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Research article

Can greater openness improve green economy efficiency of countries along the Belt and Road Initiative?

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ABSTRACT

Openness is the core concept of the Belt and Road initiative (BRI), which plays a significant role in promoting the sustainable economic development of countries along the BRI. This study uses the entropy method to measure openness based on six dimensions: trade, investment, finance, tourism, technology, and information. Simultaneously, a super-SBM model with undesired output is proposed to measure green economy efficiency (GEE). Using the panel data of 66 countries along the BRI from 2008 to 2019, we empirically examine the impact of openness on GEE. The results are as follows: (1) The openness level of countries along the BRI is generally increasing, but the relative differences between countries tend to widen. (2) Openness has a significant U-shaped nonlinear effect on GEE, and the conclusion is still valid after considering the robustness test; (3) The spatial econometric model shows that openness not only affects the GEE of the local country, but also has a spillover effect on neighboring countries. Therefore, we believe that BRI countries should strengthen policy communication, break down border barriers, actively promote the orderly flow and diffusion of openness elements, and pay attention to the quantity and quality of openness development, which is key to the high-quality construction of the BRI.

1. Introduction

Since the Belt and Road Initiative (BRI) was proposed in 2013, China has continuously promoted its construction and has gradually turned its vision into reality. This has given new impetus to the economic recovery and development of countries along the BRI, and even the world [1–6]. However, most BRI countries are still in the process of industrialization, and their development modes are relatively extensive [7]. High levels of pollution, energy consumption, and emissions are the main characteristics of economic development in these countries [8]. In addition, high population concentration and fragile ecological background render this mode of development unsustainable [9]. As shown in Fig. 1, the total CO_2 emissions of all BRI countries[1] increased steadily from 15.37 billion tons in 2008 to 21.08 billion tons in 2019, representing an increase of 37.17%. Throughout the period, BRI countries accounted for more than 50% of the world's total CO_2 emissions. Therefore, the contradiction between the extensive economic growth model driven by various factors and the resource environment has become increasing prominent, restricting the development of the green economy of the BRI.

Green economy is a sustainable economic development model [10], and green economy efficiency (GEE) comprehensively

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[1] Scope of countries along the BRI can be found in Table A in the Appendix.

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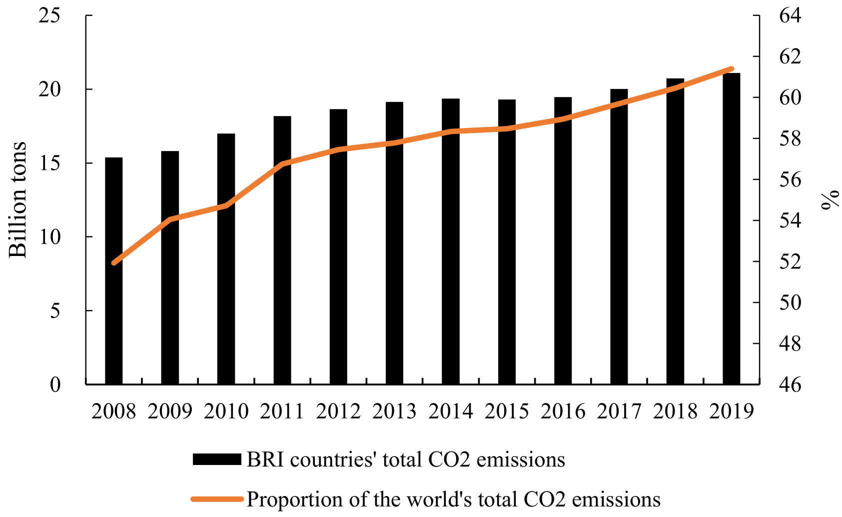

Fig. 1. Evolution trend of total CO_2 emissions along the BRI.
Source: Authors' calculations based on the data from the World Bank's public database.

considers resource inputs and environmental costs, which are effective indicators for measuring the level of green economy [11,12]. Effectively improving GEE has become an important starting point for promoting high-quality development of the BRI [13]. The Chinese government has attached great importance to green development since the BRI's proposal. Especially in 2017, the Ministry of Environmental Protection, the Ministry of Foreign Affairs, the National Development and Reform Commission, and the Ministry of Commerce jointly issued the "*Guiding Opinion on Promoting Construction of a Green 'One Belt One Road*'", which emphasized the promotion of GEE along the BRI through the opening of trade, investment, finance, and other elements. As an important avenue for technology transfer, spillover, and diffusion, the openness of elements promotes the economic development of countries along the BRI, while the green technology embodied in them also facilitates the improvement of GEE [14]. Statistics show that the implementation of the BRI has greatly accelerated the development of trade and investment in countries along the route. From 2013 to 2018, the total trade volume of countries along the BRI increased from $ 13.32 trillion to $ 14.10 trillion, accounting for 34.94%–35.74% of total world trade.[2] Foreign direct investment (FDI) of countries along the BRI increases from $ 431.36 billion to $ 482.73 billion, accounting for 36.14%–37.21% of total world FDI.[3] Of course, some scholars have raised doubts about this, calling the BRI "China's version of the Marshall Plan" [15] or "Chinese-style neocolonialism" [16]. With the continuous opening of international market elements along the route, China and developed countries along the BRI will transfer their polluting industries to middle- and low-income countries, turning them into "polluting sanctuaries" [17,18]. Therefore, in the context of deepening economic exchanges and cooperation, what is the development trend of the comprehensive openness levels of countries along the BRI? Can greater openness effectively balance the relationship between economic growth and environmental protection, thereby improving GEE? Is there a spillover effect on the GEE of neighboring countries when expanding openness?

The marginal contribution of this study involves three aspects. First, based on existing literature, we construct a national-level openness evaluation system based on six dimensions—trade, investment, finance, tourism, technology, and information—and systematically evaluate the openness of countries along the BRI from 2008 to 2019. Second, a theoretical relationship between openness and GEE is constructed, broadening the research perspective. Furthermore, based on the panel data of 66 countries along the BRI, this study discusses the nonlinear impact of openness on GEE using the double fixed effect model, and uses the generalized method of moments (GMM) model and instrumental variable method to test robustness. Third, considering the spatial autocorrelation of GEE, this study uses a spatial econometric model to explore the spatial impact of openness on GEE, that is, to analyze the impact of openness on the GEE of none's own country and neighboring countries.

The remainder of this paper is organized as follows. The next section presents a literature review, followed by a theoretical analysis. Next, we examine openness in BRI countries and present the research methodology and data, and an analysis of empirical results. Finally, we present the discussion and conclusion.

2. Literature review

2.1. Evaluating GEE literature

As an important reflection of green development, GEE incorporates resource and environmental factors into traditional economic

[2] The data is from the World Bank's public database.
[3] The data is from the UNCTAD FDI database.

efficiency measurements,[4] which can truly reflect the health and green levels of regional economic development [19]. Presently, relevant research on GEE has mainly focused on the following three aspects:

The first concerns the measurement of GEE. Most scholars construct an "economy-society-environment" three-dimensional input-output evaluation index system, and then use data envelopment analysis (DEA) or stochastic frontier analysis (SFA) to calculate GEE. In terms of research scale, it involves global [20], national [21], urban agglomeration [22], important basin [23], province [24] and city [19]. Compared with SFA, DEA, as a non-parameter method, does not require specific production function forms and can handle multiple input and output data, which has obvious advantages [25].

The second aspect regards analyzing the spatiotemporal evolution characteristics of GEE. On the one hand, the Theil index, Gin coefficient, coefficient of variation, kernel density estimation, and other methods have been used to analyze the temporal evolution rule of GEE. For example, based on the Theil index and coefficient of variation, Yang et al. found that the relative differences of GEE of China's urban agglomerations presented a W-shaped trend from 2003 to 2018 [26]. Feng et al. used standard deviation ellipse to investigate the evolution trend in the GEE of 285 cities in China and concluded that the overall level of GEE of China's urban agglomerations showed an obvious upward trend [27]; On the other hand, exploratory spatial analysis, standard deviation ellipse, spatial Markov transfer matrix, and other spatial methods have been used to reveal the spatial distribution rules of GEE. For example, based on the exploratory spatial analysis, Cui and Lui found that the GEE of 13 cities in the Jing-jin-ji region of China presented spatial correlation and dependence [28]. Using a standard deviation ellipse, Liu et al. found that China's GEE showed a northeast–southwest pattern [29]. Based on the spatial Markov transfer matrix, Zhou et al. (2020) found that the GEE of China's cities had a strong "club convergence" phenomenon, and the evolution of different GEE types had significant path dependence [30].

The third aspect concerns the drivers of GEE. Existing literature shows that natural resources [31], economic development [32], industrial structure adjustment [33], industrial agglomeration [34], technological innovation [35], human capital [36], transport infrastructure [37], trade [38], FDI [39], digital economy [40], and environmental regulation [41] have a significant impact on GEE. GEE is dynamically changing and is influenced by various factors, and the mechanisms and effects of different factors on GEE are also different.

2.2. Investigating the influence of openness on GEE: a comprehensive review

Brown first proposed the concept of "interdependence" as an outgrowth of openness [42]. Kojima took the lead in introducing trade dependence and used it to represent national openness [43]. With the rise of new growth theories, the academic community has increasingly focused on studying openness, especially the impact of trade openness on economic growth [44,45]. However, owing to the lack of in-depth research on the definition and measurement of openness [46], previous studies have only considered the impact of a specific aspect of openness on GEE. Research conclusions generally include positive or negative effects, nonlinear effects, and spillover effects. The details are as follows.

From the perspective of trade openness, Talberth and Bohara established a panel dataset in eight countries to analyze the relationship between trade openness and green GDP and found that there was a significant U-shaped nonlinear relationship between them [47]. However, using panel data from 123 countries covering 2000 to 2017, Tawiah et al. found that trade openness had a vital negative impact on green economic growth [48]. In addition, Jiang et al. considered the establishment of Pilot Free Trade Zone (PFTZ) as a random event of Shanghai's trade openness to analyze its impact on GEE and found that the PFTZ had a positive influence on GEE and the degree of influence gradually increased over time [49].

From an investment openness perspective, this includes FDI and outward direct investment (ODI). Regarding FDI, Yu et al. found that FDI had a positive impact on GEE of Chinese cities through technology and agglomeration [50]. Based on the data of 284 cities in China from 2008 to 2019, Yu and Liu found that due to the threshold mechanism of environmental regulation, FDI had a U-shaped influence on GEE of East and Central China across the threshold, showing a positive effect, while Western China had an inhibitory effect [51]. Similarly, Zheng et al. found that environmental regulation played a positive moderating role in the relationship between FDI and marine GEE [52]. Regarding ODI, Wu et al. found that China's ODI has improved the GEE of BRI countries, and institutional quality played a positive moderating role in the relationship between the two [53]. Wang and Wang adopted the System GMM (SYS-GMM) to explore the influence of ODI on GEE and found that ODI significantly improved China's GEE, and that reverse technology spillover became an important mediating mechanism affecting the relationship between the two [54].

With the continuing progress of global and regional economic integration, international factors of frequent production flow between countries and forms of openness in the outside world are not limited to trade and investment. Some authors have conducted research from other perspectives on openness, such as finance, tourism, technology, and information. For example, Xie et al. used a spatial measurement model to study the direct and spillover effects of financial agglomeration on the GEE of Chinese cities and hypothesized that financial agglomeration may improve GEE, but it had a negative spillover effect on the GEE of neighboring cities [55]. Hu et al. examined the impact of tourism economy on GEE and found that it had a significant inverted U-shaped impact on the GEE [56]. Based on the data of 278 Chinese cities, Liu and Dong used a spatial econometric model to analyze the relationship between technological innovation and GEE and found that technological innovation had positive direct and indirect effects on GEE [35]. Wu et al. [57], Wang et al. [58], and Tian and Pang [59] found that internet development had a significant positive impact on GEE.

[4] Traditional economic efficiency refers to the minimum input and maximum output of a country or region's economic operation under certain technological conditions, while the core element of GEE should simultaneously consider resource, ecological environment, and economic growth [22]. There is a huge difference between the two.

In summary, the literature provides rich materials for exploring the relationship between openness and GEE, but there is still room for further deepening in some aspects: (1) Previously, only trade, investment, finance, and other single data were used to measure the degree of openness of a country, which may lead to a bias in the effect of openness on GEE. Therefore, this study integrates various open perspectives to accurately reflect the level of openness of countries along the BRI. (2) There is no unified conclusion regarding the relationship between openness and GEE. Based on the preliminary construction of the theoretical relationship between the two, this study focuses on exploring the nonlinear impact of openness on GEE. (3) With the continuous progress of BRI construction and trade, the elements of openness flow more frequently in geographical space, and the spatial spillover effect of openness needs to be further revealed. In view of this, using panel data of 66 countries along the BRI from 2008 to 2019, we first construct an evaluation index system of openness and GEE and systematically demonstrate the influence of openness on GEE and its spillover effect using the two-way fixed effect model, dynamic panel model, and spatial econometric model. This is expected to provide policy support to facilitate the high-quality development of the BRI.

2.3. Theoretical analysis

In recent years, the concept of a green economy has been actively promoted and implemented globally; however, most BRI countries are still constrained by rough economic development models, biased industrial structures, and insufficient technological innovation. The pursuit of open development has accelerated the free flow of factors of production in BRI countries, which has indeed negatively impacted the ecological environment while promoting economic growth. Therefore, we believe that the influence of improving openness on the GEE of BRI countries is a “double-edged sword.” Relevant explanations are reflected in following two aspects:

On the one hand, firstly, driven by the dual effects of profit chasing by enterprises and the government’s excessive emphasis on economic growth, most developing countries in the early stages of opening-up adopt loose environmental control policies, which may become “havens” for polluting foreign enterprises [60,61], leading to ecological damage and restricting GEE. In addition, a large amount of economic and industrial activities will be concentrated in the main central cities, and because of the limitations of urban space and resources, failure to match these economic activities in a timely manner will generate excessive congestion effects, which will also hinder GEE. Finally, in the early opening phase, outdated infrastructure, scarce talent and funding, and inadequate public service facilities make it difficult to effectively improve resource allocation efficiency and promote technological progress.

On the other hand, the heterogenous film theory emphasizes the significant impact of openness on enterprise efficiency [62–64]. Only when opened to a certain extent, domestic enterprises can continuously learn from advanced countries’ technology and management experiences through demonstration, competition, and correlation effects [65–67]. Innovation in enterprise production technology can improve production efficiency and reduce energy consumption and environmental pollution. Moreover, active integration into international markets makes it convenient for enterprises to search for information, reach more international users, and reduce transaction costs [68]. Finally, we believe that greater openness can accelerate the rational allocation of resource elements and the coordinated division of labor among industries. The competitive effect brought about by opening-up to the outside world will further drive away enterprise with low green technology efficiency, providing a strong impetus for industrial green transformation, thereby promoting local countries’ GEE. Therefore, the pollution halo and pollution haven hypotheses are not completely opposite. Openness may have a nonlinear impact on GEE.

Furthermore, as the BRI integration deepens, countries’ economic and social links become more closely linked. Expanding openness

Table 1
Comprehensive evaluation index system of openness.

System	Subsystem	Index	Index Interpretation	Weight
Comprehensive evaluation index system of openness	Trade openness	Import dependence	Import/GDP	0.0209
		Export dependence	Export/GDP	0.0343
	Investment openness	Level of foreign direct investment	FDI/GDP	0.1287
		Level of outward foreign direct investment	OFDI/GDP	0.3133
	Finance openness	Level of legal finance openness	Chinn-Ito index①	0.0334
		level of realistic finance openness	(External financial assets + external financial liabilities)/GDP	0.0913
	Tourism openness	Level of inbound tourism openness	Inbound tourism revenue/GDP	0.0774
		Level of outbound tourism openness	Outbound tourism revenue/GDP	0.0390
	Technology openness	Level of international patent application	Number of International patent applications/ Population	0.1430
		Level of science paper	Number of science papers/Population	0.0887
	Information openness	Internet penetration rate	Users accessing the internet/Population	0.0225
		Mobile phone penetration rate	Mobile phone ownership/Population	0.0074

Note: ①Chinn-Ito index was constructed by Chinn and Ito who built dualistic dummy variables on whether IMF members had multiple exchange rates, controls on current transactions, restrictions on capital account transactions and policy information on the surrender of export earnings by Annual Report Exchange Arrangement Exchange Restrictions (AREAER) and used principle component analysis to evaluate [74]. The larger Chinn-Ito index, the higher level of legal finance openness.

will capture neighboring countries' development resources, increase the regional resource allocation imbalance, and consequently have a detrimental influence on adjacent countries' GEE. Simultaneously, it will improve neighboring countries' GEE by encouraging the flow of creative element, industrial ties, reciprocal imitation effects, and demonstration effects. So, we believe that openness has a significant spatial spillover effect.

2.4. Examining openness in BRI countries

Openness reflects the extent to which a country or region participates in international cooperation and development. Drawing lessons from existing research [69–73], this study establishes a comprehensive evaluation index system of openness that includes six dimensions: trade, investment, finance, tourism, technology, and information (Table 1). Considering the large differences in the dimensions, we normalize each index and transform it into a dimensionless score between 0 and 1. The weights of all indexes are then calculated based on the entropy method, and the results are listed in Table 1. Finally, we calculate the comprehensive score of each country' s openness according to Eq. (1):

$$S_i = \sum_{j=1}^{n} W_j \times Z_{ij} \tag{1}$$

where S_i is the comprehensive evaluation value of openness of country i; Z_{ij} is the standardized value of index j for country i; W_j is the weight of index j.

Table B in the Appendix presents openness of countries along the BRI from 2008 to 2019. As shown in Fig. 2, since 2008, openness of the BRI has shown the following characteristics: (1) The kernel density curve keeps shifting to the right, indicating that openness gradually increases over time. (2) The shape of the curve changes from "high and narrow peak" to "short and narrow peak", indicating that the relative differences in openness among BRI countries tend to widen.

3. Model construction and data resources

3.1. Model construction

3.1.1. Basic model

This study analyzes the effect of openness on the GEE of countries along the BRI. At the same time, because openness is a comprehensive system, its effect on GEE may also have a complex nonlinear relationship; therefore, the squared term of openness is introduced into the model. The specific model can be expressed using Eq. (2):

$$GEE_{it} = \alpha_0 + \alpha_1 OPE_{it} + \alpha_2 OPE_{it}^2 + \sum_{i=1}^{n} \beta_i \times X_{it} + \mu_i + \varphi_t + \varepsilon_{it} \tag{2}$$

where GEE_{it} is the green economy efficiency of country i in year t. OPE_{it} is the openness of country i in year t. OPE_{it}^2 is the squared term of OPE_{it}, which can be used to determine whether a nonlinear effect exists. X_{it} is a set of control variables, including industrial structure (*IS*), urbanization level (*UL*), research and development investment (*RDI*), and environmental regulation (*ER*). In addition, μ_i represents the country fixed effect, while φ_t is the year fixed effect. ε_{it} refers to the random error term.

The non-linear relationship between openness and GEE can be judged from the signs of α_1 and α_2, which show the following two situations: (1) When $\alpha_1 > 0$ and $\alpha_2 < 0$, and both are statistically significant, indicating that there is an inverted U-shaped relationship between openness and GEE. (2) When $\alpha_1 < 0$ and $\alpha_2 > 0$, and both are statistically significant, indicating that there is a U-shaped relationship.

3.1.2. Spatial econometric model

Spatial economic units do not exist in isolation but interact with neighboring economic units in space through various connections, showing geographical spatial dependence and spillover characteristics [75]. Since GEE between countries along the BRI may have spatial autocorrelation, the influence of openness on GEE can be explored through a spatial econometric model incorporating spatiotemporal effects [76]. Currently, the spatial error model (SEM), the spatial lag model (SLM), and the spatial dubin model (SDM) are the three main types of spatial econometric models. Unlike SEM and SLM, SDM fully considers the spatial correlation of independent and dependent variables, and focuses on revealing the exogenous interaction effect caused by the correlation between the GEE of a certain country and various influencing factors of neighboring countries. SDM is described in Eq. (3):

$$\begin{aligned} GEE_{it} = {} & \rho WGEE_{it} + \beta_0 + \beta_1 OPE_{it} + \beta_2 OPE_{it}^2 + \beta_3 IS_{it} + \beta_4 UL_{it} + \beta_5 RDL_{it} + \beta_6 ER_{it} + \gamma_1 WOPE_{it} + \gamma_2 WOPE_{it}^2 + \gamma_3 WIS_{it} + \gamma_4 WUL_{it} \\ & + \gamma_5 WRDL_{it} + \gamma_6 WER_{it} + \mu_i + \varphi_t + \varepsilon_{it} \end{aligned} \tag{3}$$

where ρ is the spatial autoregressive coefficient; $\beta_1, \beta_2, \cdots, \beta_6$ are the influence coefficients of all factors on GEE; $\gamma_1, \gamma_2, \cdots, \gamma_6$ are the influence coefficients of the explanatory variables of spatial lag; W is the spatial weight matrix.

W is the premise and foundation of spatial autocorrelation analysis, and its reasonable and correct construction is important for spatial model testing and econometric analysis. Currently, there is no unified spatial weight matrix in academia. However, research

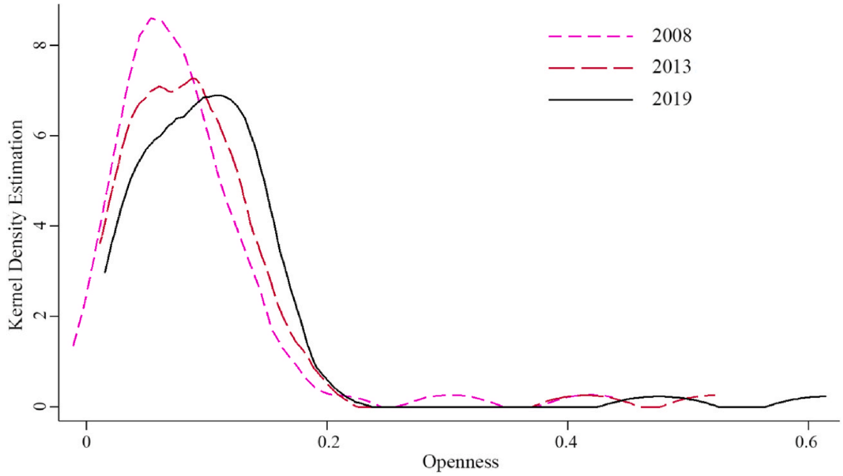

Fig. 2. Evolution trend of openness along the BRI.

based on adjacency relationships accounts for the vast majority. The BRI also includes several other countries. Whether a simple adjacency weight reflects the actual interconnectedness of the countries is debatable. Referring to existing literature [77–79], we construct four spatial weights for comparative analysis. The first is the adjacent matrix (W_1). The equation is set in Eq. (4):

$$W_1 = \begin{cases} 1, \textit{when country } i \textit{ is adjacent to country } j \\ 0, \textit{when country } i \textit{ is not adjacent to country } j \end{cases} \tag{4}$$

The second spatial weight (W_2) is the inverse distance matrix, whose equation is set in Eq. (5):

$$W_2 = \begin{cases} \dfrac{1}{d_{ij}}, \textit{when } i \neq j \\ 0, \textit{when } i = j \end{cases} \tag{5}$$

where d_{ij} is represented by the geographic distance between the capital of country i and the capital of country j.

The third spatial weight (W_3) is cultural distance matrix. Currently, the measurement of cultural distance in academia generally adopts the "Six-Dimensional Theory of Culture"[5] proposed by Hofstede [80]. According to this theory, we can construct the following measure equation in Eq. (6):

$$W_3 = \frac{1}{6}\sum_{m=1}^{6}\left\{\left(C_{mi} - C_{mj}\right)^2 \Big/ V_m\right\} \tag{6}$$

where C_{mi} is the score on the m cultural dimension of country i; C_{mj} is the score on the m cultural dimension of country j; V_m is the variance of the scores on the m cultural dimension.

The last spatial weight (W_4) is the economic distance matrix, whose equation is described in Eq. (7):

$$W_4 = \begin{cases} \dfrac{1}{\left|\overline{y}_i - \overline{y}_j\right|}, \textit{when } i \neq j \\ 0, \textit{when } i = j \end{cases} \tag{7}$$

where $\overline{y}_i$ and $\overline{y}_j$ are the average real per capita GDP of country i and j from 2008 to 2019.

3.2. Variable measurement

3.2.1. Assessment of dependent variables

DEA is a commonly used method to evaluating efficiency. However, the traditional DEA model does not consider the slack problem of input-output variables and cannot accurately calculate the efficiency value, including the undesired output [81]. In addition, when the decision-making units are all on the frontier (the efficiency value is 1), traditional DEA cannot effectively identify the differences among the units. Therefore, based on Tone's research [82], we choose the super-SBM model with undesired output to measure the GEE. The model is constructed in Eq. (8):

[5] Six-Dimensional Theory of Culture includes Long-Term Orientation/Short-Term Orientation), Indulgence/Constraint, Right Distance Index, Individualism/Collectivism, Masculinism/Feminism and Uncertainty Avoidance.

$$\min p=\frac{\frac{1}{m}\sum_{i=1}^{m}\frac{\bar{x}}{x_{ik}}}{\frac{1}{r_1+r_2}\left(\sum_{s=1}^{r_1}\frac{\bar{y}^d}{\bar{y}^d_{sk}}+\sum_{q=1}^{r_2}\frac{\bar{y}^u}{\bar{y}^u_{qk}}\right)}, s.t.\begin{cases}\bar{x}\geq\sum_{j=1,\neq k}^{n}x_{ij}\lambda_j;\ \bar{y}^d\leq\sum_{j=1,\neq k}^{n}y^d_{sj}\lambda_j\\ \bar{y}^u\geq\sum_{j=1,\neq k}^{n}y^u_{qj}\lambda_j;\ \bar{x}\geq x_k;\bar{y}^d\leq y^d_k;\bar{y}^u\geq y^u_k\\ \lambda_j\geq 0; i=1,2,\cdots,m; j=1,2,\cdots,n\\ s=1,2,\cdots,r_1; q=1,2,\cdots,r_2\end{cases} \tag{8}$$

where p is the GEE of a country; n is the number of decision-making units; m, r_1, r_2 represent the factor input, expected output and undesired output, respectively. In the calculation, we use total labor force, capital stock, and primary energy consumption as indicators of labor input, capital input, and energy input, respectively. The expected output is expressed as the gross national product of each country. The undesirable output is expressed as carbon dioxide emissions. Table 2 presents the GEE measurement index system.

Table C in the Appendix presents the GEE of the BRI countries from 2008 to 2019. As shown in Fig. 3, the GEE of the BRI has presented an overall fluctuating evolution trend, from 0.689 in 2008 to 0.618 in 2019, with a decrease of 10%, indicating that most countries along the BRI are still in the stage of high-emission and low efficiency development, and regional economic development and resource pollution have not yet been effectively decoupled. We also use the coefficient of variation (CV) to measure the difference in GEE along the BRI (Fig. 3). The CV shows a similar evolutionary trend, from 0.348 in 2008 to 0.310 in 2019, indicating that the gap in the GEE between countries along the BRI tends to narrow.

3.2.2. Independent variables

Core explanatory variables. Based on the above, openness is the core explanatory variable in this study. The higher the openness score, the greater the ability of a country to integrate into the international market.

Control variables. Control variables are important variables that affect GEE and can provide more accurate estimation results. In this study, industrial structure (*IS*), urbanization level (*UL*), research and development investment (*RDI*), and environmental regulation (*ER*) are selected as important control variables. The specific descriptions of the control variables are as follows.

Industrial structure (*IS*) is expressed as the proportion of added value of the secondary and tertiary sectors in GDP. Continuous optimization and upgrading of the industrial structure will help gradually eliminate traditional industries with high pollution levels and improve the level of clean production. In addition, it is beneficial to improve resource utilization efficiency and industrial added value.

Urbanization level (*UL*) is expressed as the ratio of the urban population to the total population. Urbanization reflects the continuous accumulation of population and various economic activities in urban areas. The impact of urbanization level on GEE may have two sides. On the one hand, with the high concentration of population in cities and the continuous expansion of built-up areas, the demand for resources and energy has skyrocketed and the damage to the ecological environment has increased. Simultaneously, during the process of urbanization, the relationship between urban and rural areas has become tense, which in turn inhibits regional economic growth. On the other hand, with the rapid progress of urbanization, human and knowledge capital will continue to gather in cities, realizing technology spillovers and innovation dives and promoting industrial innovation, which will have a positive impact on GEE.

Research and development investment (*RDI*) is measured by the percentage of RDI in GDP. In general, the level of R&D directly reflects a country's ability to innovate science and technology, thereby improving the level of resource utilization and pollution control, which is conducive to GEE.

Environmental regulation (*ER*) is measured using the environmental performance index (EPI) jointly released by Yale University and Columbia University. The EPI includes two dimensions, environmental health and ecosystem vitality, with 10 policy categories and 24 subdivision indicators that comprehensively reflect the situation of environmental governance and regulation.

The descriptive statistical results of each variable are shown in Table 3.

3.3. Data resources

This study uses data from multiple sources. GDP, total population, urban population, labor force, import and export trade volume, added value of the secondary and tertiary industries, inbound and outbound tourism revenue, RDI, international patent applications, science papers, time to export, and carbon dioxide emissions are obtained from *World Bank Database*. FDI and OFDI are obtained from *World Investment Report by United Nations Conference on Trade and Development*. Primary energy consumption comes from *U.S. Energy*

Table 2
GEE measurement index system.

System	Subsystem	Index
Inputs	Labor input	Total labor (Million people)
	Capital input	Capital stock (US $10 billion at constant 2010 price)
	Energy input	Primary energy consumption (TWh)
Outputs	Expected output	GDP (US $10 billion at constant 2010 price)
	Undesirable output	CO_2 (Million tons)

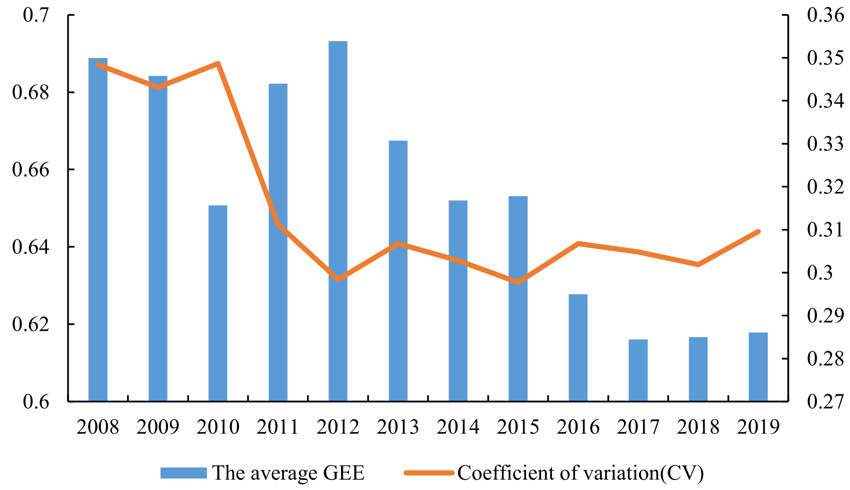

Fig. 3. Evolution trend of GEE along the BRI.

Information Administration (EIA) *database*. The Chinn-Ito index comes from Chinn and Ito's database website (https://web.pdx.edu/~ito/Chinn-Ito_website.htm). External financial assets and liabilities are obtained from *International Financial Statistical Yearbook*. The internet and mobile phone penetration rate are obtained from the *World Telecommunication/ICT Indicators Database.* Capital stock is derived from *Penn World Table version 10.0*. The environmental performance index is derived from *NASA's Socioeconomic Data and Applications Center*. In this study, the spatial scope is 66 BRI's countries (Fig. 4) with a time span of 2008–2019.

4. Results

4.1. Baseline regression results

Fig. 5 shows the Pearson correlation coefficient values for various variables. As we can see, most correlation coefficients are less than 0.5, with only a high correlation between openness and its squared term, indicating that the variables are not highly correlated.

In view of the use of panel data at the national level, this study adopts a two-way fixed effects model as the benchmark model to improve regression accuracy. As shown in Table 4, Model 1–5 show regression results of gradually adding *IS*、*UL*、*RDI*, and *ER*. With an increase in the control variables, the coefficients of *OPE* and OPE^2 are always negative and positive, respectively, and all pass the 1% significance test, indicating that openness and GEE have a nonlinear U-shaped relationship. In other words, it has an inhibitory effect on GEE in the early stages of opening-up to the outside world, whereas openness beyond a certain threshold can promote the growth of GEE. This conclusion is consistent with the above theoretical analysis. However, this is inconsistent with the findings of Song et al. [72], who showed that China's economic openness has a significant inverted U-shaped impact on the development of green economy. This may be because the BRI involves multiple countries, most of which are at different stages of industrialization, and difference measures of openness may lead to very different conclusions.

From the perspective of control variables, the regression coefficients of industrial structure is significantly positive, showing that industrial structure adjustment can improve GEE of the BRI. Only the regression coefficient of urbanization level in Model 5 in Table 4 passed the significance test. As mentioned earlier, there is uncertainty regarding the impact of urbanization on GEE. Therefore, in the process of urbanization, countries along the BRI should focus on quality construction to achieve intensive, green, intelligent, and low-carbon development. The regression coefficient of RDI is significantly negative, which is different from the existing research. One possible reason is that RDI along the BRI is still at a low level, and the transformation rate of scientific and technological achievements is low. In addition, the R&D process is a relative time cycle, and the funds invested in R&D during the current period generate opportunity costs, which reduce investment in other aspects to some extent. From a long-term perspective, RDI will have a positive

Table 3
Descriptive statistics.

Variables	Obs	Mean	Max	Min	St. Dev
GEE	792	0.654	1.387	0.175	0.209
OPE	792	0.094	0.659	0.008	0.081
OPE^2	792	0.015	0.434	0.000	0.042
IS	792	0.906	1.000	0.584	0.083
UL	792	0.587	1.000	0.161	0.207
RDI	792	0.675	4.797	0.048	0.689
ER	792	58.836	88.980	21.570	13.454

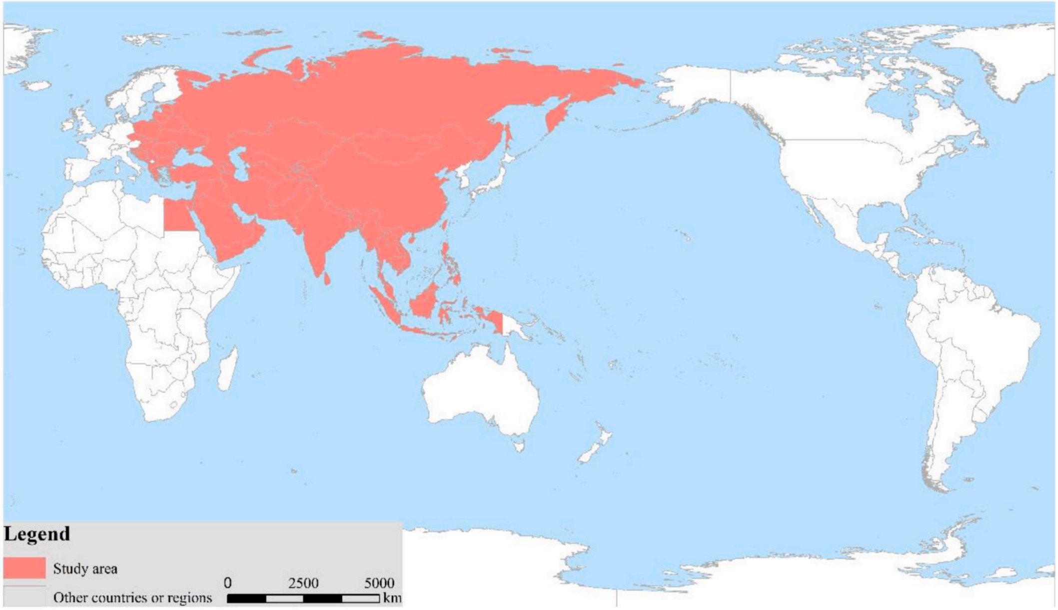

Fig. 4. Location map of the BRI.

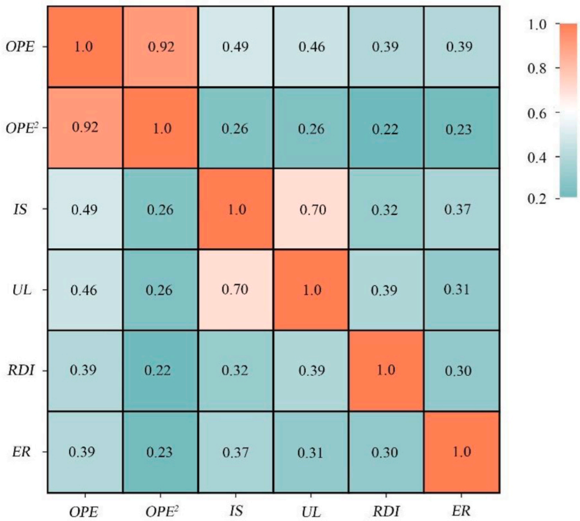

Fig. 5. Pearson's coefficient matrix.

impact on GEE. The regression coefficient of environmental regulation is significantly positive, indicating that environmental regulation plays a positive role in improving GEE of the BRI. Therefore, the government has strengthened the management and control of enterprises through regulatory planning, forcing enterprises to increase their investment in pollution treatment and ecological environment protection. However, enterprises can achieve both economic benefits and environmental protection by developing green technology, further verify the Porter hypothesis.

4.2. Robustness test

Because there may be endogeneity problems between openness and GEE, the latter has a strong path dependence [83]; that is, the current GEE may be affected by the previous GEE. Therefore, this study considers adding the first- and second-order lag terms of GEE and uses differential generalized method of moments (DIFF-GMM) and SYS-GMM for dynamic panel estimation to alleviate the endogeneity problems. Model 1–4 in Table 5 are listed the first-order serial correlation test-AR(1), second-order serial correlation test-AR(2), and the excessive identification test (Hansen). The results show that except for Model 2, the AR(1) values pass the

Table 4
Baseline regression.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
OPE	−1.708***	−1.807***	−1.885***	−1.775***	−1.902***
OPE^2	1.694***	1.816***	1.945***	1.837***	1.907***
IS		0.665***	0.633***	0.575***	0.680***
UL			0.433	0.473	0.686**
RDI				−0.032***	−0.033**
ER					−0.002***
Country-Fe	Yes	Yes	Yes	Yes	Yes
Year-Fe	Yes	Yes	Yes	Yes	Yes
constant	0.810***	0.219	0.005	0.047	−0.305
R^2	0.110	0.128	0.131	0.136	0.150

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

significance test, while the A(2) values do not pass significance test, indicating that there is only first-order sequence correlation without second-order sequence correlation, so the first-order and second-order lag terms of GEE can be used as the instrumental variables. At the same time, the Hansen values do not pass the significance test (except for Model 4), indicating that there are no endogenous problems of the instrumental variables. To sum up, Model 1and Model 3 are reasonable, indicating that GEE has the characteristics of "inertia" and is easily affected by GEE in the early stage. Openness has a significant negative impact on GEE, whereas the squared term of openness has a significant positive impact on GEE, further proving the existence of a U-shaped relationship between the two.

Owing to the possible reverse causal relationship between openness and GEE, this study uses the time to export (ln *Time*) as an instrumental variable to handle possible reverse causal relationships. On the one hand, the longer the time spent on export trade, the higher the transportation cost, which will have a significant impact on a country's trade openness and even the overall level of openness. On the other hand, the export time is largely influenced by a country's natural geographical location. Compared to coastal countries, inland countries do not have a coastline and need to engage in foreign trade by borrowing ports and going out to sea, resulting in longer export times. Therefore, the time to export cannot establish a direct connection with GEE, which is consistent with the hypothesis of correlation and exogeneity. Model 5 and Model 6 in Table 5 report the 2SLS regression results. The estimated coefficient of ln *Time* is significantly negative at the 1% level, indicating that the instrumental variable has a good correlation. In addition, the F-statistic is greater than the critical value of 10, indicating that there is no weak instrumental variable problem. Finally, the estimated coefficients of *OPE* and *OPE*^{2} remain significant, further supporting the findings of this study.

4.3. Spillover analysis

4.3.1. Spatial autocorrelation test

Existing literature has found that GEE in different regions shows significant spatial autocorrelation [84]. Therefore, we first conduct a spatial autocorrelation test on the GEE for subsequent spatial econometric model analysis. In this study, we use Stata.16 software to calculate the Global Moran's I of GEE of countries along the BRI from 2008 to 2019 under the adjacent weight (W_1), inverse distance weight (W_2), cultural distance weight (W_3), and economic distance weight (W_4), and use the p-value to test its significance (Table 6). Except for W_1,Global Moran's I from 2008 to 2019 under other weights is positive, and the p-values all pass the significance test, indicating that the GEE of countries along the BRI does not have a random distribution in space, and countries with high (low) GEE tend to cluster in space with other countries with high (low) GEE. Compared with Global Moran's I of four weights, $W_2 > W_4 > W_3 > W_1$, which indicate that at the transnational level, the simple adjacent weight is likely to reduce the agglomeration characteristics between

Table 5
Robustness tests.

Variables	DIFF-GMM		SYS-GMM		Fe-IV	
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GEE_{t-1}	0.225***	0.143***	0.524***	0.442***		
GEE_{t-2}		0.208***		0.085***		
OPE	−3.185***	−1.776***	−2.202***	−1.314***		−7.392**
OPE^2	6.155***	3.393***	4.059***	2.434***		7.334**
iv					−0.009***	
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Country-Fe	Yes	Yes	Yes	Yes	Yes	Yes
Year-Fe	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	−2.540**	−1.660*	−2.820***	−3.060***		
AR(2)	0.780	−2.680***	0.440	−0.410		
Hansen	54.140	53.390	41.160	41.410*		
F-statistic					19.097	

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

countries, distance, cultural, and economic spatial weights will enhance the agglomeration characteristics. Therefore, in terms of spatial econometric model construction, we mainly pay attention to W_2, W_3, and W_4.

4.3.2. Spatial econometric model test

According to the abovementioned Global Moran's I calculation results, the GEE of countries along the BRI has a positive agglomeration feature in space, showing a local spatial feature of high-high, low-low agglomeration. Considering this spatial interaction, we further use SEM、SLM and SDM to explore the spatial spillover effect of openness on GEE. However, it is necessary to select an appropriate spatial econometric model based on the inspection and judgment rules.

The Wald and LR tests can be used to determine whether SDM can be reduced to SEM and SLM. If the null hypothesis is simultaneously rejected, the SDM is the optimal fitting model. As shown in Table 7, the Wald and LR test results of SEM and SLM pass the significance test at 1% level, regardless of whether the model is constructed by W_2, W_3 or W_4, and reject the null hypothesis, indicating that SDM cannot be reduced to SEM and SLM. Therefore, we choose the SDM of the two-way fixed effect for the spatial regression analysis. In addition, to improve the robustness of our conclusions, we report the results obtained using the SLM model.

4.3.3. Spatial econometric model results

Table 8 presents the estimation results of the spatial effect of openness on GEE under three different spatial weight matrices. The spatial autoregressive coefficient of ρ in Model 3–6 in Table 8 is significantly positive, indicating that GEE has a positive spatial agglomeration effect. In addition, Model 3–6 in Table 8 indicate that openness and its quadratic term both pass the 1% significance test, further supporting the U-shaped impact relationship between openness and GEE of countries along the BRI. In terms of the control variables, although there are certain differences in the size of the influence coefficients under different weights, the influence direction and significance remain consistent. This is only a preliminary judgment on the spatial measurement of GEE. To explain the spatial effect of openness on GEE, we further decompose and analyze the results.

A Partial differential equation is used to decompose the spatial influence [85]. The direct effect is the influence of the explanatory variable on the GEE of the local country, and indirect effect is also called spillover effect, which is the influence of the explanatory variable on the GEE of neighboring countries. Considering that ρ of Model 3–6 in Table 8 has passed the test, a decomposition analysis of direct and indirect effect is conducted based on this, and the results are shown in Table 9. We can see that the direct effects of openness and its quadratic term on GEE pass the 1% significance test, and their spillover effects (except for the indirect effects in SDM-W_4) also pass the significance test. This indicates that openness has a U-shaped influence on the GEE of both the local country and neighboring countries. A possible reason for this is that in the early stages of opening-up, the pollution haven effect may lead to the accumulation of domestic pollution, which will have a negative impact on neighboring countries. As a country's degree of openness increases, it can effectively radiate factors such as technology and talent to neighboring countries, thereby improving production technology, upgrading the industrial structure in neighboring countries, and generating positive spillover effects.

5. Discussion

We find that the relationship between openness and GEE along the BRI is not linear but rather a U-shaped nonlinear effect. Especially after the BRI was proposed in 2013, this relationship has become more significant (Table 10). This result is similar to the conclusions of Talberth and Bohara [47], Christoforidis and Katrakilidis [86], and Saqib et al. [87]. These studies show that openness has a nonlinear impact on the green economy and ecological environment. Christoforidis and Katrakilidis used Central and Eastern European countries as an example to explore the nonlinear impact of FDI on ecological quality [86]. Saqib et al. theoretically summarized that FDI would lead to an environmental Kuznets curve pattern, which may be a development process that developing countries must go through [87]. However, in the early stages, it is necessary to strengthen government regulations and institutional construction [88]. Overall, the open process and the stage of economic growth share characteristics and overlapping consequences,

Table 6
Global Moran's I of GEE along the BRI.

Year	Global Moran's I			
	W_1	W_2	W_3	W_4
2008	0.134**	0.165***	0.149***	0.152**
2009	0.115*	0.186***	0.120**	0.174***
2010	0.148	0.246***	0.134***	0.141***
2011	0.056	0.244***	0.120**	0.079*
2012	0.009	0.258***	0.116**	0.111**
2013	−0.056	0.238**	0.100**	0.127**
2014	−0.046	0.241**	0.114**	0.149**
2015	−0.023	0.247***	0.134***	0.180***
2016	−0.026	0.230***	0.132***	0.152**
2017	−0.013	0.239***	0.135***	0.146**
2018	0.038	0.309***	0.147***	0.162***
2019	0.053	0.300***	0.146***	0.177***

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

Table 7
Identification test of spatial econometric model.

		W_2	W_3	W_4
SLM	Wald_spatial	120.63***	64.39***	53.79***
	LR_spatial	114.66***	62.16***	52.09***
SEM	Wald_spatial	103.98***	58.49***	51.25***
	LR_spatial	106.37***	63.62***	50.56***

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

Table 8
Estimation results using spatial econometric models.

Variables	SDM			SLM		
	W_2	W_3	W_4	W_2	W_3	W_4
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
ρ	0.108	0.005	0.160***	0.461***	0.145**	0.170***
OPE	−2.433***	−1.589***	−2.797***	−2.464***	−2.656***	−2.515***
OPE^2	2.254***	1.702***	2.763***	2.494***	2.540***	2.395***
IS	0.635***	0.739***	0.627***	0.639***	0.573***	0.588***
UL	1.115***	0.711**	0.755**	0.330	0.001	−0.127
RDI	−0.011	−0.033**	−0.023	−0.029**	−0.032**	−0.035**
ER	0.001**	0.002***	0.001***	0.000	0.000	0.000
WOPE	17.976***	2.036	−1.785			
$WOPE^2$	−31.031***	0.512	1.892			
WIS	−3.910***	−1.394**	−2.228***			
WUL	−5.936	−3.849	0.439			
WRDI	−0.099	−0.003***	0.025			
WER	−0.002**	−0.003	−0.002***			
Country-Fe	Yes	Yes	Yes	Yes	Yes	Yes
Year-Fe	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.237	0.166	0.151	0.083	0.093	0.090

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

Table 9
Direct and indirect effects of openness on GEE.

Variables	SDM-W_4		SLM-W_2		SLM-W_3		SLM-W_4	
	Direct effect	Indirect effect	Direct effect	Indirect effect	Direct effect	Indirect effect	Direct effect	Indirect effect
OPE	−2.852***	−2.531*	−2.482***	−2.166**	−2.649***	−0.451*	−2.515***	−0.501**
OPE^2	2.810***	2.586	2.504***	2.197**	2.524***	0.432*	2.384***	0.476**
IS	0.574***	−2.426***	0.666***	0.596**	0.592***	0.104	0.610***	0.125*
UL	0.763***	0.632	0.324	0.308	−0.011	0.003	−0.140	−0.029
RDI	−0.022	0.023	−0.029**	−0.025	−0.032**	−0.005	−0.035**	−0.007
ER	0.001***	−0.002***	0.001	0.000	0.000	0.000	0.000	0.000

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

Table 10
Heterogeneity tests.

Variables	Model 1	Model 2
	2008–2012	2014–2019
OPE	−2.106	−1.358**
OPE^2	3.564*	1.409**
Control Variables	Yes	Yes
Country-Fe	Yes	Yes
Year-Fe	Yes	Yes
constant	−0.358	1.349***
R^2	0.078	0.215

Note: *, ** and *** indicate that statistics are significant at the 10%, 5% and 1% level of significance, respectively.

and in the early phases of both, greater focus is placed on scale expansion, which has a considerable detrimental influence on the ecological environment. As national power accumulates to some level and the demonstration, competitiveness, and correlation impacts of companies are fully expressed, the move from quantity to quality alleviates the conflict between people and the environment.

We also find that openness has a significant U-shaped spillover effect on the GEE of neighboring countries. This result deepens the research perspectives and conclusions of Jiang et al. [89] and Cao et al. [90]. Jiang et al. explored the spillover effect of FDI on air pollution in China from a spatial perspective and found that the negative spillover effect was significant [89]. Cao et al. focused on the spillover effect of financial development on green growth and found a significant positive spillover effect [90]. These studies only analyze the linear spillover effect of a single open factor and lack nonlinear exploration. In addition, the establishment of spatial weights has a significant impact on the accuracy of the spatial spillover effects. At the domestic level, it seems that the adjacency weight between cities is more precise, whereas at the international level, the weight setting between countries becomes more complex. Breaking the dark box of weights and establishing the corresponding weights at different spatial levels is very important.

6. Conclusions and policy implications

6.1. Conclusions

Green is the distinctive background of high-quality joint construction of the BRI, and expanding opening-up plays a key role in promoting the sustainable economic development of countries along the BRI. Using the sample data of 66 countries along the BRI from 2008 to 2019, this paper measures openness and GEE, and further uses the two-way fixed effect model, GMM, SDM, and SLM to empirically test the impact of openness on GEE and its spillover effect. The findings are as follows:

First, the openness level along the BRI is generally on the rise, but the relative differences between countries tend to expand. Meanwhile, the overall GEE along the BRI shows a downward trend, and the relative differences between countries tend to narrow.

Second, the expansion of opening-up has a U-shaped impact on GEE of countries along the BRI, and this conclusion is very robust after adding control variables and adopting the GMM model and instrumental variable methods. In addition, the GMM model also indicates that there is a cumulative effect of the GMM itself, which is affected by the early GMM.

Third, the GEE of BRI countries has a positive global spatial autocorrelation, and different spatial weights have certain differences. Based on this, this study uses a spatial econometric model to analyze the spatial spillover effect of openness, indicating that openness not only affects the GEE of the local country but also has a spillover effect on neighboring countries.

6.2. Policy implications

Based on the above research conclusions, and in combination with the green development requirements of the BRI in the new era, this study puts forward the following policy implications.

First, it is necessary to strengthen political communication and remove border barriers in BRI countries. The BRI has been widely concerned by the international community as an inclusive, open, and shared international cooperation platform since it was proposed in 2013. As the initiator of the BRI, China has been committed to promoting sustainable economic development along the BRI. However, some countries and scholars have questioned and criticized the BRI, asserting that it is a "Chinese version of the Marshall Plan", "Chinese style neo colonialism", "China's debt trap", and so on. Therefore, BRI countries should strengthen mutual political trust and break down political barriers to promote the free diffusion of open factors, such as trade, investment, and finance, to form a spillover diffusion effect, which is the prerequisite for the long-term development of the BRI.

Second, owing to the U-shaped impact of openness and GEE, all BRI countries need to strengthen their control of open factors, taking into account both quantity and quality. On the one hand, especially in developing countries along the route, it is necessary to continuously improve the business environment, promote trade liberalization, encourage enterprise to "go global" and "bring in", and promote rapid economic growth. On the other hand, countries must strengthen their institutional management in terms of government effectiveness, regulatory quality, rule of law, and corruption control; formulate strict foreign investment access policies; select some advanced technologies and enterprises with rich management experience to enter the domestic market; and promote domestic scientific and technological progress and innovation.

Third, all BRI countries must actively adjust and optimize their industrial structure, promoting the deep integration of traditional advantageous industries with emerging green industries, advanced manufacturing industries, and modern service industries. In addition, all BRI countries should formulate urbanization development strategies according to their own resource endowment advantages and environmental carrying capacity to achieve continuous improvement of the degree of population agglomeration, human capital accumulation, and technological level.

6.3. Limitations and future research directions

First, openness is a very complex system, and we integrate only six aspects. In terms of the indicator system construction, this still needs to be improved. Second, we do not conduct a detailed analysis of the sub-dimensions of openness. Each dimension of openness often has different attribute characteristics, and the green development effects generated by each dimension may have significant differences. Third, this study focuses more on exploring the impact of openness on GEE, but lacks a complex mechanism path test between the two. Future research could explore various transmission pathways in depth within a theoretical framework using methods such as the mediating effect model and constructing interaction terms. Fourth, this study only analyzes the comprehensive efficiency of

GEE. GEE can also be divided into pure technical efficiency and scale efficiency, and the relationship between the two can be studied in more detail. Fifth, there is still room for improvement in the selection of the control variables, such as incorporating some institutional and political variables.

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Data availability statement

Data used in this paper are available from the correspondence author on reasonable request.

CRediT authorship contribution statement

Wei Ma: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Na Bo:** Supervision, Software, Investigation. **Xinmin Wang:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table. A
List of 66 countries along the BRI.

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

Table. B
Openness of countries along the BRI from 2008 to 2019.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Afghanistan	0.008	0.009	0.009	0.012	0.012	0.012	0.011	0.012	0.012	0.013	0.016	0.015
Albania	0.076	0.087	0.092	0.096	0.092	0.096	0.099	0.097	0.099	0.102	0.102	0.106
Armenia	0.070	0.080	0.091	0.096	0.099	0.101	0.104	0.107	0.105	0.107	0.110	0.112
Azerbaijan	0.051	0.048	0.055	0.062	0.068	0.071	0.071	0.081	0.095	0.096	0.091	0.087
Bahrain	0.151	0.148	0.144	0.143	0.141	0.144	0.143	0.183	0.160	0.156	0.150	0.154
Bangladesh	0.015	0.014	0.016	0.017	0.017	0.019	0.019	0.018	0.019	0.020	0.021	0.021
Belarus	0.052	0.054	0.055	0.064	0.066	0.062	0.056	0.059	0.070	0.072	0.074	0.074
Bhutan	0.041	0.036	0.040	0.043	0.045	0.050	0.046	0.049	0.050	0.050	0.052	0.053
Bosnia and Herzegovina	0.074	0.066	0.068	0.069	0.060	0.059	0.056	0.059	0.059	0.065	0.067	0.066
Brunei Darussalam	0.084	0.084	0.082	0.081	0.089	0.091	0.110	0.106	0.117	0.119	0.130	0.142
Bulgaria	0.109	0.106	0.103	0.104	0.108	0.112	0.110	0.109	0.110	0.116	0.109	0.109
Cambodia	0.064	0.065	0.070	0.081	0.088	0.086	0.089	0.104	0.104	0.105	0.109	0.111
China	0.047	0.049	0.055	0.062	0.069	0.078	0.086	0.094	0.105	0.108	0.118	0.115
Croatia	0.113	0.116	0.115	0.122	0.124	0.125	0.124	0.125	0.127	0.133	0.135	0.140
Cyprus	0.303	0.381	0.395	0.390	0.470	0.522	0.548	0.636	0.628	0.659	0.608	0.614
Czech	0.135	0.136	0.147	0.151	0.157	0.159	0.166	0.172	0.171	0.176	0.170	0.165
Egypt	0.066	0.061	0.060	0.056	0.046	0.033	0.034	0.033	0.034	0.051	0.054	0.055
Estonia	0.141	0.142	0.154	0.157	0.162	0.164	0.170	0.167	0.165	0.166	0.162	0.159
Georgia	0.065	0.066	0.058	0.062	0.085	0.095	0.096	0.104	0.112	0.117	0.122	0.127
Greece	0.115	0.119	0.118	0.122	0.127	0.130	0.129	0.122	0.122	0.123	0.125	0.136
Hungary	0.135	0.137	0.137	0.140	0.146	0.144	0.144	0.143	0.145	0.144	0.140	0.140

(continued on next page)

Table. B (*continued*)

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
India	0.022	0.021	0.023	0.025	0.026	0.026	0.027	0.026	0.026	0.027	0.029	0.031
Indonesia	0.043	0.041	0.042	0.034	0.035	0.036	0.037	0.039	0.040	0.044	0.047	0.050
Iraq	0.025	0.027	0.027	0.027	0.028	0.031	0.033	0.041	0.044	0.046	0.049	0.059
Iran	0.055	0.053	0.056	0.059	0.052	0.058	0.065	0.069	0.074	0.071	0.076	0.077
Israel	0.203	0.192	0.193	0.189	0.190	0.181	0.184	0.189	0.184	0.185	0.187	0.188
Jordan	0.111	0.104	0.110	0.105	0.105	0.103	0.103	0.101	0.100	0.103	0.106	0.110
Kazakhstan	0.042	0.044	0.047	0.052	0.057	0.057	0.058	0.058	0.065	0.062	0.062	0.063
Kyrgyzstan	0.089	0.077	0.077	0.080	0.071	0.067	0.068	0.070	0.082	0.073	0.073	0.077
Kuwait	0.080	0.087	0.090	0.090	0.090	0.094	0.097	0.110	0.111	0.112	0.111	0.115
Lao PDR	0.025	0.028	0.035	0.035	0.042	0.046	0.049	0.049	0.047	0.047	0.049	0.051
Latvia	0.097	0.103	0.109	0.120	0.121	0.126	0.120	0.130	0.128	0.135	0.133	0.130
Lebanon	0.123	0.119	0.121	0.116	0.115	0.115	0.117	0.107	0.107	0.110	0.115	0.121
Lithuania	0.117	0.112	0.115	0.117	0.117	0.117	0.119	0.122	0.123	0.130	0.130	0.132
North Macedonia	0.064	0.062	0.064	0.070	0.072	0.073	0.075	0.077	0.076	0.079	0.082	0.084
Malaysia	0.112	0.109	0.106	0.110	0.114	0.114	0.125	0.127	0.128	0.132	0.132	0.134
Maldivas	0.148	0.133	0.140	0.146	0.145	0.150	0.153	0.143	0.140	0.131	0.131	0.138
Moldova	0.060	0.055	0.051	0.053	0.056	0.059	0.061	0.063	0.064	0.063	0.062	0.062
Mongolia	0.079	0.081	0.080	0.083	0.084	0.086	0.087	0.085	0.088	0.096	0.104	0.110
Montenegro	0.090	0.091	0.094	0.097	0.104	0.108	0.106	0.113	0.113	0.117	0.112	0.112
Myanmar	0.011	0.009	0.009	0.009	0.009	0.011	0.016	0.019	0.022	0.025	0.027	0.031
Nepal	0.025	0.027	0.027	0.027	0.028	0.031	0.033	0.041	0.044	0.046	0.049	0.059
Oman	0.077	0.082	0.081	0.086	0.088	0.092	0.091	0.093	0.095	0.097	0.099	0.102
Pakistan	0.020	0.017	0.019	0.019	0.018	0.018	0.019	0.019	0.020	0.020	0.021	0.022
Palestine	0.036	0.037	0.039	0.041	0.040	0.039	0.038	0.039	0.037	0.041	0.043	0.045
Philippines	0.040	0.039	0.036	0.036	0.037	0.039	0.052	0.053	0.053	0.056	0.058	0.058
Poland	0.083	0.085	0.089	0.091	0.097	0.100	0.102	0.113	0.117	0.118	0.119	0.120
Qatar	0.093	0.097	0.102	0.102	0.109	0.117	0.128	0.132	0.139	0.139	0.139	0.144
Romania	0.078	0.084	0.091	0.092	0.093	0.093	0.094	0.096	0.097	0.102	0.103	0.102
Russian	0.068	0.077	0.082	0.082	0.088	0.092	0.093	0.100	0.100	0.098	0.101	0.101
Saudi Arabia	0.070	0.076	0.076	0.076	0.077	0.081	0.084	0.087	0.088	0.092	0.092	0.093
Serbia	0.092	0.094	0.099	0.103	0.113	0.112	0.114	0.117	0.119	0.122	0.121	0.121
Singapore	0.419	0.398	0.417	0.407	0.413	0.415	0.426	0.428	0.431	0.444	0.446	0.475
Slovakia	0.108	0.109	0.116	0.120	0.125	0.129	0.132	0.132	0.138	0.144	0.140	0.135
Slovenia	0.159	0.163	0.167	0.176	0.174	0.176	0.176	0.179	0.176	0.181	0.178	0.174
Sri Lanka	0.037	0.035	0.034	0.035	0.037	0.030	0.031	0.033	0.036	0.038	0.041	0.041
Syria	0.011	0.012	0.014	0.023	0.021	0.024	0.025	0.026	0.028	0.027	0.027	0.026
Tajikistan	0.036	0.037	0.039	0.041	0.040	0.039	0.038	0.039	0.037	0.041	0.043	0.045
Thailand	0.068	0.057	0.057	0.063	0.068	0.069	0.072	0.075	0.080	0.084	0.086	0.096
Turkey	0.054	0.058	0.059	0.060	0.062	0.063	0.066	0.067	0.068	0.072	0.066	0.068
Turkmenistan	0.028	0.024	0.027	0.032	0.034	0.032	0.032	0.032	0.031	0.032	0.032	0.032
Ukraine	0.051	0.050	0.053	0.054	0.056	0.057	0.061	0.070	0.071	0.072	0.070	0.069
United Arab Emirates	0.106	0.109	0.109	0.112	0.118	0.122	0.121	0.133	0.136	0.137	0.141	0.145
Uzbekistan	0.026	0.026	0.019	0.020	0.020	0.022	0.024	0.025	0.026	0.033	0.048	0.053
Vietnam	0.059	0.056	0.063	0.067	0.068	0.070	0.073	0.077	0.081	0.086	0.092	0.095
Yemen	0.053	0.055	0.054	0.055	0.054	0.053	0.052	0.045	0.047	0.048	0.051	0.052

Table. C
GEE of countries along the BRI from 2008 to 2019.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Afghanistan	0.813	0.704	0.655	0.547	0.649	0.690	0.722	0.723	0.772	0.744	0.660	0.647
Albania	0.788	0.791	0.744	0.713	0.733	0.701	0.660	0.781	0.724	0.660	0.709	0.727
Armenia	0.668	0.690	0.666	0.648	0.673	0.638	0.627	0.646	0.640	0.640	0.647	0.683
Azerbaijan	0.641	0.696	0.671	1.129	1.096	1.065	1.022	0.754	0.728	0.712	0.707	0.701
Bahrain	0.589	0.604	0.561	0.535	0.555	0.547	0.548	0.549	0.531	0.519	0.509	0.498
Bangladesh	0.720	0.703	0.681	0.703	0.681	0.668	0.661	0.651	0.634	0.628	0.634	0.616
Belarus	0.375	0.391	0.382	0.547	0.548	0.518	0.507	0.497	0.479	0.478	0.482	0.481
Bhutan	0.865	0.915	0.823	0.477	0.582	0.581	0.552	0.607	0.454	0.438	0.428	0.352
Bosnia and Herzegovina	0.499	0.445	0.410	0.616	0.617	0.602	0.597	0.604	0.591	0.587	0.588	0.580
Brunei Darussalam	0.770	0.872	0.763	0.704	0.727	0.741	0.702	0.731	0.668	0.645	0.631	0.637
Bulgaria	0.471	0.489	0.456	0.601	0.612	0.594	0.577	0.580	0.586	0.581	0.592	0.600
Cambodia	0.825	0.750	0.704	0.755	0.732	0.725	0.672	0.615	0.546	0.522	0.523	0.510
China	0.379	0.392	0.376	0.578	0.579	0.559	0.548	0.548	0.542	0.534	0.530	0.526
Croatia	0.872	0.865	0.817	0.865	0.902	0.850	0.836	0.858	0.831	0.806	0.834	0.846
Cyprus	0.920	0.915	0.891	0.940	0.982	0.918	0.857	0.878	0.852	0.843	0.868	0.880
Czech	0.724	0.710	0.704	0.694	0.716	0.675	0.671	0.697	0.682	0.681	0.690	0.706
Egypt	0.463	0.463	0.439	0.632	0.642	0.622	0.612	0.623	0.618	0.613	0.626	0.631
Estonia	0.618	0.583	0.553	0.565	0.590	0.555	0.559	0.582	0.566	0.564	0.577	0.637
Georgia	0.700	0.616	0.599	0.547	0.550	0.555	0.531	0.524	0.477	0.471	0.489	0.493

(continued on next page)

Table. C (*continued*)

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Greece	0.959	0.935	0.926	0.883	0.890	0.844	0.835	0.858	0.850	0.814	0.826	0.856
Hungary	0.816	0.823	0.773	0.815	0.852	0.838	0.828	0.828	0.794	0.762	0.784	0.805
India	0.463	0.459	0.453	0.467	0.466	0.446	0.441	0.451	0.452	0.452	0.451	0.450
Indonesia	0.672	0.661	0.622	0.620	0.619	0.601	0.623	0.633	0.632	0.629	0.612	0.604
Iraq	0.605	0.580	0.551	0.719	0.738	0.711	0.681	0.673	0.684	0.660	0.651	0.651
Iran	0.464	0.453	0.458	0.456	0.428	0.407	0.406	0.403	0.433	0.432	0.413	0.389
Israel	1.087	1.117	1.110	1.247	1.249	1.275	1.287	1.285	1.282	1.272	1.260	1.252
Jordan	0.542	0.537	0.514	0.585	0.577	0.548	0.528	0.527	0.519	0.501	0.497	0.490
Kazakhstan	0.450	0.465	0.453	0.618	0.630	0.626	0.621	0.620	0.614	0.614	0.618	0.625
Kyrgyzstan	0.286	0.316	0.306	0.442	0.424	0.435	0.428	0.430	0.429	0.429	0.418	0.420
Kuwait	1.096	1.040	0.756	0.749	0.755	0.751	0.740	0.713	0.684	0.656	0.650	0.642
Lao PDR	0.801	0.716	0.691	0.630	0.650	0.613	0.613	0.443	0.406	0.391	0.387	0.367
Latvia	0.974	0.937	0.796	0.874	0.917	0.912	0.910	0.937	0.902	0.881	0.871	0.889
Lebanon	0.718	0.665	0.682	0.704	0.682	0.636	0.600	0.577	0.558	0.531	0.536	0.507
Lithuania	0.870	0.858	0.788	0.836	0.862	0.855	0.851	0.864	0.842	0.823	0.830	0.843
North Macedonia	0.501	0.499	0.476	0.494	0.514	0.499	0.512	0.531	0.520	0.519	0.529	0.512
Malaysia	0.529	0.517	0.513	0.564	0.584	0.544	0.541	0.556	0.543	0.543	0.540	0.542
Maldivas	0.902	0.835	0.798	0.831	0.789	0.779	0.704	0.740	0.697	0.688	0.654	0.656
Moldova	0.514	0.530	0.495	0.520	0.518	0.525	0.538	0.557	0.512	0.497	0.503	0.527
Mongolia	0.292	0.277	0.284	0.349	0.354	0.361	0.380	0.394	0.392	0.392	0.396	0.390
Montenegro	0.621	0.775	0.579	0.655	0.678	0.646	0.631	0.629	0.644	0.623	0.601	0.587
Myanmar	1.069	1.087	0.954	0.959	1.053	1.021	0.947	0.855	0.779	0.767	0.684	0.668
Nepal	1.009	0.908	0.857	0.850	0.814	0.769	0.737	0.813	0.637	0.603	0.578	0.609
Oman	0.673	0.683	0.636	0.595	0.602	0.570	0.548	0.548	0.542	0.513	0.508	0.492
Pakistan	0.458	0.465	0.441	0.600	0.620	0.606	0.603	0.608	0.594	0.589	0.595	0.593
Palestine	1.031	1.059	1.052	1.031	1.069	1.013	0.958	0.952	0.887	0.869	0.921	0.925
Philippines	0.789	0.801	0.777	0.814	0.803	0.772	0.753	0.748	0.722	0.697	0.700	0.709
Poland	0.631	0.649	0.626	0.734	0.746	0.713	0.710	0.719	0.710	0.706	0.716	0.730
Qatar	0.950	1.041	1.066	1.062	1.038	1.018	1.011	1.010	0.730	0.705	0.712	0.696
Romania	0.681	0.727	0.673	0.689	0.722	0.720	0.703	0.723	0.724	0.715	0.724	0.757
Russian	0.482	0.458	0.461	0.473	0.492	0.477	0.469	0.466	0.460	0.459	0.465	0.470
Saudi Arabia	0.705	0.709	0.650	0.628	0.637	0.632	0.619	0.619	0.595	0.578	0.577	0.564
Serbia	0.410	0.409	0.404	0.419	0.440	0.420	0.421	0.417	0.420	0.421	0.434	0.436
Singapore	1.063	1.004	1.101	1.387	1.234	1.107	1.093	1.088	1.239	1.240	1.175	1.183
Slovakia	0.775	0.778	0.762	0.782	0.835	0.773	0.780	0.803	0.772	0.740	0.753	0.792
Slovenia	0.903	0.909	0.863	0.867	0.897	0.845	0.871	0.896	0.844	0.831	0.850	0.880
Sri Lanka	1.057	1.037	1.018	1.040	1.074	1.047	0.958	0.939	0.876	0.864	0.896	0.873
Syria	1.370	1.329	1.354	0.625	0.487	0.276	0.287	0.229	0.175	0.213	0.260	0.269
Tajikistan	0.588	0.657	0.637	0.496	0.573	0.638	0.482	0.483	0.383	0.341	0.327	0.354
Thailand	0.546	0.518	0.494	0.519	0.534	0.476	0.460	0.475	0.463	0.457	0.475	0.485
Turkey	0.833	0.800	0.784	0.832	0.850	0.821	0.793	0.801	0.771	0.761	0.771	0.782
Turkmenistan	0.318	0.335	0.332	0.381	0.392	0.386	0.385	0.391	0.395	0.398	0.403	0.407
Ukraine	0.240	0.231	0.214	0.222	0.235	0.207	0.207	0.221	0.211	0.230	0.223	0.241
United Arab Emirates	0.798	0.765	0.702	0.664	0.685	0.678	0.685	0.696	0.668	0.684	0.705	0.704
Uzbekistan	0.255	0.276	0.257	0.446	0.460	0.450	0.444	0.446	0.437	0.423	0.407	0.388
Vietnam	0.436	0.440	0.398	0.528	0.541	0.519	0.504	0.501	0.496	0.491	0.485	0.475
Yemen	0.526	0.493	0.517	0.530	0.576	0.444	0.445	0.563	0.594	0.592	0.603	0.542

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