the impact of policy, facilities, trade, finance, and culture in a more comprehensive way.

(1) The differentiated spatial pattern and endogenous dynamic mechanism of interconnection are important foundations for formulating region-specific policies and resolving the deep contradictions in regional development. The measurement of the intensity of economic connection has become the focus and difficulty of deep spatial structure research. Based on the constraint functions of supply forces of the exporting country, the demand force of the importing country, and the generalized transport costs, this paper constructs the MaxEnt gravity model of regional spatial connection. The core parameters include the income elasticity coefficient and spatial damping coefficient, and regression analysis and continuous integration methods are used to estimate them. Research shows that in the early 21st century, per capita income was directly proportional to per capita import consumption, and the income elasticity coefficient was about 1.038. The influence of spatial distance on economic connections is gradually being reduced and the spatial damping coefficient is about 0.0015. This paper provides a new frame of thought for studying the intensity of interconnections from the supply perspective.

(2) The evolution of temporal patterns of interconnection intensity shows an obvious non-circular mass structure. Developmental cold spots show an obvious continuous trend and the West Asia and North Africa region has always been the ‘snow belt’ of regional economic connection. Southeast Asia used to be a historical regional hot spot, but shows a partially decayed and oscillating trend. Continuous and enhanced hot spots are scattered in the Asia-Pacific Region, and the spatial spill-over effect of China and its neighboring countries grows in strength. In the last decade, foreign direct investment, international tourism, and railway infrastructure construction have been the most important influence factors of interconnection intensity for all the BRI countries, while the influence factors of different regions show a clear pattern of differentiation. Strengthening the regional pertinence of spatial strategies is the key to improving the efficiency of regional cooperation; aviation infrastructure projects in Southeast Asia, tariff policies in East Europe, cultural exchange in South Asia, rail infrastructure construction in West Asia, and regional power and port facilities construction in North Africa and Central Asia have a bigger influence on interconnection intensity.

(3) The intensity of interconnections is a complex system with multiple factors. The MaxEnt gravity model has great practical value and application potential, while the rationality analysis of its calculated result is restricted by the reliability and availability of relevant statistical data. For example, based on the assumption of spatial homogenization, the distance between the ex-

porting country and the importing country is represented by the capital spherical distance without considering the regional differences in traffic conditions. At the same time, there are some differences in income elasticity and spatial damping coefficients in different regions. In addition, the differences in the statistical caliber and cycle of the trade data of different countries interfere with the calculated results. In fact, any theoretical value can only be close to the actual value, and the study of the spatial difference and dynamic mechanism of interconnection intensity needs to be explored and tested in theory and practice.

(4) The BRI follows the spirit of the ancient Silk Road and features peace, cooperation, openness and inclusiveness, mutual learning and mutual benefit. It relies on existing bilateral and multilateral mechanisms and regional cooperation platforms to jointly build a community of shared interests, destiny, and responsibilities including mutual political trust, economic integration, and cultural inclusiveness. From 2013 to 2016, China's trade in goods with countries along the BRI amounted to more than 5 trillion US dollor (USD) and its outward direct investment exceeded 70 billion USD. At 7.2% annual growth rate of direct investment in countries along the BRI, more dividends will be released in the future. It proposes to introduce a new model of co-creation and sharing along the BRI in fields such as infrastructure, trade and investment, energy cooperation, and regional integration under the framework of equal cultural identity.

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