Spatiotemporal Pattern of Openness and Its Influencing Factors in Belt and Road Countries: Postprint

Authors: Ma Wei

Date: 2021-01-07T00:00:00+00:00

Abstract

The Belt and Road Initiative has inaugurated a new pattern of China' s opening-up to the outside world and will exert significant influence on the common development and prosperity of countries along the route and the world at large. Based on panel data from 66 countries along the Belt and Road during 2000–2015, this study constructs a comprehensive evaluation index system for openness and employs kernel density estimation, standard deviation ellipse, exploratory spatial data analysis, and dynamic spatial Durbin model to analyze the spatiotemporal patterns of openness and their influencing factors among countries along the Belt and Road. The results show that: (1) From 2000 to 2015, the overall level of openness along the Belt and Road demonstrated an upward trend, with disparities gradually narrowing. (2) The movement of the openness centroid can be divided into two phases: from 2000 to 2008, the centroid shifted toward the northwest, while after 2008, it gradually moved toward the east. (3) Significant spatial disparities in openness exist, with higher levels in the northwest and relatively lower levels in the central and southern regions. (4) Openness exhibits significant global spatial autocorrelation. Hot spots are concentrated in Singapore and Cyprus, while cold spots are mainly found in China, Central Asia, and South Asia. (5) Dynamic Spatial Durbin Model (DSDM) analysis reveals that economic development level, human capital, land transportation, and ports all exert both long-term and short-term effects, as well as direct and indirect effects, on openness.

Full Text

Spatio-Temporal Pattern of Openness of Countries Along the Belt and Road Initiative and Its Influencing Factors

MA Wei[1,2,3,4], **HUANG Xiao-yan**[2,3,4], **CAO Xiao-shu**[2,3,4]
[1]School of Geography and Tourism, Shaanxi Normal University, Xi' an 710119, Shaanxi, China
[2]Academy of Natural Resources and Territorial Space, Shaanxi Normal University, Xi' an 710119, Shaanxi, China
[3]Key Laboratory for Urbanization and Land Environment Geosimulation in Northwest China, Shaanxi Normal University, Xi' an 710119, Shaanxi, China
[4]Institute of Global Regional and Urban Studies, Shaanxi Normal University, Xi' an 710119, Shaanxi, China

Abstract: The Belt and Road Initiative (BRI) has inaugurated a new pattern of China' s opening-up to the outside world and will generate significant impacts on the common development and prosperity of countries along the BRI and globally. Based on panel data from 66 countries along the BRI from 2000 to 2015, this study constructs a comprehensive evaluation index system of openness and employs Kernel Density Estimation (KDE), Standard Deviation Ellipse (SDE), Exploratory Spatial Data Analysis (ESDA), and Dynamic Spatial Durbin Model (DSDM) to analyze the spatio-temporal pattern of openness and its influencing factors. The results reveal: (1) The overall level of openness along the BRI showed an upward trend from 2000 to 2015, with differences gradually narrowing. (2) The center of gravity of openness moved within Iran, but the movement direction exhibited two distinct phases: moving northwestward from 2000 to 2008, then gradually shifting eastward after 2008. (3) Significant spatial disparities existed in openness, with higher levels in the northwestern region and relatively lower levels in the central and southern regions. (4) Openness demonstrated significant positive spatial autocorrelation globally. Hotspot areas were concentrated in Singapore and Cyprus, while cold spots were mainly found in China, Central Asia, and South Asia. (5) DSDM analysis indicates that economic development level, human capital, land transport, and ports all exerted both short-term and long-term effects, as well as direct and indirect effects, on openness.

Keywords: openness; spatio-temporal pattern; Dynamic Spatial Durbin Model (DSDM); Belt and Road Initiative (BRI)

1 Introduction

Over two millennia ago, Zhang Qian' s diplomatic missions to Central Asia, the Iranian Plateau, the Arabian Peninsula, Asia Minor, and other regions opened the door to friendly exchanges between China and other nations, establishing the "Silk Road" that connected East and West across the Eurasian continent.

Subsequently, the "Silk Road" evolved into multiple routes, including the Southern Silk Road, the Steppe Silk Road, and the Maritime Silk Road. Historically, the Silk Road not only promoted economic development across Eurasia but also embodied the spirit of "peaceful cooperation, openness and inclusiveness, mutual learning, and mutual benefit," becoming a great heritage of human civilization.

In 2013, during visits to Central and Southeast Asia, President Xi Jinping proposed the major initiative of jointly building the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" (hereinafter referred to as the BRI). The BRI does not aim to reconstruct the Eurasian regional trade network of the ancient Silk Road but rather to create an open, shared, and cooperative international platform based on its cultural connotations. In March 2015, China' s National Development and Reform Commission, Ministry of Foreign Affairs, and Ministry of Commerce jointly issued the "Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road," which explicitly stated that adhering to open cooperation is one of the principles of BRI construction. However, some Western scholars have argued that the BRI represents the world' s largest economic diplomacy strategy since the Marshall Plan. In response, Chinese scholar Jin Ling contends that the BRI fundamentally differs from the Marshall Plan, as the former is a platform for equal, mutually beneficial, and pragmatic cooperation, while the latter was essentially a political security strategy and a Cold War tool.

Since the implementation of the BRI, it has greatly promoted trade and investment development among participating countries. From 2000 to 2015, the total trade volume of BRI countries increased from $2.72 trillion to $7.95 trillion, with its share of global trade rising from 34.94% to 37.21%. Foreign direct investment (FDI) inflows to BRI countries grew from $120.5 billion to $383.7 billion, increasing their share of global FDI from 35.74% to 36.14%. Thus, the BRI has inaugurated a new pattern of China' s opening-up while significantly impacting the common development and prosperity of countries along the route and worldwide.

International research on openness can be traced back to Adam Smith' s *The Wealth of Nations* in 1776, which expounded on openness' s impact on national economic growth. Smith argued that in a relatively closed and self-sufficient production environment, trade openness did not promote growth, but as social division of labor refined and labor productivity improved, its promotional effects became evident. In 1945, Brown first proposed the embryonic concept of openness– "interdependence." In 1958, Kiyoshi Kojima introduced trade dependence in *The Theory of Foreign Trade* to characterize national openness levels. By the mid-to-late 1980s, with the rise of new growth theory, openness research gained increasing academic attention, particularly focusing on openness' s impact on economic growth, though definitions and measurements of openness lacked in-depth investigation.

Domestically, after 1992, with deepening reform and opening-up and widening regional economic disparities, openness research gradually became a hot

topic in Chinese academia. Current research primarily focuses on three aspects: (1) openness evaluation, (2) relationships between openness and other socioeconomic factors, and (3) studies on openness' s influencing factors. Regarding evaluation, early international economic activities were represented by inter-country trade, so initial research mainly reflected national opening levels through trade openness. With the rapid development of international currency markets and multinational corporations, international finance and investment have become fundamental forms of national opening. Some scholars argue that openness evaluation should also encompass technology, information, and other elements. Regarding relationships with other factors, research has examined connections with economic growth, environmental quality and pollution, and income inequality. Regarding influencing factors, while numerous quantitative studies exist, most employ traditional econometric methods.

Existing research has yielded fruitful theoretical and empirical results but still exhibits shortcomings: (1) openness evaluation indicators need continuous enrichment; (2) with advancing economic globalization and regional integration, trade, investment, finance, information, and other openness elements flow increasingly frequently across geographic space, and spatial spillover effects of openness continuously strengthen, necessitating further analysis of geographic spatial effects; (3) regarding influencing factors, though substantial quantitative research exists, most rely on traditional econometric methods. This paper employs dynamic spatial panel models that incorporate spatial and temporal effects to further clarify how variables influence spatio-temporal changes in openness; (4) research areas have mainly focused on national, provincial, and city scales, with scarce studies on the BRI.

Given these gaps, this paper takes the BRI as the study area, establishes an openness evaluation index system, quantitatively measures openness indices for 66 BRI countries from 2000 to 2015, and employs KDE, SDE, and ESDA to explore spatio-temporal evolution patterns. Finally, it uses DSDM and dynamic spatial panel models for quantitative research on influencing factors to provide theoretical support for promoting orderly opening among BRI countries.

---

2 Methods and Data

2.1 Openness Index System Construction

Openness reflects the degree to which a country or region participates in international social and economic cooperation and development. Referencing existing research and following principles of systematicity, representativeness, and accessibility, this study constructs a comprehensive evaluation system covering six dimensions: trade, investment, finance, tourism, technology, and information (Table 1).

Regarding openness scoring, based on different weighting methods, approaches

can be divided into subjective weighting (e.g., Analytic Hierarchy Process, expert scoring) and objective weighting (e.g., entropy method, principal component analysis). Given that the entropy method can overcome subjectivity in weight determination and has broad applicability in evaluating comprehensive economic development, agricultural modernization, urbanization, technological innovation, and ecological environments, this paper adopts the entropy method to determine indicator weights and then uses comprehensive weighted summation to calculate openness levels.

2.2 Spatial Autocorrelation Analysis

This paper introduces Exploratory Spatial Data Analysis (ESDA) to measure spatial agglomeration of openness among BRI countries. Globally, Moran' s I index is used to determine whether openness distribution exhibits clustering or dispersion. The formula is as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\sum_{i=1}^{n}(x_i-\bar{x})^2}$$

where x_i and x_j represent openness values of countries i and j, $\bar{x}$ is the mean openness of all countries, n is the number of countries, and W_{ij} is the spatial weight matrix (1 for adjacent countries, 0 otherwise).

For local spatial autocorrelation, this paper employs Getis-Ord G_i index hotspot analysis to identify hotspot areas (high-value clusters) and cold spot areas (low-value clusters). The formula is:

$$G_i = \frac{\sum_{j=1}^{n}W_{ij}x_j}{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}x_j}$$

If G_i is significantly positive, it indicates that country i has relatively high openness and belongs to a hotspot area; conversely, it is a cold spot area. Using Jenks'natural breaks method, G_i values are divided into four categories: hotspot, sub-hotspot, sub-coldspot, and coldspot areas.

2.3 Dynamic Spatial Panel Model

2.3.1 Model Specification Given that traditional econometric models do not consider spatial interaction effects of dependent variables, and static spatial panel models ignore the time dimension, this paper utilizes dynamic spatial panel models to examine how various independent factors influence openness among BRI countries. Dynamic spatial panel models mainly include three types: Dynamic Spatial Error Model (DSEM), Dynamic Spatial Lag Model (DSLM), and Dynamic Spatial Durbin Model (DSDM). Among them, DSDM considers

spatial correlation of the dependent variable, and parameter estimates of independent variables and error terms are not affected by the degree of spatial dependence of omitted variables. Therefore, this paper selects the DSDM model, with the formula:

$$Y_t = \tau Y_{t-1} + \rho W Y_t + \eta W Y_{t-1} + X_t\beta + W X_t\theta + \mu_i + \lambda_t + \varepsilon_{it}$$

where Y_t is the dependent variable, Y_{t-1} is the one-period lagged dependent variable, X_t includes core independent variables and control variables, β and θ represent coefficients of independent variables and their spatial lag terms, τ, ρ, and η represent coefficients of temporal lag, spatial lag, and spatio-temporal lag terms respectively, μ_i denotes spatial fixed effects, λ_t denotes time fixed effects, and ε_{it} is the spatial autocorrelation error term.

Since the model incorporates temporal dimension terms, it can estimate not only direct and indirect effects of independent variables but also their long-term and short-term effects. Using the partial differential method to decompose spatio-temporal effects yields:

$$Y_t = (I_n - \rho W)^{-1}(\tau I_n + \eta W)Y_{t-1} + (I_n - \rho W)^{-1}(X_t\beta + W X_t\theta) + (I_n - \rho W)^{-1}(\mu_i + \lambda_t + \varepsilon_{it})$$

When setting $\tau = \eta = 0$, the partial differential matrix of Y_t with respect to X_t yields the short-term effect matrix (Equation 4). Further, when Y^* represents the long-run equilibrium level, taking the partial derivative with respect to X_t yields the long-term effect matrix (Equation 5). By statistically analyzing the diagonal elements (direct effects) and off-diagonal elements (indirect effects) of these matrices, we obtain short-term direct/indirect effects and long-term direct/indirect effects.

2.3.2 Variable Selection As a comprehensive product of national or regional socioeconomic development, openness is influenced by multiple factors. This paper considers independent variables including economic development level, population size, industrial structure, human capital, social security conditions, government customs policy, and transport infrastructure. Specifically:

- **Economic development level (economy)**: Measured by per capita GDP
- **Population size (population)**: Measured by population density
- **Industrial structure (industry)**: Reflected by the proportion of tertiary industry value-added in GDP
- **Human capital (talent)**: Measured by tertiary education enrollment rate
- **Social security (security)**: Terrorist activities are selected as a proxy (a dummy variable: 1 if the country has numerous terrorist incidents, 0 otherwise)

- **Government customs policy (policy)**: Reflected by tariff rates (lower tariffs indicate more open policies)
- **Transport infrastructure (transport)**: Measured by a comprehensive transport infrastructure quality index, including three sub-indicators: land transport, ports, and aviation

2.4 Data Sources

This study uses both national boundary vector data and socioeconomic data. National boundary vector data are obtained from the DIVA-GIS geographic data platform. Socioeconomic data come from multiple sources: import/export trade volumes, inbound/outbound tourism revenue, international patent applications, intellectual property usage fees, tertiary education enrollment rates, and tariff rates from the World Bank database; external financial assets and liabilities from the *International Financial Statistics Yearbook*; FDI inflows and outflows from the *World Investment Report*; international internet and mobile phone penetration rates from the ITU-D Statistics database; transport infrastructure data (land transport, ports, aviation) from the World Economic Forum' s *Global Competitiveness Report*; and terrorism activity data from the University of Maryland' s Global Terrorism Database.

As a global economic cooperation platform, the BRI has no precise regional boundaries. Based on relevant literature and materials, this paper defines the BRI as comprising 66 countries including China (Table 3).

---

3 Results and Analysis

3.1 Evolution Characteristics of Kernel Density Estimation

Using Stata 14 software, kernel density distributions of openness along the BRI were plotted for six selected years (2000, 2005, 2008, 2010, 2012, 2015) [Figure 1: see original paper]. From the distribution position, the kernel density curves showed a rightward shift overall, indicating a year-by-year increase in openness. From kurtosis, the peaks gradually moved rightward with growing right-side "long tails," suggesting that while all countries increased openness, a few reached relatively high levels (values between 0.4-0.6). From shape, openness exhibited unimodal distributions without bimodal or multimodal patterns, indicating that inter-country differences were moderating without polarization, showing a convergence trend.

3.2 Evolution Characteristics of Standard Deviation Ellipse

Using ArcGIS spatial analysis tools, standard deviation ellipses of openness along the BRI were visualized for 2000-2015 [Figure 2: see original paper]. The results show that the center of gravity of openness moved within Iran but divided

into two phases: moving northwestward from 2000 to 2008, then gradually shifting eastward after 2008. The primary reasons are: Central and Eastern European countries initially completed economic marketization transformation in the 1990s, gradually strengthening economic ties with Europe and the world, causing the BRI' s center of gravity to shift northwestward. After 2008, the global financial crisis severely impacted Central and Eastern European economies (e.g., Estonia, Latvia, and Lithuania all experienced negative growth exceeding -14% in 2009). Meanwhile, China implemented proactive fiscal policies and moderately loose monetary policies, achieving rapid and stable economic growth (GDP growth rising from 9.6% to 10.3%, an increase of 107.88%). This ensured that openness increased from 0.27 to 0.56, causing the center of gravity to gradually shift eastward after 2008.

3.3 Spatial Distribution and Agglomeration Evolution

3.3.1 Spatial Distribution Changes of Openness Based on openness evaluation results for BRI countries from 2000 to 2015, data for 2000, 2008, and 2015 were selected. Using ArcGIS 10.1 software and the natural breaks method, BRI countries were classified into five types: high openness, relatively high openness, medium openness, relatively low openness, and low openness [Figure 3: see original paper]. Spatial differences in openness were evident, with higher levels in the northwestern region and relatively lower levels in the central and southern regions.

In 2000, Singapore had the highest openness (0.51), followed by Israel, Bahrain, Estonia, Slovenia, Hungary, Maldives, and Czech Republic at relatively high levels. China, Central Asia, most of Southeast Asia, South Asia, and West Asia showed the lowest levels (openness ≤ 0.2). By 2008, Singapore' s openness reached 0.59. The relatively high openness group added Croatia, Lebanon, Lithuania, Cyprus, Malaysia, Greece, UAE, Jordan, Slovakia, and Latvia, while low openness areas decreased significantly, remaining mainly in South Asia. By 2015, Singapore and Cyprus had the highest openness (>0.6). The relatively high openness group expanded substantially, while low openness areas added Yemen and Egypt. Statistical analysis shows that the proportion of countries with relatively high or higher openness increased from 12.12% to 31.82%, while low openness countries decreased from 22.73% to 27.27%, further demonstrating the expanding openness among BRI countries.

3.3.2 Spatial Agglomeration Evolution Global Agglomeration Characteristics. Using GeoDa software, global Moran' s I indices for openness were calculated with p-value tests [Figure 4: see original paper]. From 2000 to 2015, all Moran' s I indices were positive with p-values < 0.01, indicating significant positive spatial autocorrelation—countries with high openness tended to cluster, as did those with low openness. Moran' s I showed an initial rise followed by a slight decline after 2008, with a small upward trend from 2012-2015, suggesting continuously strengthening spatial correlation. The sudden drop in 2009 reflects

the negative impact of the 2008 global financial crisis on spatial correlation of openness along the BRI.

Local Agglomeration Patterns. Global Moran' s I only reflects overall spatial correlation but cannot reveal internal clustering characteristics. Therefore, Getis-Ord G_i index hotspot analysis was introduced to examine local agglomeration patterns [Figure 5: see original paper]. Based on the analysis, 2000, 2008, and 2015 were selected as representative periods.

In 2000, hotspot areas were concentrated in Singapore and Cyprus, with cold spots mainly in China, Central Asia, and South Asia. Sub-hotspot areas were primarily in Central and Eastern Europe, while sub-coldspot areas were concentrated in Southeast and West Asia. In 2008, hotspot areas remained unchanged, cold spots contracted, and many Central and Eastern European countries shifted from sub-coldspot to sub-hotspot areas, indicating significantly improved openness in the region and corroborating the northwestward shift of the center of gravity before 2008. Cyprus experienced a dramatic change from sub-coldspot to hotspot, primarily due to strengthened economic cooperation with the EU, Eurozone accession in January 2008, and development of island leisure tourism, making it a world tourism hotspot (tourism output accounting for 12.7% of GDP).

In 2015, the spatial pattern changed slightly. Hotspot areas remained concentrated in Singapore and Cyprus. Sub-hotspot areas expanded to the Arabian Peninsula and Southeast Asia (including Malaysia, Indonesia, Saudi Arabia, Oman, Russia, and Mongolia). The Arabian Peninsula' s spatial agglomeration improved significantly, mainly because post-2008 crisis, countries actively adjusted industrial structures from oil to non-oil tertiary industries. For example, the UAE' s non-oil economy became its development core, with non-oil foreign trade totaling 1.6 trillion yuan in 2017, up 13% year-on-year, far exceeding oil sector growth. Saudi Arabia focused on developing domestic tourism, particularly Muslim tourism, while preparing to launch tourist visas. However, Yemen remained a sub-coldspot area due to domestic terrorism and political turmoil hindering socioeconomic development, making it one of the world' s least developed countries with persistently low openness.

Overall, hotspot areas were scattered, concentrated in Singapore and Cyprus. Sub-hotspot areas were mainly in Central and Eastern Europe, gradually expanding to the Arabian Peninsula and Southeast Asia. Sub-coldspot areas were concentrated in Southeast and West Asia, while cold spot areas were extensive but gradually shrinking, mainly in China, Central Asia, and South Asia.

3.4 Influencing Factor Analysis

3.4.1 Common Panel Model Analysis Using openness of BRI countries as the dependent variable and the seven factors mentioned above as independent variables, with transport further divided into land transport, ports, and aviation, all variables were logarithmically transformed to approximate normal

distribution and eliminate heteroskedasticity. Table 4 presents the results, with Models 1-5 representing different transport specifications. All models underwent pooled effects, fixed effects, and random effects tests, with Hausman tests selecting the optimal specification.

Results show that all seven factors significantly influenced BRI openness. **Economic development level** had a significantly positive coefficient: a 1% increase in per capita GDP raised openness by approximately 0.30-0.34%, indicating that economic development is the primary factor affecting openness. Higher economic development levels drive demand beyond domestic markets, strengthening trade ties and enabling capital, technology, and information exports. **Population size** had a significantly positive coefficient: a 1% increase in population density raised openness by 0.18-0.34%, as larger populations create bigger consumer markets and provide abundant low-cost labor, attracting foreign investment. Sachs argued that densely populated countries are more likely to engage internationally.

Industrial structure had a significantly positive coefficient: a 1-percentage-point increase in tertiary industry share raised openness by 0.13%. Industrial upgrading transforms growth from extensive to intensive modes, shifting exports from resource-intensive to capital- and technology-intensive products with higher added value and lower transport costs. Additionally, tertiary industry development stimulates transport infrastructure construction, facilitating large-scale cross-border flows of capital and goods.

Human capital had a significantly positive coefficient: a 1-percentage-point increase in tertiary education enrollment raised openness by 0.22%. Higher human capital enhances knowledge specialization, facilitating absorption of international technology, improving labor quality, promoting productivity growth and industrial optimization, and enhancing export competitiveness. Human capital also positively influences FDI location choices.

Social security had a significantly negative coefficient: increased terrorist incidents worsened security, significantly reducing openness. Terrorism negatively impacts international trade, causes capital flight, hinders FDI attraction, affects financial markets, lowers sovereign credit ratings, and restricts flows of people, information, and technology. In recent years, terrorist attacks in BRI countries have grown rapidly, accounting for nearly 60% of global incidents, forming a "terrorism arc" from the Middle East through Central and South Asia to Southeast Asia, significantly affecting the openness pattern.

Government customs policy had a significantly negative coefficient: higher tariff rates indicated more restrictive policies, negatively affecting trade and reducing openness. Baier and Bergstrand found that tariff reductions accounted for 33% of trade growth among 16 OECD countries from the late 1950s to the late 1980s.

Transport infrastructure had a significantly positive coefficient: a 1-unit increase in transport quality index raised openness by 0.28%. Improved transport

infrastructure enhances regional accessibility, reducing transport costs and time for people and goods, expanding exchanges and trade, attracting FDI, and promoting knowledge diffusion and technology transfer. Among three transport types, land transport and ports showed significantly positive effects, while aviation did not. This may be because Central Asian, South Asian, and some Southeast Asian countries have underdeveloped aviation with sparse airport distribution and conservative aviation policies. However, as the BRI gains international recognition and promotes unified aviation cooperation mechanisms, aviation infrastructure will play a crucial role.

3.4.2 Dynamic Spatial Panel Model Analysis Based on the spatial correlation analysis above, openness among BRI countries exhibits spatial interaction effects, necessitating dynamic spatial panel models. Table 5 compares three dynamic spatial panel models. The log-likelihood values clearly show that DSDM has the best fit, followed by DSLM, with DSEM performing worst.

In the DSDM model, population size, human capital, social security, government customs policy, and ports significantly affected openness. Economic development level, industrial structure, and land transport were significant at the 10% level, while aviation was not significant. Additionally, spatial lag terms of economic development level, human capital, land transport, and ports were significantly positive, while aviation' s spatial lag term was significantly negative, indicating that neighboring countries' economic development, human capital, land transport, and ports positively influenced domestic openness, while neighboring aviation improvements had negative effects.

To deeply analyze spatial interaction effects, this paper uses partial differential decomposition to divide each variable' s effects into six spatio-temporal categories: short-term direct, short-term indirect, short-term total, long-term direct, long-term indirect, and long-term total effects (Table 6). Overall, both short-term and long-term effects showed consistent positive/negative relationships and significance. Economic development level, human capital, land transport, and ports had positive direct and indirect (spillover) effects that passed significance tests, indicating they significantly influenced both domestic and neighboring countries' openness. Population size, industrial structure, social security, and government customs policy only significantly affected domestic openness, while aviation quality only negatively affected neighboring countries' openness. Comparing coefficient magnitudes across time horizons, the impacts of economic development level, human capital, land transport, and ports on all countries showed upward trends, while population size, industrial upgrading, and government customs policy showed downward trends in domestic effects, and social security and aviation showed upward trends in domestic and neighboring effects respectively.

4 Conclusions and Implications

Based on panel data from 66 BRI countries from 2000 to 2015, this paper constructed a comprehensive openness evaluation index system and employed KDE, SDE, ESDA, and DSDM to analyze spatio-temporal patterns and influencing factors of openness. The main conclusions are:

1. Openness along the BRI showed an overall upward trend from 2000 to 2015, with development gaps among countries gradually narrowing.
2. The center of gravity of openness moved within Iran along the BRI but exhibited two phases: northwestward movement from 2000 to 2008, then gradual eastward movement after 2008.
3. Significant spatial disparities existed in BRI openness, with higher levels in the northwestern region and relatively lower levels in the central and southern regions.
4. Openness demonstrated significant positive spatial autocorrelation globally. Locally, hotspot areas were scattered, concentrated in Singapore and Cyprus, while sub-hotspot areas were mainly in Central and Eastern Europe, gradually expanding to the Arabian Peninsula and Southeast Asia. Sub-coldspot areas were concentrated in Southeast and West Asia, while cold spot areas were extensive but gradually shrinking, mainly in China, Central Asia, and South Asia.
5. Economic development level, population size, industrial structure, human capital, social security, government customs policy, and transport infrastructure all significantly influenced openness. Due to spatial interaction effects, this paper employed dynamic spatial panel models, with DSDM showing the best fit. DSDM analysis revealed that economic development level, human capital, land transport, and ports all had significant short-term and long-term direct and indirect effects on openness.

Based on these conclusions, the following policy implications emerge:

1. The BRI remains in its initial development stage, and enhancing openness levels among participating countries is key to deepening BRI development.
2. Openness is influenced by multiple factors. First, countries should strengthen domestic economic development and optimize industrial structures to provide an economic foundation for opening-up. Second, they should promote population agglomeration and enhance human capital levels to provide human and technological support. Additionally, countries should strengthen social governance and open policy construction to provide favorable social environments. Finally, BRI countries should continuously improve transport infrastructure to enhance cross-border accessibility, providing the material foundation for orderly flows of trade, investment, and other openness elements.

3. BRI countries exhibit clear spatial effects, indicating that a country' s openness development is influenced not only by its own factors but also by neighboring countries' drivers. Therefore, international cooperation among countries with different openness levels should be strengthened to leverage spillover effects from high-openness countries (in economic development, human capital, land transport, and ports), thereby enhancing overall openness levels along the BRI.

References

[1] LIU Weidong. Scientific understanding of the Belt and Road Initiative of China and related research themes[J]. Progress in Geography, 2015, 34(5): 538-544.

[2] HABOVA A. Silk Road economic belt: China' s Marshall plan, pivot to Eurasia or China' s way of foreign policy[J]. KSI Transactions on Knowledge Society, 2015, 8(1): 64-70.

[3] PENNA M. China' s Marshall plan: All Silk Roads lead to Beijing?[J]. World Politics Review, December 9, 2014.

[4] ROLAND N. China' s Belt and Road Initiative: Underwhelming or game changer?[J]. The Washington Quarterly, 2017, 40(1): 127-142.

[5] JIN Ling. The Belt and Road Initiative: China' s Marshall plan?[J]. International Studies, 2015, (1): 88-99.

[6] BROWN W A. The international gold standard reinterpreted, 1914-1934[M]. New York: National Bureau of Economic Research, 1940.

[7] ROMER P M. Increasing returns and long-run growth[J]. Journal of Political Economy, 1986, 94(5): 1002-1037.

[8] EDWARDS S. Openness, productivity and growth: what do we really know?[J]. The Economic Journal, 1998, 108(447): 383-398.

[9] CHANG R, KALTANI L, LOAYZA N V. Openness can be good for growth: The role of policy complementarities[J]. Journal of Development Economics, 2009, 90(1): 33-49.

[10] HUCHET-BOURDON M, MOUEL C L, VIJIL M. The relationship between trade openness and economic growth: Some new insights on the openness measurement[J]. The World Economy, 2017, 39(4): 1-27.

[11] WINTERS L A, MASTERS A. Openness and growth: still an open question?[J]. Journal of International Development, 2013, 25(8): 1061-1070.

[12] SACHS J D, WARNER A, ASLUND A, et al. Economic reform and the process of global integration[J]. Brookings Papers on Economic Activity, 1995, 35(1): 1-118.

[13] KOTCHERLAKOTA V, SACK-RITTENHOUSE M. Index of openness: measurement and analysis[J]. The Social Science Journal, 2000, 37(1): 125-130.

[14] YANIKKAYA H. Trade openness and economic growth: a cross-country empirical investigation[J]. Journal of Development Economics, 2003, 72(1): 57-89.

[15] QUINN D P, INCLAN C. The origins of financial openness: a study of current and capital account liberalization[J]. American Journal of Political Science, 1997, 41(3): 771-813.

[16] BALTAGI B H, DEMETRIADES P O, LAW S H. Financial development and openness: Evidence from panel data[J]. Journal of Development Economics, 2009, 89(2): 285-296.

[17] QUINN D, SCHINDLER M, TOYODA A M. Assessing measures of financial openness and integration[J]. IMF Economic Review, 2011, 59(3): 488-522.

[18] XIONG Bin, LIU Zeyu. Study on the spatial difference and convergence of financial openness of countries along the Belt and Road from the perspective of institutional quality[J]. World Economy Studies, 2009, (5): 3-13.

[19] CHEN Sheng, PAN Hong. Empirical study on influencing factors of provincial openness in China based on the analysis of provincial panel data from 1998 to 2012[J]. Inquiry into Economic Issues, 2015, (6): 1-9.

[20] LI Jianxin, ZHONG Yexi, HUANG Jie, et al. Economic development disparities of Jing-Shan Economic Trough Belt since 2000[J]. Economic Geography, 2015, 35(8): 10-18.

[21] ZHAO Juan, SHI Peiji, ZHU Guofeng. Measurement and comparative study of the western region of openness[J]. World Regional Studies, 2016, 25(4): 93-101.

[22] ZHANG Yongnian, PAN Jinghu. Spatio-temporal pattern of economic opening rate at prefecture level cities or above in China[J]. Arid Land Geography, 2018, 41(5): 1123-1131.

[23] YANG Chaojun, YANG Wenke, LI Ning. Study on difference decomposition and spatial convergence of regional openness in China[J]. R&D Management, 2018, 30(1): 115-125.

[24] LIU Shiwei, ZHANG Pingyu, SONG Fengbin, et al. Measuring the agricultural modernization level of Heilongjiang reclamation areas in China[J]. Scientia Geographica Sinica, 2018, 38(7): 1051-1060.

[25] BABENKO V, PEREVOZOVA I, MANDYCH O, et al. World information in conditions of international globalization: Factors of influence[J]. Global Journal of Environmental Science and Management, 2019, 5: 172-179.

[26] MUTASCU M. A time frequency analysis of trade openness and CO2 emissions in France[J]. Energy Policy, 2018, 115: 443-455.

[27] LI Kai, QI Shaozhou. Trade openness, economic growth and carbon dioxide emission in China[J]. Economic Research, 2011, (11): 60-72+102.

[28] DONG F. The impact of economic openness on standard of living and income inequality in eight countries[J]. Emerging Markets Review, 2014, 21: 234-264.

[29] WEI Hao, GENG Yuan. International trade and urban-rural income gap in China[J]. World Economy Studies, 2015, (7): 89-99.

[30] ESTRADA M A R. The global dimension of the regional integration model(GDRI-Model)[J]. Modern Economy, 2013, 4: 346-369.

[31] CHEN Xiao, SONG Heng. Factors of construction level and influence of Urumqi Regional Financial Center in the core area of Silk Road Economic Belt[J]. Arid Land Geography, 2018, 41(1): 215-220.

[32] YIN Jie, LIU Yafang, YANG Dongxu, et al. Study on tourism openness of European countries along the Belt and Road[J]. Economic Geography, 2017, 37(6): 190-197.

[33] BAO Chao, ZOU Jianjun. Spatiotemporal variations of urbanization quality in northwest China[J]. Arid Land Geography, 2019, 42(5): 1141-1152.

[34] LI Zhe, SHEN Yuming, ZENG Chunshui. Science and technology innovation patterns and their spatial and temporal evolution of provinces in China[J]. Geographical Research, 2018, 37(6): 1223-1237.

[35] LU Huiling, ZHOU Lihua, CHEN Yong, et al. Degree of coupling and coordination of eco-economic system and the influencing factors: a case study in Yanchi County, Ningxia Hui Autonomous Region, China[J]. Journal of Arid Land, 2017, 9(3): 446-457.

[36] TSEKERIS T. Domestic transport effects on regional export trade in Greece[J]. Research in Transportation Economics, 2017, 61: 2-14.

[37] DEBARSY N, ERTUR C, LESAGE J P. Interpreting dynamic space-time panel data models[J]. Statistical Methodology, 2012, 9(1-2): 158-171.

[38] CHEN W Y, HU F Z Y, LI X, et al. Strategic interaction in municipal governments' provision of public green spaces: A dynamic spatial panel data analysis in transitional China[J]. Cities, 2017, 71: 1-10.

[39] JIANG Haixu, LI Yuezheng, LI Xin. A discussion on cooperation of leisure tourism industry between Changshan islands and Cyprus[J]. World Regional Studies, 2010, 19(1): 130-137.

[40] NOORBAKHSH F, PALONI A, YOUSSEF A. Human capital and FDI inflows to developing countries: New empirical evidence[J]. World Development, 2001, 29(9): 1593-1610.

[41] ZHANG Xiaolei, ZHANG Erzhen. The trade isolation effect of the Belt and Road Initiative terrorist activity risk[J]. World Economic Papers, 2017, (1):

69-86.

[42] BAIER S L, BERGSTRAND J H. The growth of world trade: tariff, transport cost and income similarity[J]. Journal of International Economics, 2001, 53(1): 1-27.

[43] FAN Xingli. Setting up the new pattern of regional civil aviation cooperation for China and the Belt and Road Initiative countries[J]. China Transportation Review, 2017, 39(1): 1-4.

Data Sources:

1. World Bank World Development Indicators: https://databank.worldbank.org/reports.aspx?source=world development-indicators
2. UNCTAD World Investment Report: http://unctad.org/en/Pages/DIAE/World%20Investment%20Repo Tables.aspx
3. Chinn-Ito Index (measures de jure financial openness): http://web.pdx.edu/~ito/Chinn-Ito_{website}.htm
4. ITU-D Statistics (telecommunications): https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx
5. World Economic Forum Global Competitiveness Report: www.weforum.org/reports
6. University of Maryland Global Terrorism Database: https://www.start.umd.edu/gtd/

Note: Figure translations are in progress. See original paper for figures.