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From the coast to the interior: global economic evolution patterns and mechanisms

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It is well established that nighttime light brightness value, which is measured from satellites, correlates with economic prosperity across the globe. Researchers have diverged over whether economic factors cluster in coastal areas or move to interior areas. By using nighttime light data and applying the random forest algorithm to measure the proportion of global "near regions" GDP, it was seen that global GDP decreased from 67.25% in 2000 to 63.02% in 2018. This research reveals that under the continuous promotion of economic globalization, there is still a spatial imbalance of economic development between global "near regions" and "far regions"; however, economic factors are gradually shifting to interior areas and forming a "coastal remoteness" evolution pattern. Within the intercontinental range, there are obvious differences in the evolution patterns and spatial structure of economic development between the sub-regions. The reduction of overseas transportation costs and diseconomies of scale are the primary reasons for the evolution of "coastal remoteness" in global economic development. Our findings can facilitate future policymaking and the management of global coastal and interior areas, as well as establish new horizons for relevant research topics within the context of land and marine-coordinated development.

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Introduction

Globally, coastal areas are growth poles with the densest population and most concentrated economic factors (Shi and Singh, 2003, Barbier et al., 2008, Emerton, 2006, Pak and Majd, 2011, Nat Commun, 2020, Tobey et al., 2010, Eurostat, 2015, Anna et al., 2021, Cetin et al., 2008). Twelve of the world's fifteen megacities are located along coastal areas (Visbeck, 2018). The distribution of global economic output shows that economic activities are primarily concentrated along coastal areas and navigable waterways (Sachs et al., 2001). Coastal areas thus form a popular research field that is drawing the attention of several scholars (Jouffray et al., 2020). As such areas are engines for rapid economic development (Ward et al., 2020, Halpern et al., 2008), the International Geosphere-Biosphere Program (IGBP) (Pernetta and Milliman, 1995), International Human Dimensions Programme on Global Environmental Change (IHDP) (IHDP, 2007), International Plan for Land-Sea Interaction (LOICZ) (Pernetta, 1994), and International Plan for Future Earth Coast (FEC) (FEC n.d.) focus on coastal areas and discuss their interactions with human development and sustainable development. These entities research topics such as dynamic coastal areas, human development, the sustainable development paths of global coastal areas, the influence of human activities on basin-coastal area interactions, and the sustainability of coastal area systems by regulating land–marine interactions.

The Wealth of Nations by Adam Smith, published in 1776, noted that coastal areas are convenient for maritime trade and have larger markets than interior areas. Since the early 21st century, economic globalization has continued apace, with global import and export trade volume reaching USD 39.30 trillion in 2018 (45.52% of the global gross domestic product [GDP]), from USD 13.11 trillion in 2000 (39.95% of the global GDP) (UNCTAD Stat n.d.), which indicates that coastal areas remain preferential for economic development. While several researchers believe that economic factors will continue to cluster in coastal areas (Adger et al., 2005), some posit a shift in capital or industry from coastal areas to interior areas (Yimin and Haochun, 2018, Kotkin, 2006, Wang et al., 2020, Irizuki et al., 2018). Questions regarding the movement and evolution patterns of economic factors between coastal and interior areas have not been conclusively answered. Considering this, within the current context, the question persists of whether economic factors will continue to cluster in coastal areas or move to interior areas. The future of global economic development planning and policy direction formulation depends on this inquiry. To address the questions asked above, we decide to review and evaluate the literature on three aspects: the range definition of the coastal area, agglomeration of economic and social elements in the coastal areas, and application of nighttime light data in the economic estimation (see the literature review in the Supplemental Information for details).

The interactive relationship between global land and marine economic factors and the method to accurately measure their economic growth and pattern evolutions have stimulated research in inter-disciplinary fields such as regional economics, management, and economic geography (Zhang and Zhu, 1997). Therefore, it is particularly important to measure the economic development levels of coastal and interior areas. In addition, the United Nations Millennium Development Goals Report 2015 emphasizes the need to strengthen the statistics of uncounted data and the application of geospatial data (UN, 2015). However, the economic aggregate data within 100 km of global coastal areas is not accurately obtained and counted, which results in a data gap in the planning and development of global coastal and interior areas. However, nighttime light data as geospatial data is widely recognized as a well solution to this problem owing to its unique properties.

As such, the following questions are presented: How much GDP can be enclosed by land within 100 km of an ice-free coast or sea-navigable river? What spatial characteristics of economic activities will economic globalization cause in these regions? Will GDP continue to gather in coastal areas, spread to interior areas, or both, and can spatial agglomeration and diffusion coexist? What is its inherent mechanism? These new economic geography inquiries require a thorough theoretical analysis. Therefore, from the perspective of a coastal social and economic factor evaluation, combined with the mainstream standard definitions of a coastal area, our research relies on Hirschman's regional uneven growth theory (Hirschman AO, 1958), based on the global scale, aims to more accurately measure the degree of concentration of economic factors in the areas within 100 km of an ice-free coast or sea-navigable river, identify its spatial-temporal evolution pattern, and reveal its inherent formation mechanisms by using modern techniques like multi-source nighttime light data and random forest algorithms. Furthermore, we explain the evolution of this spatial-temporal evolution pattern from the perspectives of marine transportation advantages and industrialization development stages. This research is relevant for the following reasons: on the one hand, it fills the gap in GDP statistical data of land within and beyond 100 km of an ice-free coast or sea-navigable river. On the other hand, it will help enrich the research system of sustainable development and provide a valuable practical reference for future global coastal and interior areas management.

Methods

In national economic accounting, the direct indicator of total production is the GDP, which is the total value added of each production department (or industry) and the results of the activities within them. To clarify the evolution of global economic factors moving between coastal and interior areas, this research undertook the following steps as its methodology: First, the correlation between nighttime light data and GDP is tested to determine how nighttime light data can accurately characterize economic conditions. Second, a random forest algorithm is used to estimate the global economic aggregate of 100 km of coastal areas. Finally, to determine the spatial evolution patterns of global and intercontinental economic factors according to regional economic proportions, we analyze which regional economic proportion reflects each regional economic aggregate against the total aggregate. This will compare the changes in regional economic proportions over time and then reflect the direction and degree of economic movement.

$$e_i = \frac{E_i}{\Sigma E_i} \times 100\% \quad (1)$$

In Eq. (1), e_i is the regional economic proportion of the economy; E_i is the economic aggregate of some regions; $\sum E_i$ is the economic aggregate of all regions.

Correlation test between nighttime light data and GDP. Currently, GDP is a comprehensive and quantitative measure of a country's economic activity. Several studies have found that the nighttime light data have a strong correlation with GDP, which can effectively characterize the economic scale of each economy, as shown in Supplementary Table S1. Before using nighttime light data to estimate the GDP of land within 100 km of an ice-free coast or sea-navigable river, clarifying the correlation between nighttime light data and GDP is necessary. Using SPSS 19, a Spearman correlation test was performed on the nighttime light data and GDP (constant 2010 US dollars) of countries with clear administrative divisions in global coastal areas (excluding those

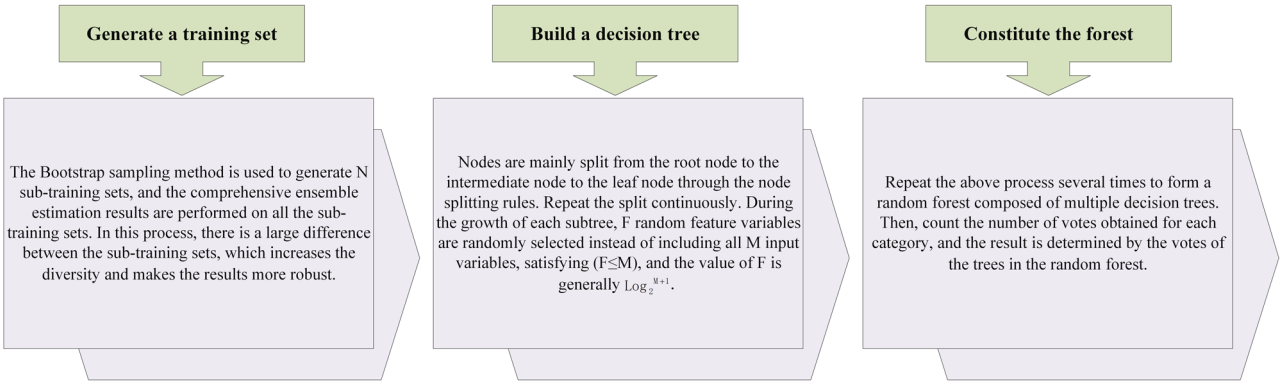

Fig. 1 Flow chart of the random forest algorithm.

without clear statistical data or small island countries); before the Spearman correlation test, the normal distribution test was conducted on the nighttime light data of the global coastal countries and their GDP. Because the sample size N was 2840, which is greater than 2000, the W test was selected, and the sig. value was 0.000 < 0.005. Therefore, as the two variables belonged to a non-normal distribution, the Spearman correlation test was used (see Supplementary Table S2), with a coefficient of 0.921 and a sig. value of 0.000 < 0.005, which is significantly correlated at the level of 0.01, indicating that the nighttime light data has a strong correlation with regional GDP. Therefore, nighttime light data can effectively estimate the level of socio-economic development in a region.

Random forest algorithm. Random forest algorithm is one of the most popular research fields, which is an ensemble learning algorithm based on Breiman's decision tree proposed in 2001 (Stephan et al., 2015, Biau and Scornet, 2016). It can effectively handle big data scenarios without reducing the dimensionality of the data samples. This method is robust to missing and unbalanced data and has high prediction accuracy. However, since the global "near regions" are the regional cut of the global coastal area economies. And there are differences in economic development among global coastal area economies. Thus, we use random forest algorithms to form a unique mathematical model for each economy in global coastal areas according to its annual GDP value and nighttime light data. And then based on this mathematical model and combined with nighttime light data in the global "near regions," the GDP of each region in the global "near regions" is estimated.

First, the Bootstrap sampling method is used to extract multiple samples from the original samples, of which two-thirds are used as training samples and one-third as OOB (Out-of-Bag) verification samples; in this research, the samples are nighttime light data and GDP statistics of countries with clear administrative divisions in global coastal areas. Subsequently, decision trees are modeled following each Bootstrap sample, and following this, these decision trees are integrated, and the result is obtained through voting scores (Ziegler and Konig, 2014, Dou et al., 2019). The algorithm flow is shown in Fig. 1.

In the actual process, we used the random forest code provided in SK-Learn (scikit-learn) in Python to determine the model parameters of the random forest algorithm. In the bagging integration, a plurality of weak estimators (nonlinear algorithms) is established in parallel, and then the results of the plurality of weak estimators are synthesized for the output. Bootstrapping extracts n training samples from the original sample set by way of put-back sampling, performs k rounds of extraction in total to obtain k mutually independent training sets, and trains each training set to obtain k models. For the classification problem, the k models obtained in the previous step are subjected to a voting scheme to obtain classification results. For regression problems, the mean of the above models as a result (all models are of equal importance) is calculated. Moreover, using the spatial method to divide the research area into spaces is necessary. Grid size depends on the scale of the research area and the accuracy requirements of the research problem. It can be determined by comparing the grid accuracy of various scales. Each grid has a dependent variable value (0–63) and a set of explanatory variable values. If the study area is divided into F grids, it will represent F (explanatory variable-dependent variable) samples.

Results

The past 20 years have seen the peak of the expansion of globalization. It is common belief that economic factors will further converge on coastal areas globally. However, based on nighttime light data and the random forest algorithm, we re-estimate the long-term economic aggregate of the global "near regions" and "far regions" and find that the actual results may differ from what we expected.

Economic estimations and characteristics of the evolution patterns of global "near regions" and "far regions". It is estimated that the GDP of global "near regions" increased from USD 33,124.2 billion in 2000 to USD 51,523.6 billion in 2018, while that of "far regions" increased from USD 16,134.8 billion in 2000 to USD 30,238 billion in 2018 (Fig. 2). However, the proportion of GDP in "near regions" (accounting for 18.43% of the world's landmass) decreased from 67.25% in 2000 to 63.02% in 2018, while that of "far regions" (accounting for 81.57% of the world's landmass) increased from 32.75% in 2000 to 36.98% in 2018 (Figs. 3, 4, and Table 1). Moreover, the GDP density (defined as GDP per sq km) is a useful measure for reflecting the spatial imbalance. During the study period, the difference in GDP density between the global "near regions" and "far regions" reflected a downward trend, from 9.3 times to 7.7 times (Fig. 3).

In the past 20 years, global economic development has generally constituted a "coastal remoteness" spatial evolution pattern. This reflects that the economic factors have not always been concentrated near the sea in the stage of high economic development but instead have shown a tendency to gradually diffuse to the "far region." From the perspective of economic proportion, the global economy is primarily concentrated in the "near regions," which form an obvious core-periphery structure with the "far regions." There is a spatial imbalance in economic development, and the phenomenon of polarization is obvious. While the "near regions" continue to generate most of the world's economic output, there is a trend towards a shift in economic factors to the "far regions," leading to a gradual

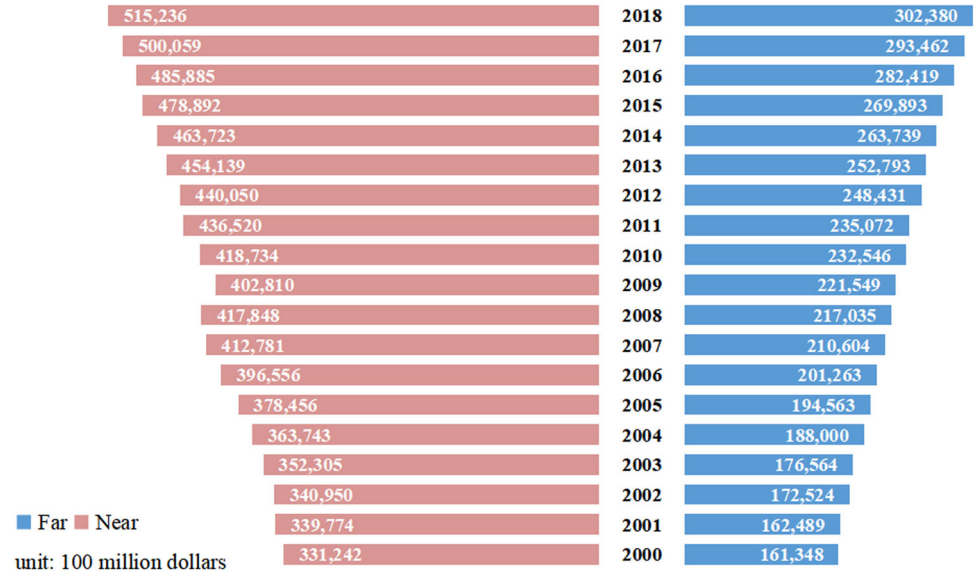

Fig. 2 GDP by global "near regions" and "far regions".

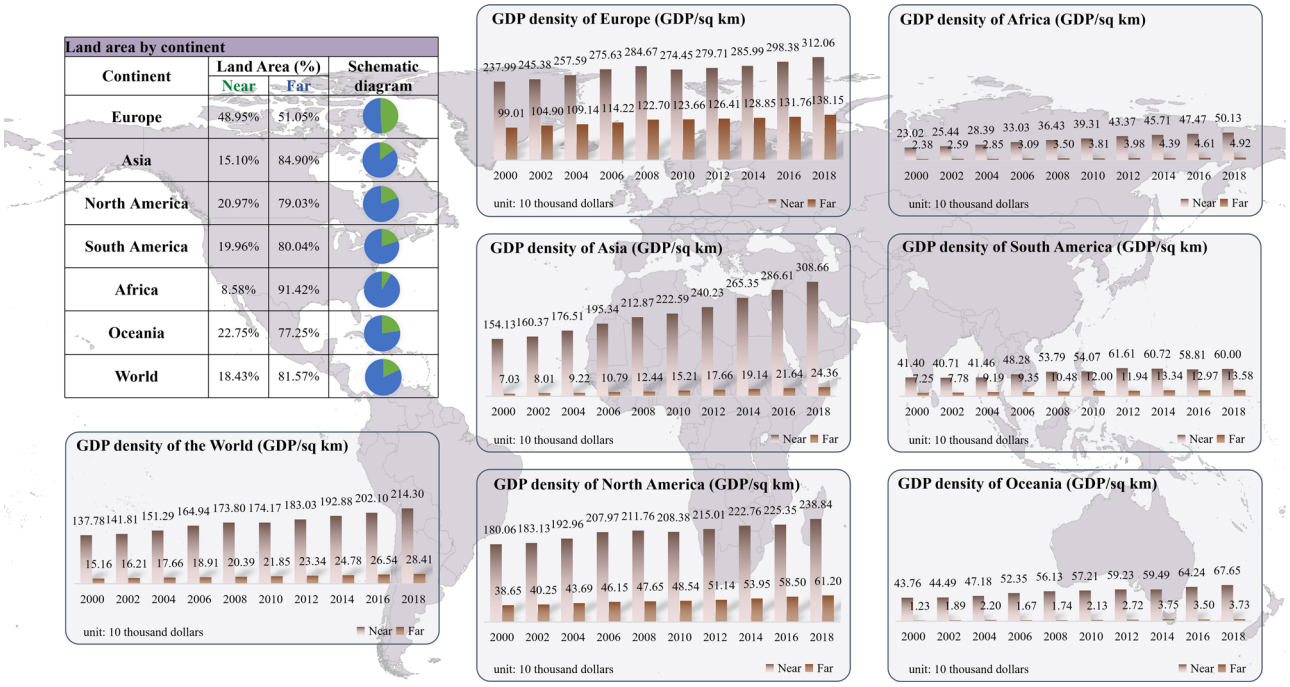

Fig. 3 Land area ratio and GDP density of global and intercontinental "near regions" and "far regions".

weakening of the high concentration of economic development in the global coastal areas. The diffusion trend is a result of economic globalization, marketization, trade liberalization, and informatization. These factors enable the characteristics of freedom, separability, and openness of regional space to emerge (Ahmad and Wu, 2022). Especially in the late 2010s, economic globalization facilitated the rapid development of the knowledge economy. The "near region" (core areas) appeared to be knowledge-intensive, informalized, and servitized. Owing to the intangibility of the network, the spatial development of the "far regions" (marginal area) demonstrated the diversity and constantly absorbed and utilized the potential of the economic, cultural, and institutional environment of the "near region" to enhance its economic development potential and attract economic factors to move toward the interior areas.

Characteristics of the economic evolution pattern of intercontinental "near regions" and "far regions". As explained and confirmed in the previous paragraphs, economic factors are gradually shifting from "near regions" to "far regions" globally. Will there be differences if this pattern transformation is applied on an intercontinental basis? Thus, we screened the six continents with the most frequent economic activities in the world, namely, Europe, Asia, North America, South America, Africa, and Oceania, and analyzes the changes in the flow of economic factors in the "near regions" and "far regions" of each continent. From 2000 to 2018, the agglomeration degree and evolution pattern of economic factors in the "near regions" and "far regions" of the six continents showed heterogeneity (Fig. 5A–F and Table 1).

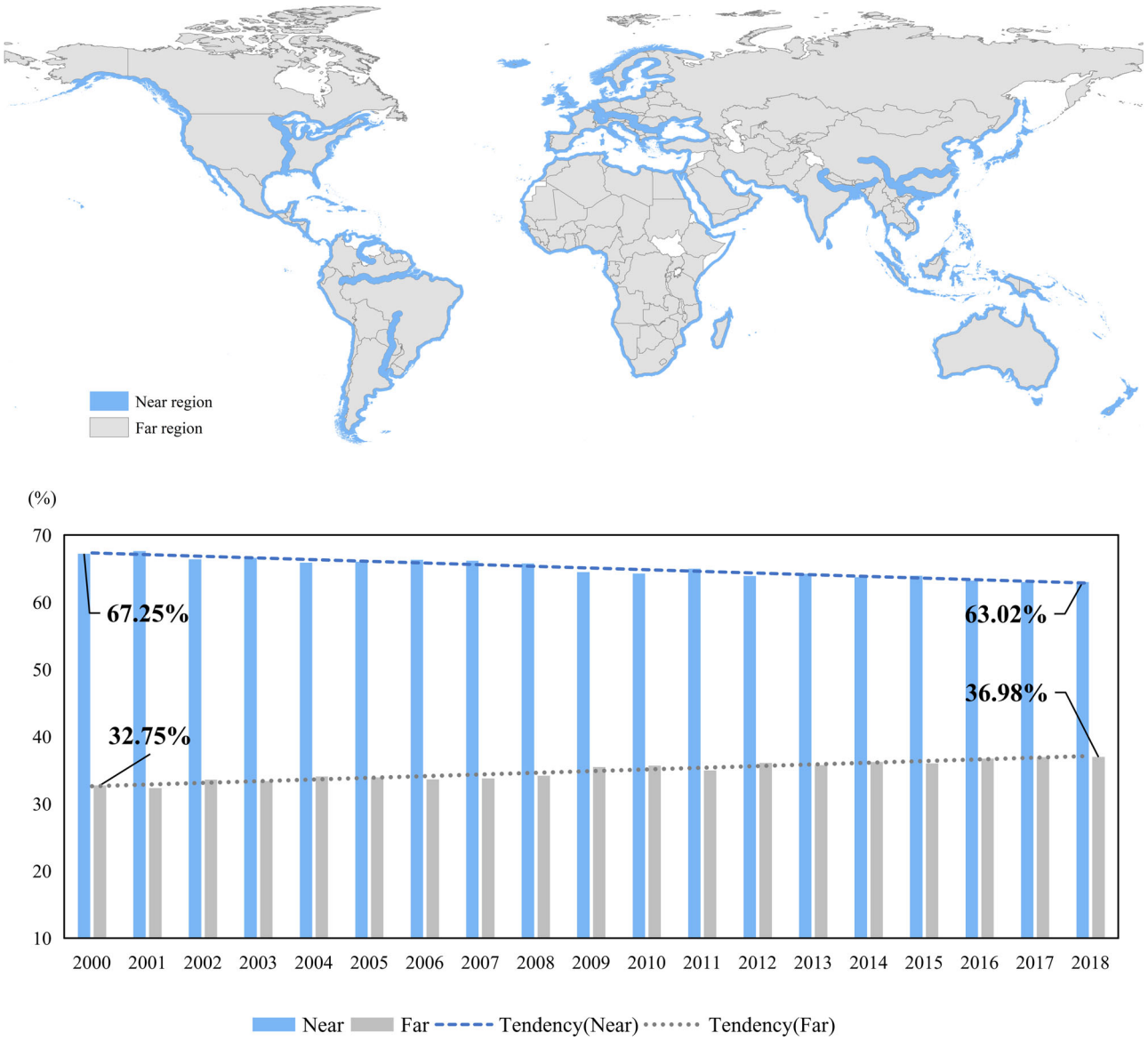

Fig. 4 Economic proportion and evolution trajectory of global "near regions" and "far regions".

Economic evolution pattern of "near regions" and "far regions" in Europe. The economic proportion of the European "near region" (accounting for 48.95% of the European landmass) decreased over the study period, from 69.74% in 2000 to 68.41% in 2018, while the economic proportion of the European "far regions" (accounting for 51.05% of the European landmass) increased from 30.26% in 2000 to 31.58% in 2018. Moreover, the GDP density of the European "near regions" is approximately 2.3 times that of the "far regions" (Figs. 3 and 5A).

In general, the economic development of Europe presents an evolution pattern corresponding to "coastal remoteness," with relatively low fluctuations, and the economically dominant areas are still concentrated in its "near regions." The pattern evolves as follows. First, geographically, 48.95% of Europe's land area is adjacent to the sea area, making it an area with both sea- and land-based features. Nevertheless, this land area is relatively small and narrow compared with other continents, and the productivity of its various economies is rather limited. Consequently, the entire European Union has had to rely on its unique geographical location conditions and comparative advantages and make extensive use of its port and maritime facilities to enable foreign trade (Mudronja et al., 2020), which leads to a high concentration of economic activity along the coastal area. Second, most of the economies in Europe are in the late stage of industrialization or post-industrialization development (Andal, 2022). Imports and exports are no longer dominated by traditional manufacturing products, and the tertiary industry accounts for a relatively high proportion; for instance, the proportion of the service industry in the whole EU increased from 62.05% to 65.07% from 2000 to 2018 (World Bank, 2022). Additionally, the manufacturing industry is also dominated by high-end, sophisticated products that are less dependent on marine transportation, resulting in more industries moving to "far regions" with relatively low economic density. Third, there has been a rapid development of transportation and communication technology in Europe; for example, the European Commission presented the "Sustainable and Smart Mobility Strategy" that will create new opportunities for the economic development of the interior regions (UN, 2020). Fourth, amidst the international financial crisis, the European debt crisis, and changes in the political pattern following Brexit, the balance between the development of the European coastal areas and the interior areas was disrupted, which led to the

Table 1 Economic proportion of the global and intercontinental "near regions" and "far regions".

Year	GDP proportion(%)													
	Asia		Europe		North America		South America		Africa		Oceania		World	
	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far
2000	79.58	20.42	69.74	30.26	55.28	44.72	58.75	41.25	47.55	52.45	91.30	8.70	67.25	32.75
2001	79.63	20.37	70.20	29.80	55.67	44.33	60.16	39.84	47.98	52.02	90.41	9.59	67.65	32.35
2002	78.06	21.94	69.16	30.84	54.69	45.31	56.63	43.37	48.02	51.98	87.40	12.60	66.40	33.60
2003	79.09	20.91	69.60	30.40	53.77	46.23	55.96	44.04	49.04	50.96	88.90	11.10	66.61	33.39
2004	77.29	22.71	69.35	30.65	53.96	46.04	52.96	47.04	48.29	51.71	86.35	13.65	65.93	34.07
2005	76.84	23.16	68.24	31.76	54.92	45.08	57.00	43.00	48.46	51.54	90.83	9.17	66.05	33.95
2006	76.30	23.70	69.82	30.18	54.46	45.54	56.28	43.72	50.06	49.94	90.24	9.76	66.33	33.67
2007	76.17	23.83	69.56	30.44	54.41	45.59	55.02	44.98	49.75	50.25	89.72	10.28	66.22	33.78
2008	75.26	24.74	68.99	31.01	54.11	45.89	56.15	43.85	49.44	50.56	90.46	9.54	65.81	34.19
2009	71.94	28.06	68.20	31.80	54.16	45.84	54.25	45.75	49.32	50.68	88.46	11.54	64.52	35.48
2010	72.24	27.76	68.03	31.97	53.25	46.75	52.92	47.08	49.22	50.78	88.77	11.23	64.29	35.71
2011	72.50	27.50	68.04	31.96	54.52	45.48	56.66	43.34	49.27	50.73	88.51	11.49	65.00	35.00
2012	70.74	29.26	67.97	32.03	52.73	47.27	56.28	43.72	50.55	49.45	86.50	13.50	63.92	36.08
2013	71.53	28.47	68.88	31.12	52.70	47.30	53.53	46.47	50.04	49.96	82.98	17.02	64.24	35.76
2014	71.14	28.86	68.03	31.97	52.28	47.72	53.18	46.82	49.46	50.54	82.36	17.64	63.75	36.25
2015	71.15	28.85	68.58	31.42	52.32	47.68	52.68	47.32	49.55	50.45	83.16	16.84	63.96	36.04
2016	70.19	29.81	68.47	31.53	50.55	49.45	53.06	46.94	49.15	50.85	84.38	15.62	63.24	36.76
2017	69.89	30.11	68.58	31.42	49.93	50.07	52.38	47.62	48.94	51.06	84.24	15.76	63.02	36.98
2018	69.25	30.75	68.41	31.59	50.87	49.13	52.43	47.57	48.88	51.12	84.24	15.76	63.02	36.98

European economic activity gradually shifting to the interior "far regions" (Hua, 2020). Furthermore, in the selected European countries of Germany, Britain, France, and Italy, which account for over 50% of the total European output value, the change range of national economic factors between the "near regions" and "far regions" is relatively stable (Fig. 6). This is also one of the reasons for the relatively weak economic development and evolution in the "near regions" and "far regions" of the entire European continent.

Economic evolution pattern of "near regions" and "far regions" in North America. The economic proportion of the "near regions" of North America (accounting for 20.97% of the North American landmass) in the total economy of the continent decreased from 55.28% in 2000 to 50.87% in 2018, while that of the "far regions" (accounting for 79.03% of the North American landmass) increased from 44.72% in 2000 to 49.13% in 2018 (Fig. 5B), and the difference in GDP density between the two sub-regions decreased from 4.7 times to 3.9 times (Fig. 3).

Economic development in North America has exhibited a "coastal remoteness" evolution pattern. We believe that this pattern largely depends on changes in the spatial evolution of American economic factors. Notably, the average annual GDP of the US accounts for 83% of the total GDP of North America, and simultaneously, the average annual GDP of the "near regions" of the US accounts for 84% of that of the North American "near regions." Such a large economic aggregate makes the US the main driving force behind the economic development trend in North America. Currently, the US has just entered the post-industrialization development stage, and the economic focus has shifted from the manufacturing industry to tertiary industries, such as production-oriented services. In 2016, the value-added components of the three industries in the United States were 1.1%, 20.0%, and 78.9%, respectively, and their employment components were 1.6%, 18.4%, and 80.0%, with capital and labor flowing continuously to the service industry (National Bureau of Statistics of China, 2016). Nevertheless, the development of these industries is less dependent on the advantages of proximity to the international market in the "near regions" and that of convenient maritime transportation; instead, their industrial spatial layouts are more flexible. Owing to the impact of these factors, the economic share of "near regions" in the US in the past 20 years has dropped from 56.1% in 2000 to50.95% in 2018, contributing to a decline in the economic share of the North American "near regions." Moreover, Mexico, as another typical country in North America, has demonstrated a pattern of "coastal proximity" economic development (Fig. 6). Judging from the per capita income level, Mexico is in the middle and late stages of industrialization. However, based on its current international economic and political form, Mexico is still the leading country for industrial transfer among developing countries. Furthermore, domestic labor-intensive industries need to be approached via the coast to benefit from low shipping rates. Although Mexico's economic factors are driven by the sea, its annual economic share in North America is barely 6%, which is not sufficient to influence the overall economic evolution pattern of the two sub-regions in North America.

Economic evolution pattern of "near regions" and "far regions" in Asia. The economic proportion of "near regions" of Asia (accounting for 15.1% of the Asia landmass) in the total economy of the continent dropped from 79.58% in 2000 to 69.25% in 2018. However, it remained higher than the global average, while that of "far regions" (accounting for 84.9% of the Asia landmass) increased from 20.42% in 2000 to 30.25% in 2018. Additionally, the difference in GDP density between the two sub-regions in Asia decreased rapidly during the study period, from 21.9 times to 12.7 times (Fig. 3).

The results reveal that the economic development constituted a "coastal remoteness" evolution pattern in Asia (Fig. 5C) and the economic factors in Asia show the diffusion effect of shifting from "near regions" to "far regions," rather than the agglomeration effect that approaches "near regions" constantly. Additionally, the total economic aggregate of its "near regions" has exceeded 2/3 of that of Asia. We infer that the emergence of these phenomena is inextricably linked to Asia itself, although it embraces various economies. The largest proportion of the Asian economy is concentrated in Japan, China, India, and South Korea. However,

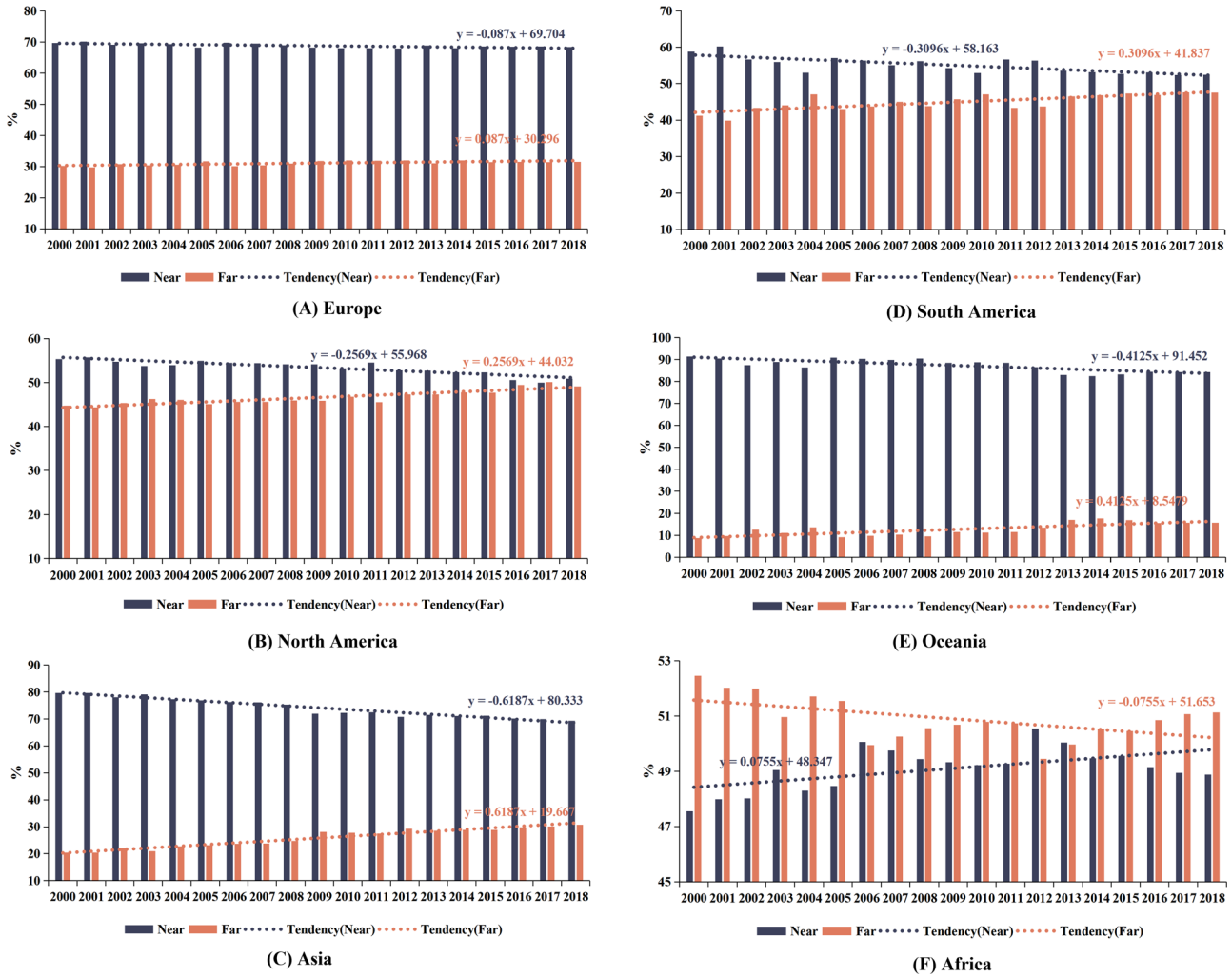

Fig. 5 Economic proportion and evolution trajectory of intercontinental "near regions" and "far regions". Figure 5 contains the economic evolution pattern equations of the "near regions" and "far regions" of all continents. Figure 5(**A**)-(**F**) represent the economic proportion and evolution trajectory of the European, North American, Asian, South American, Oceanian, and African "near regions" and "far regions," respectively.

with their narrow and long land areas, Japan, South Korea, and Southeast Asian island countries are covered by almost 100 km of coastal areas, and almost all of their economic output value can be included in that of Asia, promoting a larger economic proportion of the Asian "near regions." Therefore, the movement trends of economic factors in the "near regions" and the "far regions" of China and India will directly influence the economic evolution pattern in both Asian sub-regions. China has rapidly contributed to Asia's economic growth (from 17.36% in 2000 to 36.75% in 2018) since the beginning of the 21st century. At the same time, in recent years, the central and western regions of China have vigorously promoted the intelligent transformation and upgrading of traditional industries, accelerated the development of strategic emerging industries, and continuously sought industrial leapfrogging development. The economic development rate of the interior area has been significantly higher than that of the eastern coastal area (Sun et al., 2021), which contributed to the economic proportion in the "near regions" declining from 57.44% in 2000 to 55.81% in 2018, constituting the "coastal remoteness" economic evolution characteristics. Therefore, with China's economic development gaining momentum, it directly impacts the economic development pattern of Asia, and the economic proportion of Asian "near regions" also shows an obvious downward trend. Moreover, the "coastal remoteness" characteristics of economic development in many Asian economies, helped to further strengthen the overall "coastal remoteness" evolution pattern of economic development in Asia. For example, as a populous country, the economic proportion in the "near regions" of India also shows a fluctuating downward trend, from 47.98% in 2000 to 46.48% in 2018. Similarly, Thailand and Bangladesh's economic evolution patterns also showed a "coastal remoteness" feature, with the economic proportion of their "near regions" dropping from 80.94% and 96.56% in 2000 to 65.33% and 92.02% in 2018, respectively (Fig. 6). In contrast, from the perspective of global value chains, Asia's overall economic pattern is being reconstructed. At the beginning of the 21st century, the alternates of the 'flying-geese' pattern accelerated the transformation and transfer of industries in the Asia-Pacific region. Asia's economy is gradually transitioning from the primary to the middle and late stages of industrialization. Asia's role as a processor of labor-intensive industries in developed countries is dwindling, and the industrial structure of intercontinental economies is evolving. Thus, it is not necessary to overly rely on the maritime advantages of the "near regions" for the processing and transshipment of large-scale manufacturing industries. Thus, it is possible to see the diffusion of intercontinental economic factors to the "far regions" as a reflection of Asian economic evolution patterns and industrial structure transitions.

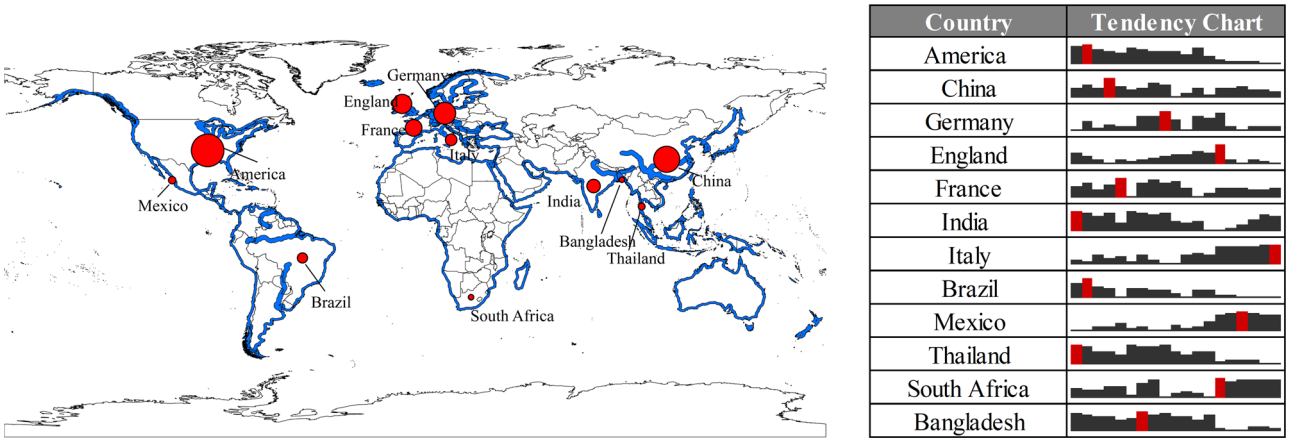

Fig. 6 Characteristics of economic spatial evolution in typical countries. In the tendency chart, the red histogram indicates the year with the highest economic proportion of the "near regions" in various countries.

Additionally, Asian countries possess enormous economic aggregates and diversified industrial structures that are fully capable of executing internal circulation as well as continuously developing and breaking through the interior area's economy, thus making up for the over-reliance on the advantages of coastal ports for international trade under the current turbulent international political and economic situations. It should be mentioned that China's implementation of the 'Belt and Road' strategy, as well as the 'China Railway Express' around the vast inland hinterland of Asia and Europe, typifies the transfer of Asian economic factors to interior areas (Wan et al., 2018, Lee et al., 2021).

Economic evolution pattern of "near regions" and "far regions" in South America. The economic proportion of the "near regions" of South America (accounting for 19.96% of the South American landmass) in the total economy of South America decreased from 58.75% in 2000 to 52.43% in 2018, while that of the "far regions" (accounting for 80.04% of the South America landmass) increased from 41.25% in 2000 to 47.57% in 2018 (Fig. 5D). Moreover, the difference in GDP density between the two sub-regions decreased from 5.7 times to 4.4 times (Fig. 3).

The results show that the economic development of the entire South American continent has followed a "coastal remoteness" evolution pattern. Geographically, South America is endowed with rich marine resources, being surrounded by the Atlantic Ocean on the east, the Pacific Ocean on the west, and Panama Canal on the north. Therefore, owing to their abundant resources, countries in South America export many primary products, such as petroleum and agricultural products, and use port infrastructure to facilitate foreign trade, which explains why more than 50% of the economic factors in the past 20 years have been concentrated in the "near regions." Particularly in recent years, owing to the financial crisis, global overcapacity, and other factors, South America's foreign trade development has slowed down, and economic growth has gradually turned to expanding domestic demand. Therefore, the economic factors on the continent have gradually shifted to the "far regions." Brazil and Argentina, the two major economies, contribute over 70% to South America's economy and are transitioning to the late stage of industrialization. The service industry has gradually become the main pillar of its economic development, accounting for approximately 60% of the total (World Bank, 2022). Consequently, the development of the service industry is not dependent on low-cost maritime transportation, which has reduced the economic proportion of Brazil's "near regions" from 56.17% to 48.86% during the study period. Similarly, the proportion of Argentina's economy has also decreased from 64.97% to 53.00%, and its economic development has obvious characteristics of "coastal remoteness." Therefore, the overall economic development in South America is characterized by an evolution pattern of "coastal remoteness" (Fig. 6).

Economic evolution pattern of "near regions" and "far regions" in Oceania. The economic proportion of the "near regions" of Oceania (accounting for 22.75% of the Oceanian landmass) in the total economy of Oceania decreased from 91.3% in 2000 to 84.2% in 2018, while that of the "far regions" (accounting for 77.25% of the Oceanian landmass) increased from 8.7% in 2000 to 15.8% in 2018 (Fig. 5E). Meanwhile, the difference in GDP density between the two sub-regions declined from 35.6 times to 18.2 times (Fig. 3).

Based on the results, Oceania's economic development also constitutes a "coastal remoteness" evolution pattern. Additionally, despite the sharp imbalance in the overall level of economic development between the two sub-regions of Oceania, the economic differences between the two sub-regions are gradually shrinking Oceania comprises Australia, New Zealand, and several island countries. Other than Australia, most of the land area of the countries in Oceania lies within the globally recognized 100 km coastal area. The Australian economy constitutes over 85% of the Oceanian economy. As the continent's most developed country and trendsetter, Australia occupies an important position and can represent the development trend of the entire Oceania economy. Therefore, the emergence of the evolution pattern of the above pattern is primarily caused by two factors. First, due to the high concentration of ocean-type economies, its economic development is primarily concentrated in the southeast coastal area, resulting in the cost of production factors in the "near regions" having continuously increased, thus aiding the transfer of economic factors to the interior areas. Second, as an ocean-type continent, foreign trade is the major source of Oceania's economic development, making it vulnerable to the global economic environment. The international financial crisis weakened the international market and hampered foreign trade, resulting in great fluctuations in the "near regions" economic development of the continent. Thus, shifting the focus of economic development to interior areas and developing domestic demand have become the focal points of economic policies to maintain economic stability in Oceania.

Economic evolution pattern of "near regions" and "far regions" in Africa. The economic proportion of the "near

regions" of Africa (accounting for 8.58% of Africa's landmass) in the total African economy increased from 47.55% in 2000 to 48.88% in 2018, while that of the "far regions" (accounting for 91.42% of Africa's landmass) decreased from 52.45% in 2000 to 52.12% in 2018. Regarding GDP density, the "near regions" of Africa constitute approximately 10 times that of the "far regions," and account for less than 10% of the continent's landmass, thus creating nearly half of Africa's economic output (Fig. 3).

The results show that the economic development in Africa shows a "coastal proximity" evolution pattern with a lower change range between the two sub-regions. However, Africa's coastal areas enjoy far greater production capabilities and resource endowments than its interior areas. With the Indian Ocean to its east, the Atlantic Ocean to its west, and the Strait of Gibraltar to its north, Africa has abundant resources in marine organisms, minerals, and marine space resources. Nevertheless, some of its countries with poor development foundations, late start, and lower levels of development in Africa (According to the International Yearbook of Industrial Statistics released by UNIDO in 2016 (UNIDO, 2016), only three countries in the African region, namely Mauritius, South Africa, and Tunisia, are classified as "emerging industrial economies"; 19 other economies are classified as "developing industrial economies," and the remaining 32 economies are classified as "underdeveloped industrial economies" (GDP per capita is mostly less than US $1000) (World Bank, 2022)), have to create the conditions to increase their economic benefits by taking advantage of low-cost coastal freight rates to carry out foreign trade, gather in the coastal area continuously, participate in the international division of labor to promote Africa's industrialization development process and facilitate the diversified development of the national economy, which would help alleviate the food security crisis across the continent to a certain extent. Consequently, the economic density of the "near regions" of Africa is much higher than that of the "far regions," and the economic share of the "near regions" shows an upward development trend, which constitutes an evolution pattern of "coastal proximity" (Fig. 5F). Similarly, as an emerging economy with great contribution to the African economy, South Africa is located at the intersection between the Indian Ocean and the Atlantic Ocean, with its east, west, and south sides comprising coastal lowlands. It provides a window for the African continent to participate in the international economy and form a cluster of many ports and harbors, which lead to further development in entrepot trade and external trade and account for a significant portion of its economy (African Union, 2018). Consequently, the economic proportion of its "near regions" increased from 27.06% in 2000 to 29.11% in 2018, showing a "coastal proximity" economic evolution pattern (Fig. 6).

Although Africa's economic development generally presents a "coastal proximity" evolution pattern, the degree of such evolution is relatively weak, because many nations in Africa are in the initial stages of industrialization or even at the pre-industrialization stage, where their economic development mostly depends on self-sufficient traditional handicrafts and agriculture, and most products are sold locally. Therefore, economic factors do not need to be significantly close to coastal areas to conduct foreign trade by taking advantage of maritime transportation. Further, to some extent, Africa's economic development level does not support higher trade costs, hindering the "coastal proximity" economic development pattern for rapid and sustained growth.

Discussion

The spatial distribution of economic activities is largely determined by the convenience of geographic location for human habitation and goods transportation (Henderson et al. 2018). The

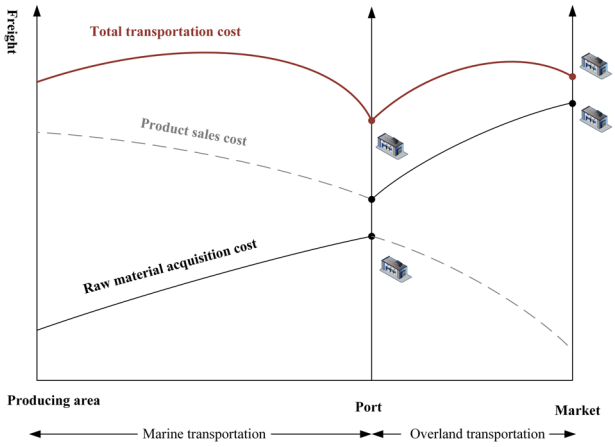

Fig. 7 Schematic diagram of maritime advantages.

first main finding of this article is that in the past 20 years, the global "near regions" have comprised approximately 65% of the global economic aggregate, and their economic density is approximately eight times that of the "far regions," which reflects the non-equilibrium development trend between the "near regions" and "far regions" globally and creates an obvious core-periphery structure. This high agglomeration of economic factors is caused by the unbalanced geographical and spatial distribution of transportation costs (Radelet and Sachs, 1998, Head et al., 1994, Porter, 1990, Hanson, 2001, Krugman, 1991). This can be verified using Hoover's location theory (Hoover, 1948), which notes that freight could be an important factor affecting economic activities through the research of transportation mode and freight structure, which in turn affects the location selection of economic activities (Fig. 7). The advancement of economic globalization has contributed to the continuous expansion of foreign trade. As the most important mode of freight transportation, marine transportation accounts for over 80% of the world's global freight volume and more than 70% of the world's total global trade (UNCTAD, 2017). Therefore, when two modes of transportation are required for reloading and transshipment, loading and unloading freight combined with the loss of decreasing freight rates will cause a sharp increase in freight at the transshipment distribution point, as can be seen from the rise in the transfer port of the two curves of raw material acquisition fee and product sales cost in Fig. 7. To obtain maximum profits, it is preferable to construct a factory near a port (marine loading and unloading port), so that the number of instances of loading and unloading can be reduced, thereby reducing transportation costs. Generally, it can be considered that the port seat has the lowest freight costs. Therefore, on a global scale, the closer the economic activities are carried out to the coastal ports or "near regions," the lower the freight costs and the more desirable the geographical features for trade. Therefore, the global "near regions" are the most favorable locations for the operation of global economic activities, and the significance of ports and cities in "near regions" as "gateways" is great. By taking advantage of superior maritime transportation conditions and lower transportation costs, the economies in the "near regions" can participate in international trade more freely and benefit from higher profits, thus making it the center of agglomeration.

Another significant finding of this research is that it was observed that the continuous advancement of economic globalization did not intensify agglomeration in coastal areas but instead diffused and shifted it to interior areas in the past 20 years, making global economic development an evolution pattern of "coastal remoteness." This phenomenon warrants us to re-

examine whether the importance of the global "near regions" as the core area of the global economy is shifting. Based on our discussion, the following reasons may explain this phenomenon.

(1) The rapid development of inland transportation. Owing to the rapid development of inland and multimodal transportation in recent years, international transportation costs have declined, resulting in the rapid expansion of foreign trade to interior areas. A decrease in transportation costs enables manufacturers to produce in interior areas far from the ports, and the relatively low land rent and labor costs in interior areas reduce the overall cost of interior areas, attracting many enterprises to these areas.

(2) The proportion of emerging high-tech industries and service industries increased significantly, while demand for sea transportation decreased. With productivity improvement as well as the transformation and upgradation of industrial structure, product formats have become more diversified, the market share of high-tech products has gradually increased, more economies have been transformed to the late or post-industrialization stage, and the social networking pattern has become more prominent. Further, the proportion of non-tradable service industries has increased. For instance, most countries in North America, Western Europe, and East Asia participate in complex global value chains, and their economic development has entered or gradually entered a high-level stage. These countries can offer advanced products and services and perform innovative activities, making a relatively small impact of the price advantages of ocean transportation on there; further, the distribution of production materials and opportunities in the two continents is more equitable, thus promoting the economic factors to continuously transfer from "near regions" to "far regions" to obtain a broader inland market.

(3) Excessive agglomeration results in the coexistence of diseconomies of scale and economic spillovers. As a high-density economic agglomeration area, the global "near regions" create a self-reinforcing mechanism that forms the "Matthew effect"—which means that the scale within the cluster is constantly expanding and the internal advantages are constantly increasing to attract more technology and capital. This increases its scale, thereby creating a phenomenon of "increasing returns" of scale until a certain limit is reached; however, there is a certain threshold to this limit, after which the increase does not translate to better results. When the economic factors are gathered excessively, it will lead to an increased cost of input factors in the "near regions," and cause traffic congestion, increases in land prices, environmental pollution, inadequate infrastructure construction, and other problems (Tibbetts, 2002). This leads to a decline in the regional economy, an increase in human living costs, and a reduction in the well-being index, consequently forming diseconomies of scale, which will trigger the gradual spread of economic development from the "near regions" with high economic density to the "far regions" with low economic density. This will particularly be observed in developed countries in the late or post-industrialization stage that are in pursuit of a high standard of living. Furthermore, apart from the transfer of economic factors caused by the negative effects of excessive agglomeration, there are also spillover effects of transportation and other factors on the global "far region" economy when the economic development of the advantageous location zone ("near regions") reaches a certain level and the agglomeration effect begins to spread in the region.

Further, the evolution pattern of global and intercontinental economic factors found in our article supports Friedman's assertion on the evolution of regional spatial structure to some extent. Specifically, Friedman asserts that the evolution of a region's economic spatial structure must pass through four stages: low-level equilibrium development, polar core development, diffusion development, and high-level equilibrium development according to its industrialization development stage (Friedman, 1966). The appearance of "coastal remoteness" within the global economic development evolution pattern in the "near regions" and "far regions" indicates that the current global economy is transitioning from a polar nuclear development stage to a diffusion development stage and is gradually moving toward a high level of equilibrium. Moreover, there are also differences in the spatial evolution structure reflected by the different stages of industrialization development on different continents. Although the economies of Europe and North America, which have entered the post-industrialization stage, constitute a "coastal remoteness" evolution pattern in the "near regions" and "far regions," the extent of this evolution is not significant. Therefore, the region's economic spatial evolution structure in Europe and North America is what Friedman calls a high-level equilibrium development. As a whole, Asia, South America, and Oceania are going through the middle and late stages of industrialization, and their economies have shifted significantly from coastal areas to interior areas, which is in line with Friedman's stage of the diffusion development stage. African economies are still at an early stage of industrialization and even at the pre-industrialization stage, and economic factors in the two major sub-regions are relatively unchanged. Moreover, the evolution of the region's economic spatial structure is akin to what Friedman called a low-level balanced development stage. Simultaneously, global and intercontinental economic factors have entered a stage of diffusion and high-level equilibrium, demonstrating an evolution pattern of "coastal remoteness."

More than that, the history of human civilization also demonstrates that the process of economic development is a process of gradually expanding living space and gradient transfer. Initially, civilizations developed around rivers, middle or lower deltas, and plains, which facilitated the development of agriculture and animal husbandry. Furthermore, with the emergence of the commodity economy, the acceleration of the industrialization process and development of international trade required ports and marine transportation. Therefore, the advantages of coastal areas have gradually emerged. Moreover, with the upgrading and transformation of industries, to maximize the potential for a broader market and a more comfortable living environment, the boundaries of living activities were constantly widened inward, as were the economic factors. This also explains from another perspective the research concluded that the global economic factors are gradually shifting from the global "near regions" to the wider "far regions."

Global coastal areas are bounded between land and sea, and both exert influence on the coastal area simultaneously (Luan et al., 2020), which leads to the increasing density and diversity of economic activities in this region. In our research, we have fully focused on this point—that is, the global "near regions" represent a large proportion of the global economy. Many international scientific programs (such as IHDP, IGBP, and FEC) as well as coastal countries and regions are aware of the necessity of implementing integrated coastal area management owing to the high intensity of economic output and high density of production factors in coastal areas. Among these are the "Coastal Zone Management Act, 1972" of the US (Office for Coastal Management, 1972), "The Basic Plan on Ocean Policy" of Japan (Headquarters for Ocean Policy, 2018), "Integrated Coastal Zone Management, 2002" of the EU (European Communities, 1999), and other coastal area policies and proposals aimed at reducing development pressure and improving carrying capacity in coastal areas.

Significantly, we observed that the "coastal remoteness" evolution pattern of economic development in different regions

indicates that the economic factors in the global and most intercontinental areas are gradually shifting from the coastal areas to the interior areas. This trend may continue in the future. Therefore, the contradictory relationship between the socio-economic and resource environments of each subregion will also shift accordingly. Therefore, under these new circumstances, global strategic planning should also gradually shift its focus to interior areas to ensure a balanced distribution of policymaking between coastal and interior areas.

Conclusion

For the exploration of the evolution pattern of economic factors in the global coastal and interior two regional systems, there is an incompleteness of temporal and spatial scale in current research. Clarifying the global coastal and interior economic development evolution pattern is essential to effectively assess the sustainable development of the global economy, as this will facilitate regional strategic management and decision-making. In general, our research results can approximately describe the overall pattern of the spatial evolution of global and continental economic factors:

(1) The intensity of economic activity in global coastal areas is still much higher than that in interior areas. The economic aggregate of the global "near regions" increased from USD 33,124.2 billion in 2000 to USD 51,523.6 billion in 2018, while that of the global "far regions" increased from USD 16,134.8 billion in 2000 to USD 30,238 billion in 2018. Further, the global "near regions" account for about 65% of the global economy with 18.43% of the land area, while the "far regions" account for only about 35% of the global economy with 81.57% of the land area. Moreover, the economic density of the global "near regions" is about eight times that of the "far regions." In general, the spatial imbalance of economic development between the global "near regions" and "far regions" is relatively apparent. This verifies Hoover's location theory (Hoover, 1948), which states that a geographical location with low freight will have a high degree of economic agglomeration.

(2) "Coastal remoteness" is a general feature of global economic development. The economic proportion of the global "near regions" decreased from 67.25% in 2000 to 63.02% in 2018, while that of the "far regions" increased from 32.75% in 2000 to 36.98% in 2018; additionally, global economic factors gradually transferred from the "near regions" to "far regions." Simultaneously, the economic development gap between the two sub-regions is gradually narrowing, and the global "far regions" are displaying great economic development potential. Thus, the formulation of policies should be moderately shifted to the interior area and well laid out in advance.

(3) Regarding the intercontinental scope, the economic development evolution pattern of the two regional systems is different due to their differing industrialization stages and dependence on marine transport conditions. The results can be seen in the economic development of Africa, which exhibits an evolution pattern of "coastal proximity," while Europe, North America, Asia, South America, and Oceania exhibit an evolution pattern of "coastal remoteness." However, no significant change in the amplitude of economic factors movements occurred between the two sub-regions in Europe and Africa. Considering the heterogeneity in the evolution pattern of economic factors in the coastal and interior areas within the intercontinental range, policy formulation according to their respective particularities is required.

In summary, this research validates and supplements Hirschmann's regional uneven growth theory at a larger spatial scale. The innovations and originalities are mainly reflected in the following three aspects: Firstly, we combine nighttime light data with random forest algorithms to identify the economic aggregate of "near regions" and "far regions" on a global and intercontinental scale, overcoming the limitations of traditional statistical means in capturing and measuring such large-scale regional economic information. Secondly, we provide an objective characterization of the economic aggregate and dynamic changes of "near regions" and "far regions" at both global and intercontinental scales, which addresses the problem of the dynamic change trends judgment of coastal and interior areas that are of focus in global scientific programs, and fulfills the need for more accurate data and statistical information; Thirdly, we reveal the fundamental characteristics of economic factors' "coastal remoteness" and "coastal proximity" in the context of the rapid improvement of economic globalization. Additionally, due to the absence of multi-source data support and statistical analysis of driver tracing, our current research reveals only a spatial evolution pattern in economic factors on a global and intercontinental scale. On one hand, due to a lack of data in other fields, we only used nighttime light data combined with statistical data to estimate the global economic aggregate in the "near regions" and "far regions" for a long time series. On the other hand, space constraints did not permit us to use statistical analyses on the mechanism and causal factors of the economic evolution pattern at the global and intercontinental levels in detail. This also included exploring the reasons for the minor movement amplitude of economic factors between coastal and interior areas in Europe and Africa. Therefore, we only began with the existing theory and analyzed it from two perspectives: the advantages of marine transportation and the stages of industrialization, which may appear to be biased and subjective. With the continuous updating and iteration of information technology, and to remedy the shortcomings of this research, we aim to collect and find more information sources for the formulation of global coastal and interior area planning policies and strategies through the integration of multi-source data (remote sensing data, sensor network data, and social network data) in the future. We also aim to provide more accurate and practical information, use metrological analysis to perform a detailed examination of the driver tracing and mechanism explanation of the spatial evolution pattern of economic factors in the global "near regions" and "far regions," and provide relevant and diverse information for aiding the global coastal and interior regional decision-making process, which will be the purpose and value of this and the following research.

Data availability

The nighttime light data can be found at https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/YGIVCD. Historical GDP data is available from https://data.worldbank.org.cn/. The world vector map is taken from https://datacatalog.worldbank.org/search/dataset/0038272. The global coastline vector data and 1:50 m global water vector data are derived from https://www.naturalearthdata.com/.

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Author contributions

The authors confirm their contribution to the paper as follows: XJ: methodology, formal analysis, writing - original draft; WL: conceptualization, writing - review & editing, funding acquisition; JY, WY and XX: validation; SW and DY: data curation, formal analysis; BX and YD: manuscript revision; FL and SW: editing, supervision. All authors substantially contributed to the article and approved the submitted version.

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