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Coevolution of Economic and Industrial Linkages within the Land-Sea Industrial Structure of China

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Abstract: The joint development of continental and marine economies has become an important driving force for the upgrading of industrial structures. However, because of the differences in resource endowment and development potential, developing industrial structures and the quality of economic development are uneven among regions. In this study, the added values of three land-sea industries in the three marine economic circles of northern, eastern, and southern China, were employed to clarify the evolutionary behavior of the industrial structure of these three circles on the land and sea; the synchronization, lag, equilibrium, and dislocation of developing the industrial structure were also explored which a gray relational model based on convex judgment and gray time difference analyses were used to construct a relational model from the static and dynamic aspects of the system, and the internal and external linkages of the industrial structure of the three circles were analyzed from the perspective of industrial correlation. The results show that: (1) Correlations among the linkages of the three economic circles in the marine industrial structure, both including and without temporal and spatial differences, and the marine feedback driver, differ markedly. (2) The effects of feedback for marine industrial development from the Eastern Marine Economic Circle were stronger, whereas those of the Southern Marine Economic Circle were weak and those of the Northern Marine Economic Circle were ambiguous. (3) A significant difference was observed in the degree of coevolution among the land-sea industrial structures of these areas. The Northern Marine Economic Circle exhibited a slightly higher degree of coevolution than the other two economic circles, showing a stable trend of coevolution and wide spatial development. The eastern and southern circles displayed high degrees of coordination in developing their industrial structures. The research results provide a reference for regional adjustment and optimization of industrial structure.

Keywords: land-sea industrial structure; convex gray correlation model; economic coevolution; coordinate economic development

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1. Introduction

The 21st century has been called the "century of the marine economy", which was stated in the "United Nations Convention on the Law of the Sea", published in May 2001. The sea is both a cradle of life and a source of resources, as it contains abundant strategic resources critical to human development, such as energy, minerals, water, and rare metal resources [1]. Explosive population growth, the overexploitation of land resources, and

environmental degradation have pressured lands to facilitate the development of human societies [2]. The marine environment provides a second space from which resources may be acquired for socioeconomic development [3]. Most of the marine developing countries are facing the problem of insufficient energy; thus, they must plan for the research and development of marine renewable energy resources [4]. Coastal communities worldwide attach great importance to developing the marine economy. Under the guidance of the marine power theory, the United States was transformed from a naval power into a marine power. An old maritime empire, the United Kingdom, continued to focus on marine development and enjoyed the dividends of using marine resources. Japan became a maritime nation in the early 1990s. According to the "Bulletin of Marine Economic Statistics of China 2020" [5], despite the impact of COVID-19, China's gross operating profit was USD 1.1596 trillion in 2020, contributing 7.34% of the total gross domestic product (GDP), which is twice the contribution of China's marine GDP in 2000.

The rapidly developing marine economy is inseparable from the land, which serves as a firm foundation for overall socio-economic development. Land-sea economics is a subsystem within the economic development system, which forms a complex network through the bidirectional flow of resources, mutual energy flows and environmental influences, and complementary rights and interests between terrestrial and marine resources [6]. The interactions between continental and marine industries are important linkages for promoting the coordinated development of terrestrial and marine environments. The exploitation of marine resources and the sustainable development of marine industries depend on existing land economies and technologies, while the processing of marine products and constructing infrastructure must also be conducted on land, especially in coastal zones. This transfers marine development from the sea to the land, and promotes the mutual development of land-sea economies via industrial linkages. Specific industrial structures serve as the corresponding levels of economic development. Continental and marine industries are interconnected, and the evolution of their industrial structures also influences one another. If the development of land-sea industries is separated, a lack of rational planning and a clear understanding of the linkages among the industrial structures of these economies and their development will be greatly hindered.

Marine resources play a key supporting role in developing land-sea economies [7,8]. Based on the continuous and dynamic preservation, protection, and development of natural resources, coastal zone management should encourage cooperation and exchange between local governments and federal agencies to ensure the reasonable and coordinated economic growth of land-sea industries [9,10]. However, because of the high uncertainties regarding marine and coastal species (e.g., endemism, diversity, and population sizes), contradictions between sustainable development and social and socioeconomic priorities, and the ambiguity of developmental positions, rights, and interests, different countries (and regions within them) encounter bottlenecks in resource management and coordinated industrial development [11–14].

By considering the land and marine systems independently; comprehensively combining their industrial outputs and the structures of their economic systems; and considering the connection of information flow and logistics as the link between them, land-sea industrial development may be scientifically planned to promote the construction of complementary systems for utilizing terrestrial and marine resources [15]. Structural correspondences, complementary relationships, and spatiotemporal co-occurrences exist between continental and marine industrial systems, as well as competition among marine industrial systems [16]. Therefore, extending the network; coordinating the extension; repairing, strengthening, and enhancing coordination between land-sea industrial chains are effective means of promoting the coordinated development of the land and sea [17,18].

Many nations have gradually shown the importance of the interactions between the land and sea by comprehensively promoting the coordinated development of coastal areas [19,20]. Some researchers used input-output methods to analyze the coordinated development of economic linkages in land-sea industrial structures [21–23]. In addition,

the changing environments, resources, science, and technologies of coastal areas pose challenges to developing marine economies in different regions. Therefore, marine industries should be diversified, and a complex relational network should be constructed with continental industries to facilitate flexibility in land-sea industrial development and coordination of these industries [24–26].

Some researchers have used Granger causality tests, variance decomposition analyses, and other econometric methods to test the existence of causality between land-sea industries [27–33]. Gray system theory, a degree of order model, fuzzy system theory, and an information entropy model were used to measure the correlations between different marine industrial values [30,34,35]. Meanwhile, kernel density and coupled models were used to study the spatiotemporal differentiation of land-sea industries in different regions [36–43].

Analysis shows that the research on the coordinated development of land-sea industrial structures was in the preliminary stages. Past research results can be divided into two foci. First, the utilization and management of land-sea resources in coastal areas have been analyzed from the perspective of the systems theory. Second, the mechanism(s) underlying dynamic correlations and collaborative developmental status have been quantitatively analyzed based on data-driven land-sea integration. Under the coordinated development of the land-sea industry, the development of land and sea industry has a synergistic effect and coupling effect through exploring the specific layout of the land and sea industry on the coastal zone, the comprehensive management of the coastal zone, and coastal space planning considering the development factors of the land and sea industry. Although an increasing number of research has been conducted in land-sea industrial relations from the perspective of land-sea economics, the research on land-sea economic and industrial structural linkages remains limited and scattered; the perspectives on such linkages are relatively simple, and the spatial differentiation between them is very rare. In addition, there have been few studies on the driving effect(s) of marine and continental industries over different periods, and the analyses of the effects of time differences between continental and marine economic and industrial structures based on a dynamic perspective are relatively rare.

Therefore, the research aims of this paper are adjusting and optimizing the key industrial structures in various regions by the following three points, which include understanding the developmental status of land-sea economies and industrial structures comprehensively, pointing out the problems existing in their development, and exploring the spatiotemporal differences in the linkages of land-sea economies and industrial structures. We considered three marine economic circles in China as the research objects, employed gray system and coordinated development theories as theoretical foundations, and analyzed the present situation of land-sea industrial development. We examined the dynamic differentiation and coevolution of land-sea industries in these three marine economic circles over time and space. Consequently, we provide a new perspective for studying the coordinated development of land-sea industries, with an emphasis on recommending China's overall strategy for land-sea industrial and high-quality economic development.

2. Materials and Methods

2.1. Gray Relational Model

Most researchers agree that input-output models are the main method by which internal and external linkages in economic systems may be analyzed, as other quantitative frameworks, such as econometrics and statistics, require sufficient data and are subject to other strict data requirements. Gray system theory is suitable for analyses with small sample sizes, and helps simplify calculations of economic and industrial linkages. Due to the lack of marine economic research in China, it is necessary to use a gray correlation model to analyze the relationship between marine and continental industries within and among periods. Yin et al. used the degree of convexity to develop a relevant gray correlation model that avoids the influence of the selection method of the gray model to simulate the original data, and makes the best use of the information in the sequence itself [44].

By considering the influences of the amplitude and period of a sequence of data, it has favorable (occasional) symmetry, parallelism, and uniqueness. In this study, we aim to calculate the linkages of land-sea industrial structures using both static and dynamic correlations. First, the improved reference gray correlation model, based on the degree of convexity, was used to measure the static correlation of the industrial structure. Gray time difference analysis was then used to explore the dynamic correlations between continental and marine industries in advance and by lag time.

Gray relational grade model based on convexity. Assuming that $X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\}$ and $X_j = \{x_j(1), x_j(2), \ldots, x_j(n)\}$ are characteristic behaviors of a series of data in (a,b), based on the gray relational grade model of convexity proposed by Yin et al. [44]. The gray relational degree of the improved model of X_0 and X_j is defined in Equation (1):

$$\gamma_{0,j} = \frac{1}{l}\sum_{i=1}^{l} \xi_{0,j}(i) \tag{1}$$

where,

$$\zeta_{0,j}(i) = \frac{1}{1+\alpha\left(1-\frac{\min\{C_0(i),C_0(j)\}}{\max\{C_0(i),C_0(j)\}}\right)+(1-\alpha)\left(1-\frac{\min\left\{|y_0(i)|,\left|y_j(i)\right|\right\}}{\max\left\{|y_0(i)|,\left|y_j(i)\right|\right\}}\right)}, 0 \le \alpha \le 1, i = 1, 2, \cdots \tag{2}$$

The length of this wave period is defined as *C*. *L* is the corresponding polyline. The wave period is shown as:

$$\hat{d}_L(L,k) \cdot \hat{d}_L(L,k+1) \le 0, \hat{d}_L(L,k+C) \cdot \hat{d}_L(L,k+C+1) \le 0 \tag{3}$$

The wave amplitude for sequence is *y*:

$$y(i) = y_{\max} - y_{\min} \tag{4}$$

where y_{max} is the maximum of all the ordinate values in *L*(*k*,*k*+*C*), and y_{min} is the minimum in it.

If $\gamma_{0,i} > \gamma_{0,j}$, the relational degree of X_i, X_0 is stronger than X_j.

Gray time difference analysis. Gray time difference analysis is based on gray correlation theory, wherein the time advance and lag are added to measure the dynamic correlations between sequences. The time difference correlation analysis measures the correlation between the reference sequence and the compared sequence before or after several periods, such that *k* is the leading period (or lag period), *K* is the maximum time difference, and X_0 is the reference sequence. When $k < 0$, the compared sequence is X_i ahead of the reference sequence, X_0. When $k > 0$, it is considered to represent a lag [45]. Generally, the calculated results of this synchronous index are ±3 years. If the advance is over 3 years, it is a leading indicator; otherwise, it is a lagging indicator.

2.2. Coevolution Model

2.2.1. Degree of Relative Advantage

The formula for calculating the relative advantage of continental and marine industries can be expressed as Equation (5):

$$X_i = \frac{M_i}{L_i}(i = 1, 2, 3) \tag{5}$$

where L_i and M_i represent the shares of value added from continental and marine industries (i), respectively, in the gross economic or gross marine product. When $X_i > 1$, the development of the marine service sector has more evident industrial advantages. The differences in industrial advantage can lead to differentiated layouts among industrial structures.

2.2.2. Degree of Deviation

Deviations in industrial structures represent the coevolution among industries and provide a means of quantitatively analyzing the development of linkages between continental and marine industrial structures. The lower the deviation, the higher the degrees of coevolution among continental and marine industries. The formula for calculating the degree of deviation is given in Equation (6):

$$P = \sum_{i=1}^{3} |M_i - L_i| \tag{6}$$

2.2.3. Coefficient of Coevolution

A coefficient can describe the characteristics of coordinated development among industries and quantitatively analyze the development of linkages between continental and marine industrial structures. However, compared with the coefficient of industrial structure, the coefficient of coevolution is better understood and mutually validated, which allows the analytical results to capture the linkages more reliably within China's land-sea industrial structure. The formula for calculating the coefficient of coevolution is given in Equation (7):

$$S = \frac{\sum_{i=1}^{3} M_i L_i}{\sqrt{\sum {M_i}^2 \sum {L_i}^2}} \tag{7}$$

The means of L_i and M_i in Equation (7) are the same. The coevolution coefficient of industrial structure ranges from 0 to 1; if the calculated result is equal to 1, it means that land-sea industrial structures are consistent. If the coefficient decreases gradually with time, this indicates that the synergy degree between continental and marine industrial structures is decreasing.

Economic development at the national level can be reflected in the evolution of industrial structures. According to relevant theories of industrial economics [46], there is a general rule that the evolution of land-sea industrial structures ranges from primary to intermediate to advanced.

2.3. Data Sources and Processing

According to the regional division standard of the Ministry of Natural Resources of the People's Republic of China, the Northern Marine Economic Circle in China, Shandong, Tianjin, Liaoning, and Hebei includes the Bohai Bay, Shandong, and the Liaodong Peninsula. Jiangsu, Zhejiang, and Shanghai constitute the Eastern Marine Economic Circle and include the terrestrial and marine areas along the coast of the Yangtze River Delta. The Southern Marine Economic Circle comprises Guangdong, Fujian, and Guiqiong, including the coastal area of the Pearl River Delta, which is the southernmost marine economic circle in China and the forefront of China's foreign trade. In this study, we analyze the current developmental status of the land-sea industrial structures in these three economic zones and clarify the synchronization, lag, equilibrium, and dislocation of the development of these structures.

The added values of the three continental and marine industries were chosen as the research objects, and the linkages of the land-sea economic and industrial structures of the three economic zones were compared based on historical data from 2006 to 2019. The data were extracted from the China Statistical Yearbook, China Marine Statistical Yearbook, and statistical bulletins of the relevant provinces. To counteract the effects of inflation, the data were indexed. The processed data are presented in Tables 1 and 2.

Table 1. Processed data for the added values of major marine industries in three economic circles.

Year	Primary Sector			Secondary Sector			Service Sector		
	North	East	South	North	East	South	North	East	South
2006	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2007	117.57	117.56	125.05	117.05	116.56	112.32	121.91	119.90	118.50
2008	117.94	132.55	108.76	120.25	112.75	142.59	115.25	113.21	112.91
2009	116.74	127.79	107.80	100.54	109.65	113.33	107.64	104.64	118.27
2010	104.28	110.06	111.31	128.33	124.38	126.04	122.07	122.27	117.90
2011	128.70	108.12	114.00	117.87	113.32	111.53	116.30	114.67	114.25
2012	112.25	121.34	106.61	106.64	105.40	113.14	113.18	110.16	111.50
2013	110.85	102.24	111.83	108.35	102.04	107.16	112.10	108.76	111.64
2014	100.08	123.12	104.96	106.64	102.41	111.60	122.37	105.44	122.59
2015	98.74	117.08	110.07	99.18	106.89	106.83	103.20	109.27	111.93
2016	105.54	107.15	113.95	90.06	106.29	105.93	98.50	109.48	111.48
2017	103.26	113.40	106.08	119.04	110.95	112.57	113.68	112.69	112.06
2018	103.20	108.62	106.40	105.97	104.78	106.08	107.64	106.94	108.09
2019	102.73	108.49	106.82	105.29	106.66	108.86	106.91	108.88	110.45

Note: this paper takes 2006 as the base period and indexes the data from 2006 to 2019.

Table 2. Processed data for the added values of major land-based industries in three economic circles.

Year	Primary Sector			Secondary Sector			Service Sector		
	North	East	South	North	East	South	North	East	South
2006	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2007	119.92	112.89	113.10	117.95	117.29	121.46	118.24	123.28	122.47
2008	116.08	112.20	117.98	123.08	115.02	113.66	119.75	119.31	116.91
2009	106.97	104.74	101.01	108.21	104.68	106.13	115.85	115.67	110.84
2010	114.79	113.90	115.21	115.83	117.79	120.97	119.55	119.76	114.80
2011	111.16	120.25	119.80	118.13	115.06	118.85	121.41	119.00	117.61
2012	109.01	107.86	107.63	108.23	105.22	106.15	114.70	111.56	111.27
2013	104.96	102.77	103.99	106.07	105.74	106.34	115.26	115.77	115.85
2014	104.19	100.85	106.94	103.35	106.22	108.42	107.31	111.35	105.90
2015	102.61	107.10	105.70	98.03	102.66	104.10	110.31	111.30	111.18
2016	98.22	103.76	110.34	97.15	107.49	107.57	106.81	113.80	113.73
2017	92.78	98.99	98.62	104.47	109.34	105.87	109.54	111.54	114.95
2018	104.50	102.18	105.74	82.81	110.80	110.00	97.57	112.22	115.75
2019	104.89	104.42	111.67	103.86	104.29	106.34	109.21	109.01	109.34

Note: this paper takes 2006 as the base period and indexes the data from 2006 to 2019.

3. Structural Feature Analysis

3.1. Continental Economic Industrial Structure

Longitudinal comparisons and the analyses of the added values of the continental industries in the three economic circles over time revealed that the Northern Marine Economic Circle (Figure 1) played a leading role in the continental secondary sector, whereas the primary sector was always in a low state of development. From 2006 to 2015, this circle presented a primary industrial pattern. In 2016, the continental service sector of the economy gradually surpassed the secondary sector, and an advanced developmental trend gradually emerged. In the Eastern Marine Economic Circle (Figure 2), the secondary and service sectors on land displayed clear advantages when compared to the primary sector. From 2006 to 2012, the industrial structure maintained a primary mode of development ("2-3-1"), and in 2013, the pattern of industrial development was upgraded to an advanced structure ("3-2-1"). The added value of the second and third continental sectors of the Southern Marine Economic Circle (Figure 3) continued to increase. From 2006 to 2014, the continental industrial structure of this circle was at an intermediate stage of development. Not until 2015 did the third continental industry rise further, finally realizing an advanced

industrial structure ("3-2-1"), and the gap between the added value of the second and third sectors gradually increased.

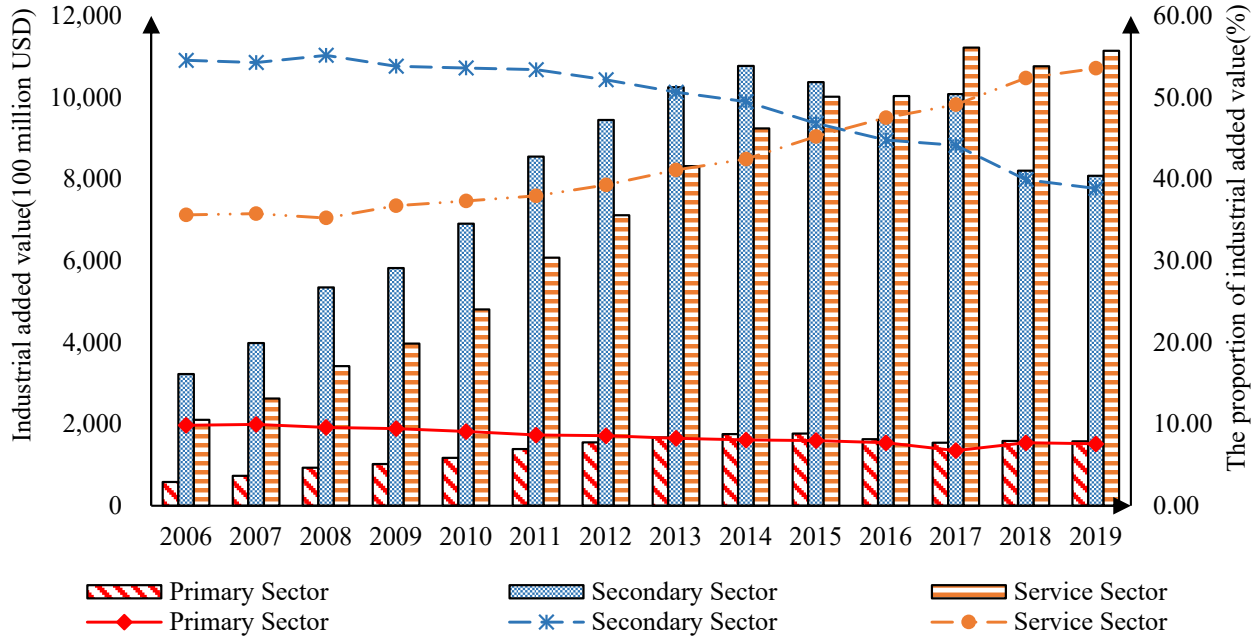


Figure 1. Industrial added values of continental three sectors in the Northern Marine Economic Circle of China (2006–2019).

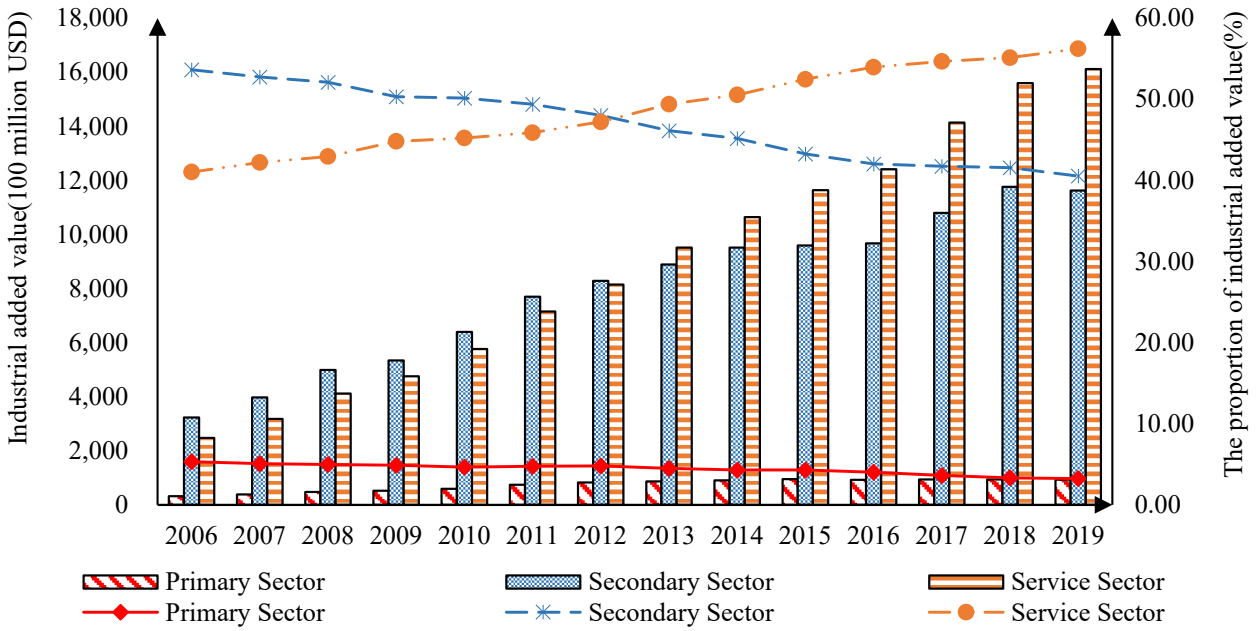


Figure 2. Industrial added values of continental three sectors in the Eastern Marine Economic Circle of China (2006–2019).

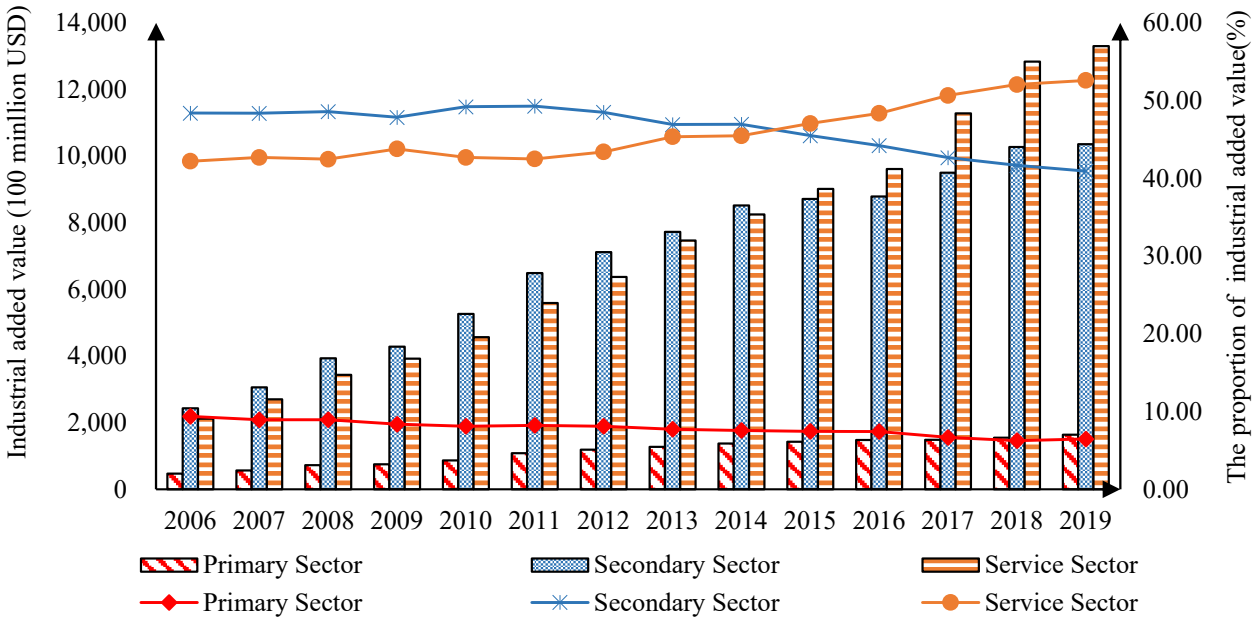


Figure 3. Industrial added values of continental three sectors in the Southern Marine Economic Circle of China (2006–2019).

3.2. Marine Economic Industrial Structure

The added values of the three marine industries in the Northern Marine Economic Circle show increasing trends to different degrees (Figure 4). Among them, the marine primary sector exhibited the smallest growth, and the added value of the marine service industry presented a positive linear trend in development. From 2006 to 2013, the marine secondary sector dominated, such that the marine industrial structure presented a primary stage of development ("2-3-1"). Since 2014, the added value of the marine service sector has continued to rise, widening the gap with the secondary sector, and an advanced ("3-2-1") structure has gradually emerged. The added values of the secondary and service sectors in the eastern and southern economic circles (Figures 5 and 6) were much higher than those of their primary sectors, and the industrial structure has evolved to an advanced ("3-2-1") and stable stage of industrial development.

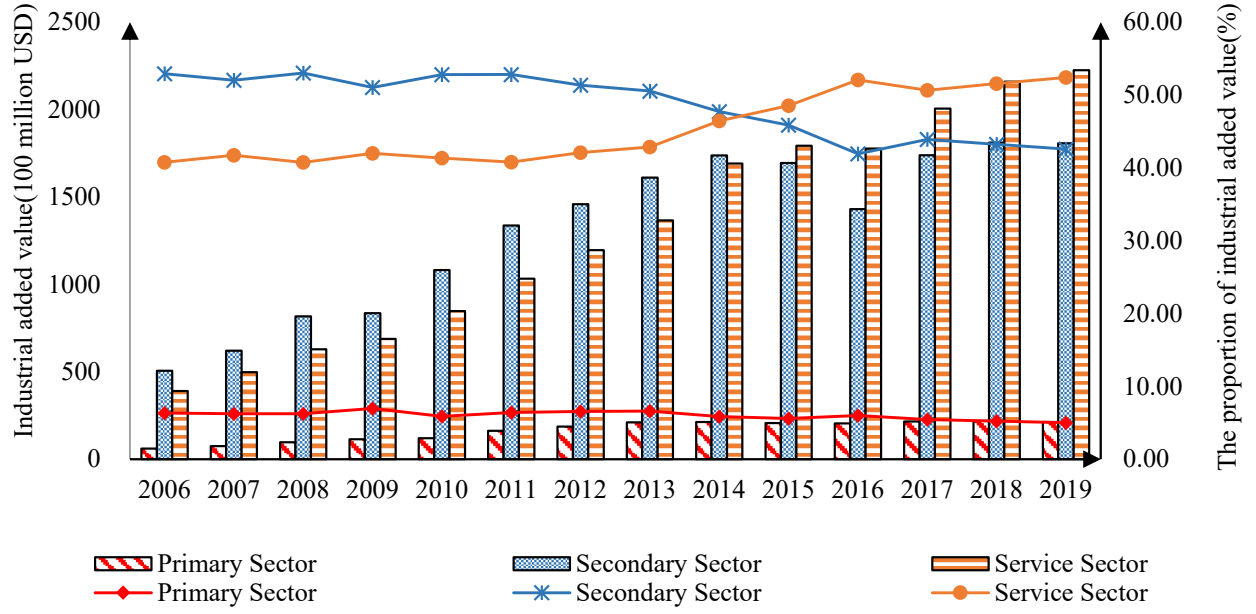


Figure 4. Industrial added values of three marine sectors in the Northern Marine Economic Circle of China (2006–2019).

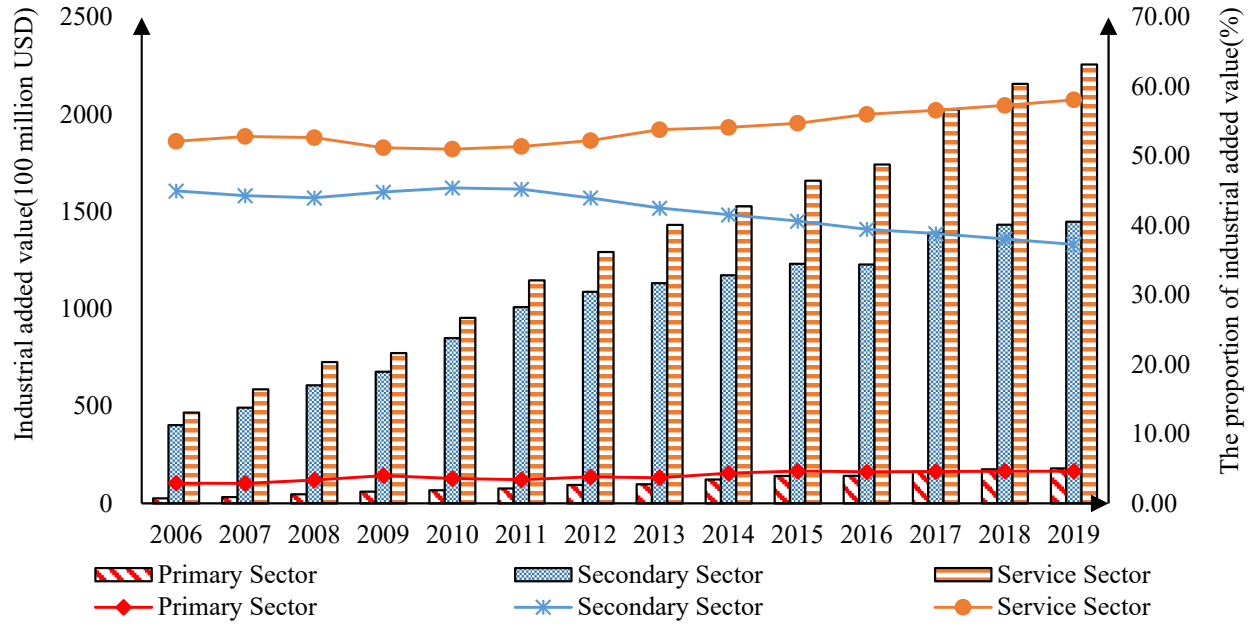


Figure 5. Industrial added values of three marine sectors in the Eastern Marine Economic Circle of China (2006–2019).

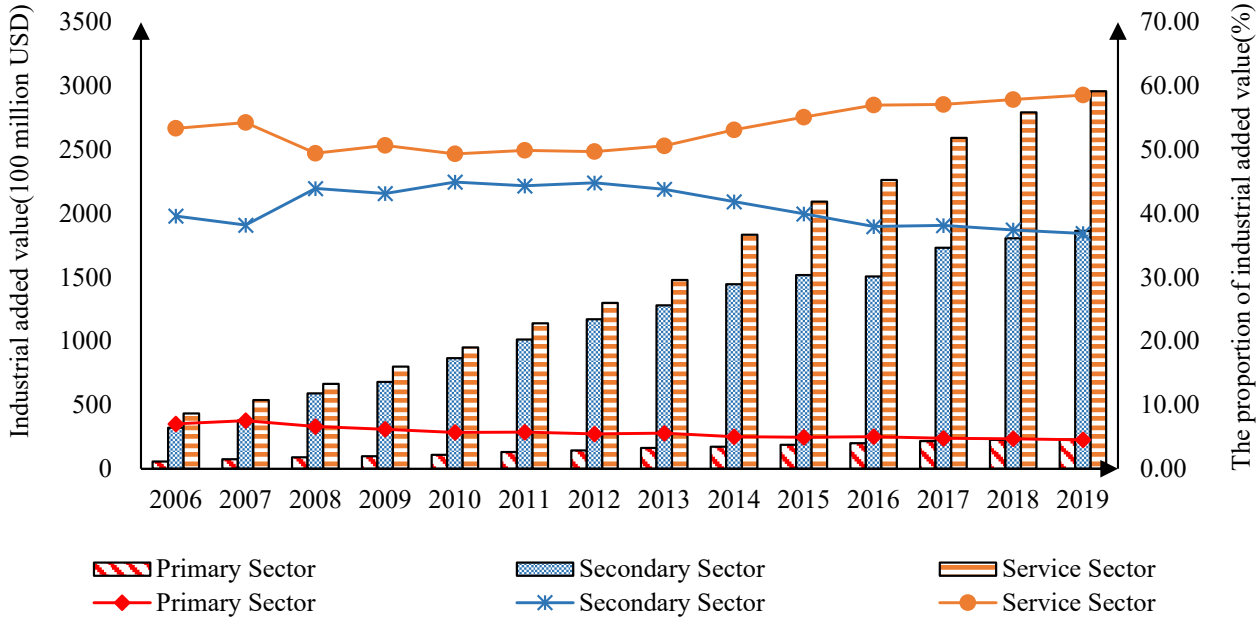


Figure 6. Industrial added values of three marine sectors in the Southern Marine Economic Circle of China (2006–2019).

3.3. Analysis of Linkage Development

Before 2014, the marine secondary sector in the Northern Marine Economic Circle accounted for a high proportion, and its Hoffman coefficient [47] was much larger than the national marine Hoffman coefficient. The marine shipbuilding industry, chemical industry, salt industry, oil, and gas industry were relatively advanced in development; the seawater utilization industry and marine biological medicine industry were also well developed. The low proportion of the marine service industry was mainly due to its low level of scientific research and the lower development of coastal tourism and marine transportation relative to the Chinese national average. Under the policy of the National 13th Five-Year Plan, and with the establishment of coastal provinces and cities in the marine economic demonstration zone and increased investment in marine science and technology, the service sector in the Northern Marine Economic Circle has developed rapidly. The development

of the oil, gas, and ship industries requires advanced technologies and equipment, which provide new opportunities for developing the secondary manufacturing industry on land. Marine mining, chemical, and other industries also need the support of continental mining and metallurgical technologies. The transportation of offshore oil, gas, seawater, and marine energy resources can alleviate the crisis of increasingly depleted terrestrial resources, reduce the production costs of enterprises, and promote the development of relevant continental industries with technological progress, such as in seawater utilization. Therefore, developing the land area of the Northern Marine Economic Circle is essentially synchronized with marine industrial development.

From 2006 to 2012, the continental industrial structure of the Eastern Marine Economic Circle presented a primary ("2-3-1") mode of development. With the rapidly developing service sector, a stable, advanced ("3-2-1") mode developed from 2013 to 2019. Moreover, the marine industrial structure was always advanced, and the overall layout was reasonable. The industrial structure in this economic circle was upgraded and transformed in 2013. The economy of Shanghai, which is dominated by the wholesale/retail, industrial, and financial sectors, transformed the service sector within approximately 20 years. The proportions of these three industries grew from 4:65:31 in 1990 to 0.3:27.0:72.7 in 2014. To date, Shanghai has formed an industrial structure with a high-end service industry dominated by the financial and information industries. However, developing Zhejiang and Jiangsu is still dominated by traditional service industries, with industry as its main support. Shanghai and Zhejiang exhibit advanced ("3-2-1") marine industrial structures, and their coastal tourism and marine transportation industries are highly developed. The mode of industrial structure development for Jiangsu Province is primary ("2-3-1"), mainly due to the high contributions of marine engineering, electric power, shipping, and other industries. Overall, the marine industrial structure in the Eastern Marine Economic Circle is better than that on land, and the marine economy plays a stronger role in feeding economic growth.

The land-sea industrial structure of the Southern Marine Economic Circle is like that of the Eastern Marine Economic Circle. From 2006 to 2014, the structure presented a primary ("2-3-1") developmental pattern that gradually became advanced ("3-2-1") between 2015 and 2019. The marine industrial structure is advanced, and the overall layout is relatively reasonable, allowing for the synchronous development of the industrial structure. The Southern Marine Economic Circle has been in an advanced stage of industrial evolution ("3-2-1") for many years. Aided by the global economic transfer of industry in the 1980s, the Southern Marine Economic Circle formed an industrial structure dominated by manufacturing electronic and communications equipment and by the heavy chemical industry; however, with China's accession to the World Trade Organization, the service sector of the high and new information technology industry and the modern service industry have become the pillars of this region. In 2019, the combined value added of the four marine industries, which include marine fishery, coastal tourism, marine oil and gas industry, marine electricity, and seawater utilization industry, contributed as much as 85% to its major marine industries in this economic circle.

4. Results

4.1. Internal and External Linkage Analysis

The internal and external linkage between land and sea industrial structure has two aspects in this paper. On the one hand, the internal linkage refers to the relationship between the primary industry, the secondary industry, and the tertiary industry within the land industrial system or the marine industrial system. On the other hand, the external linkage means that the land industry is the external environment of the marine industry system, and, similarly, the marine industry is the external environment of the land industry system.

4.1.1. Calculating Simultaneous Correlations

The primary, secondary, and service sectors of the three economic circles were taken as the original sequences, and the gray correlation degrees based on the convexity of the

three industries on land were measured (Table 3). Table 3 shows that the highest contemporaneous correlations of the Northern Marine Economic Circle were seen between the primary marine and primary continental sectors, secondary marine sector and continental service sector, and the marine service sector and secondary continental sector.

Table 3. Gray correlations among three land-sea industries in the Northern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.7426	0.7288	0.6942	0.6277	0.7672	0.7254	0.6779	0.7825	0.6764

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

From Table 4, it can be concluded that the primary and secondary marine sectors in the Eastern Marine Economic Circle are strongly correlated with the marine service sector. Furthermore, the marine service sector was strongly correlated with the primary continental sector in the same period. A close correlation was observed between the primary marine sector and the continental service sector in the Southern Marine Economic Circle, and between the marine secondary and service sectors and the secondary continental sectors in the same period (Table 5).

Table 4. Gray correlations among three land-sea industries in the Eastern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.6679	0.6539	0.6800	0.6179	0.6059	0.6654	0.7213	0.6579	0.6757

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

Table 5. Gray correlations among three land-sea industries in the Southern Marine Economic Circle.

γ_{11}	γ_{21}	γ_{31}	γ_{12}	γ_{22}	γ_{32}	γ_{13}	γ_{23}	γ_{33}
0.6146	0.6663	0.6262	0.7043	0.6885	0.6310	0.7407	0.6687	0.6066

Note: γ_{ij} is the degree of gray correlation based on the convexity between the marine i and continental j industries in the same period. The values of i and j correspond to: 1 = primary sector; 2 = secondary sector; 3 = service sector.

4.1.2. Calculating Gray Time Differences

Northern Marine Economic Circle. To obtain the highest correlation in the same period, the Northern Marine Economic Circle was taken as the reference sequence three times in succession, and the gray correlations based on convexity were analyzed between the Northern Marine Economic Circle and the continental primary and secondary sector sequences when the maximum time difference was $k = 3$. According to the results in Table 6, $\max(\beta_{11}) = 0.7426$, $\max(\beta_{23}) = 0.7825$, both of which are $k = 0$, indicating that the interactions between the primary, secondary, and service industries in this economic circle were relatively balanced, and there was no evident driving effect. When $k = -1$, $\max(\beta_{32}) = 0.7780$, indicating that the marine service sector in the Northern Marine Economic Circle plays a more significant role in supporting the secondary continental sector.

Table 6. Gray time difference correlations in the Northern Marine Economic Circle ($K = 3$).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{11}	0.6422	0.5988	0.6023	0.7426	0.6280	0.5543	0.6154
β_{23}	0.6418	0.6024	0.5844	0.7825	0.5675	0.5699	0.7681
β_{32}	0.6101	0.6820	0.7780	0.7254	0.7099	0.6805	0.5968

Note: β_{ij} represents the gray time difference between marine industry i and continental industry j, where i,j = 1,2,3 . . . , etc.

Eastern Marine Economic Circle. To obtain the highest correlation in the same period, we analyzed the correlations in gray time differences between the three marine industries

in the Eastern Marine Economic Circle and the sequences of the continental secondary and service sectors, when k = 3. It can be observed from Table 7 that max(β_{13}) = 0.7213 and max(β_{23}) = 0.6579 when k = 0, indicating that there were equilibrium relationships between the primary marine sector and continental service sector, and between the secondary marine sector and continental service sector of the Eastern Marine Economic Circle. When K = 1, max(β_{31}) = 0.7499, indicating that the marine service sector in this economic circle has a stronger driving effect on primary production than its reverse effect.

Table 7. Gray time difference correlations in the Eastern Marine Economic Circle (K = 3).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{13}	0.6325	0.5500	0.6221	0.7213	0.5787	0.5967	0.5521
β_{23}	0.5976	0.6362	0.6536	0.6579	0.6203	0.6223	0.6264
β_{31}	0.5862	0.5663	0.6262	0.6800	0.7499	0.6687	0.6104

Southern Marine Economic Circle. To obtain the highest correlation in the same period, we analyzed the gray time difference correlations between the three marine industries and the continental secondary and service sectors in the Southern Marine Economic Circle. As shown in Table 8, max(β_{13}) = 0.7407 when k = 0, indicating that the interaction between the primary marine sector and continental service sector in this economic circle is relatively balanced, and there is no significant driving effect. When k = −2, max(β_{22}) = 0.7542, indicating that the secondary continental sector of the Southern Marine Economic Circle has a more significant driving effect on the marine secondary sector. When k = −1, max(β_{32}) = 0.7675, indicating that the supporting and driving effects of secondary production on the marine service sector were stronger than its reverse effect.

Table 8. Gray time difference correlations in the Southern Marine Economic Circle (K = 3).

	$k = -3$	$k = -2$	$k = -1$	$k = 0$	$k = 1$	$k = 2$	$k = 3$
β_{13}	0.5751	0.6049	0.6542	0.7407	0.6610	0.7379	0.6782
β_{22}	0.7356	0.7542	0.7452	0.6885	0.7257	0.6583	0.6489
β_{32}	0.6489	0.6198	0.7675	0.6310	0.6606	0.7070	0.5977

4.1.3. Model Results

Although the land-sea industrial structure of the Northern Marine Economic Circle has transformed into an advanced ("3-2-1") economic system, the leading advantages of the continental and marine tertiary sectors have not been given full play, due to the short formation time and the instability of the "3-2-1" structure of the marine industry. Based on our analysis of the time difference correlations of the three land-sea industrial structures in this economic circle, only the tertiary marine sector has played a major driving role in the development of the secondary continental sector. With the realization of a "3-2-1" advanced industrial structure, the ability of the land-sea economy to drive reversals in the system was weakened. The rate of development of the marine economy in this economic circle still needs to be increased to make use of the available natural resources, steadily develop the primary continental and marine sectors, accelerate the development of their secondary and tertiary sectors via gradient transfer between regions, and to stabilize the "3-2-1" industrial structure.

In the Eastern Marine Economic Circle, there are strong correlations between the primary and secondary marine industries and the tertiary continental industry, as well as between the tertiary marine industry and the primary continental industry. The continental and marine tertiary industries also play an increasingly important role. As a financial center, with the establishment of the Lingang New Area and the Shanghai Pilot Free Trade Zone, Shanghai has witnessed the coordinated development of strategic services, such as financial and computer services and storage and high-end manufacturing industries, including integrated circuits and 5G chips. Jiangsu Province, with Nanjing as its capital,

is a traditional industrial base with comparative advantages in its smart power grid, information technology service industry, and high-end equipment manufacturing industry. Jiangsu has many "double first-class" universities with strong research and development capabilities and strengths, and it has been relatively easy to promote the high-quality development of continental and marine economies through scientific and technological innovation. Zhejiang Province, with Hangzhou as its capital, heavily relies on Alibaba and the "Three Reforms and One Demolition" campaign to drive lifestyle improvements through technological innovation. The continental service sector has tremendous potential for development. The prosperity index of the Port of Ningbo–Zhoushan has been rising for years, as the port infrastructure has continuously improved and the marine transportation industry has developed. As the economic belt with the most developed continental economy and the highest degree of urban agglomeration in China, the Eastern Marine Economic Circle needs to coordinate with countries across the "Belt and Road" to allocate regional resources, lead the development of marine and related industries with free trade and demonstration zones, and demonstrate with its experience for the high-quality development of national land-sea economies. According to our analyses of the time difference correlations between continental and marine industries in the Eastern Marine Economic Circle, the marine service sector strongly drives and promotes the primary continental sector. This economic circle has formed an advanced ("3-2-1") industrial structure, especially regarding marine economic development, which has strong economic feedback.

The Southern Marine Economic Circle displays the greatest correlation among the secondary and tertiary marine sectors and the secondary continental sector, primary marine sector, and continental service sector. The continental processing and manufacturing industries correspond to the marine chemical, oil, and gas industries. Furthermore, the secondary marine industry is an expansion and extension of the second continental industry, and their linkage is clear. From the Pearl River Delta economic zone to the Guangdong–Hong Kong–Macao Greater Bay Area, the regional cooperation and exchange in the Southern Marine Economic Circle has changed from a simple manufacturing industry to include financial, real estate, and other tertiary industries, driving the rapid and high-quality development of coastal tourism, marine transportation, and transportation in this economic circle. Although the land-sea industrial structure of the Southern Marine Economic Circle presents an advanced "3-2-1" pattern, the dominance of the tertiary land-sea industry is not obvious, and the interregional differences within the economic circle are large. According to our analysis of the time difference correlations between continental and marine industries in this economic circle, marine reversal is weak, and the support of the continental economy of the marine economy is prominent.

4.2. Analyses of Coevolution

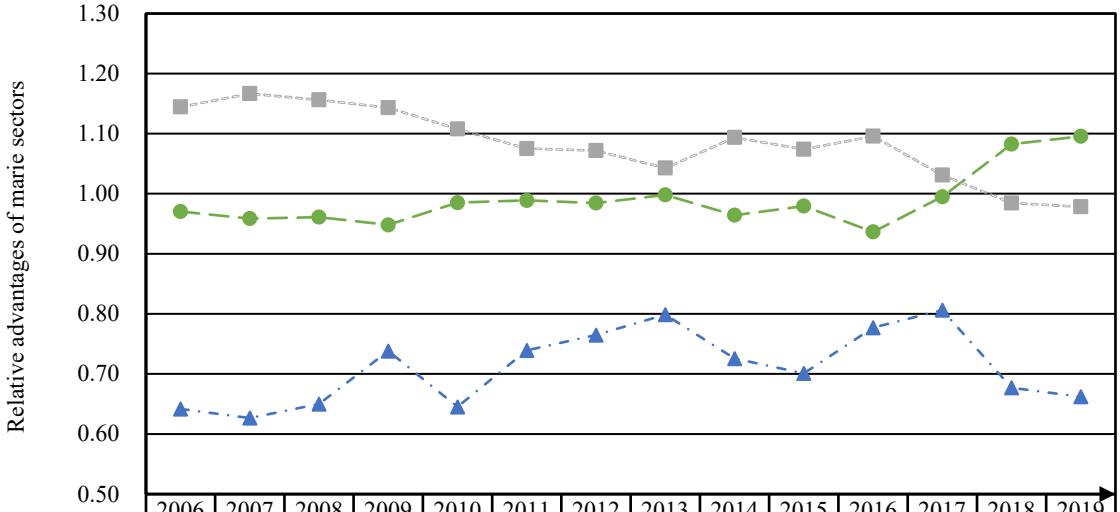
Based on the deviations and coevolution coefficients between industrial structures, we analyzed the degree of coevolution between continental and marine industrial structures in three coastal economic zones from 2006 to 2019.

4.2.1. Measuring the Degree of Relative Advantage

Using the Formula (3), the relative advantages of land-sea industries in the three coastal economic zones were obtained (Figures 7–9).

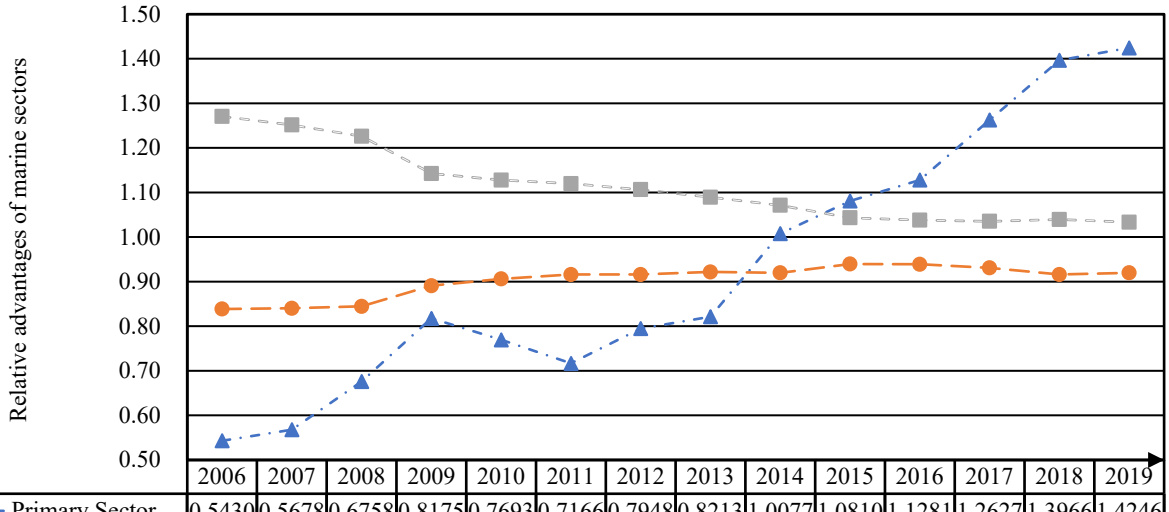
As shown in Figure 7, the primary continental sector in the Northern Marine Economic Circle has a comparative advantage over the other sectors. This sector formed early, and its mode of development has been stable. However, because of the pollution and the damage caused by marine disasters, the advantages of the primary marine sector have been weakened, and the relative advantages of the secondary and tertiary marine industries are nearly equal. In recent years, the advantages of the secondary continental and marine sectors have gradually exceeded those of their tertiary industries. Comparatively, marine services have more advantages; however, the effects of the continental high-tech

industry were weaker than those of the marine transportation industry and feedback of coastal tourism.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.641	0.626	0.649	0.738	0.645	0.739	0.764	0.798	0.725	0.701	0.777	0.806	0.677	0.662
Secondary Sector	0.970	0.958	0.961	0.948	0.985	0.988	0.984	0.998	0.964	0.979	0.936	0.995	1.082	1.095
Service Sector	1.144	1.166	1.156	1.143	1.107	1.075	1.071	1.042	1.093	1.074	1.095	1.031	0.984	0.978

Figure 7. Relative advantages of three land-sea industries in the Northern Marine Economic Circle (2006–2019).

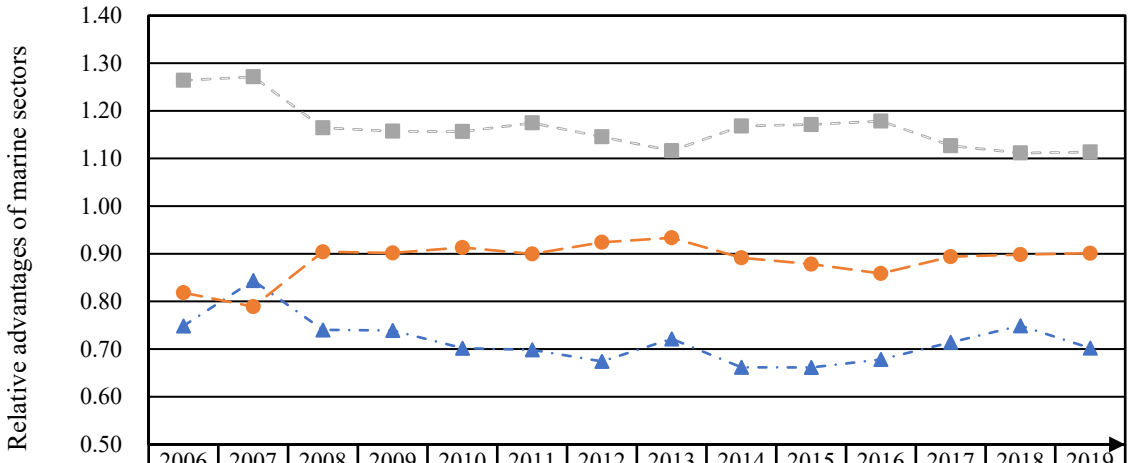


	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.5430	0.5678	0.6758	0.8175	0.7693	0.7166	0.7948	0.8213	1.0077	1.0810	1.1281	1.2627	1.3966	1.4246
Secondary Sector	0.8385	0.8402	0.8445	0.8907	0.9061	0.9159	0.9159	0.9217	0.9197	0.9395	0.9388	0.9309	0.9159	0.9197
Service Sector	1.2707	1.2516	1.2262	1.1426	1.1279	1.1199	1.1064	1.0894	1.0712	1.0432	1.0381	1.0354	1.0395	1.0334

Figure 8. Relative advantages of three land-sea industries in the Eastern Marine Economic Circle (2006–2019).

The relative advantages of the primary continental and marine sectors in the Eastern Marine Economic Circle are relatively weak (Figure 8), though the development of the primary continental sector is stronger. However, the advantages of the primary continental sector have gradually decreased, and the primary marine sector has varied and risen overall. In 2014, the advantages of the primary continental and marine sectors surpassed those of their secondary sectors because of the long-term balanced development of the continental and marine industrial structures. Compared to the secondary continental sector, that of the sea showed a stable upward trend from 2006 to 2010, and has remained at 0.92 since 2011. The development of the secondary continental industry began earlier in this region, which has accumulated more advanced technologies and greater investment

experience, among other aspects, and therefore, it has a strong advantage when compared to other sectors. With the continuous diffusion of advantageous resources from continental industry, the advantages of the secondary marine industry have gradually improved.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Primary Sector	0.748	0.843	0.740	0.739	0.702	0.698	0.674	0.721	0.661	0.661	0.678	0.714	0.748	0.702
Secondary Sector	0.818	0.789	0.904	0.901	0.913	0.899	0.924	0.933	0.891	0.878	0.858	0.894	0.898	0.901
Service Sector	1.264	1.271	1.164	1.157	1.156	1.174	1.145	1.116	1.168	1.171	1.178	1.126	1.111	1.113

Figure 9. Relative advantages of three land-sea industries in the Southern Marine Economic Circle (2006–2019).

Jiangsu and Zhejiang are large provinces supported by the manufacturing industry, and the linkage between the land and sea is relatively perfect in the secondary sector of the economy, where technology and equipment are closely linked. Comparing the tertiary continental and marine sectors in the Eastern Marine Economic Circle, developing the continental sector has the advantage. In 2013, the continental industrial structure of the region shifted toward tertiary industries. With the rapid development of the secondary continental sector, the spillover of investments, technologies, human capital, and other resources have become a strong driving force for developing the secondary marine industry. Emerging marine industries have broad market prospects and are attractive to capital and talent, and have therefore developed rapidly. The gradual maturation of the marine industry has also promoted the evolution of continental industrial structures. This study infers that the marine service sector has a stronger feedback effect; thus, by 2015, the relative advantages of the primary continental and marine sectors exceeded those of their tertiary sectors.

As shown in Figure 9, the development of primary industries in the Southern Marine Economic Circle is dominant and that of the primary marine sector has gradually slowed, largely due to the frequent occurrence of natural disasters, such as storm surges, in this region. The development of the secondary continental sector is stronger than its marine equivalent. The relative advantage of this industry fluctuated slightly from 2008 to 2019; however, it remained stable overall, and the development trend is similar to that of the Eastern Marine Economic Circle. The technological diffusion brought about by the development of the manufacturing industry in the secondary continental sector is evident. Compared with the continental economy, the tertiary marine sector in the Southern Marine Economic Circle has been strongly developed, similar to that in the Eastern Marine Economic Circle.

Comprehensive analyses of the relative advantages of the three studied marine economic sectors are shown in Figures 7–9. The advantages of continental and marine industries in the three regions display the same characteristics, wherein the tertiary continental and marine industries have the greatest advantages overall, followed by the secondary, and lastly, the primary industries. The relative advantages of the tertiary continental and marine industries were all >1 every year, indicating that the tertiary industry has the great-

est absolute advantage. The relative dominance of the continental, marine, and secondary sectors of the economy in each year was ~1. In recent years, because of the development of the secondary marine industry, its dominance has been >1, but with fluctuation around 1, indicating that the secondary marine and continental sectors in the three regions are roughly equal, whereas the secondary continental sector has a slight advantage. The comparative advantages of the primary continental and marine industries were >0.6, except in individual years, which indicates that primary continental industries have advantages over their marine counterparts. Nevertheless, different trends were observed among the three regions, with a variable rising trend in the Northern Marine Economic Circle, a rapid upward trend in the Eastern Marine Economic Circle, and a variable downward trend in the Southern Marine Economic Circle. The dominance of the Eastern Marine Economic Circle exceeded a value of 1 for the first time in 2014 (=1.008) and an increase of 23.17% from 2013, indicating the strong development of the primary marine sector in this region.

4.2.2. Measuring the Degree of Deviation

The degrees of deviation between continental and marine industrial structures in the three coastal economic zones were obtained using Equation (4) and are shown in Figure 10.

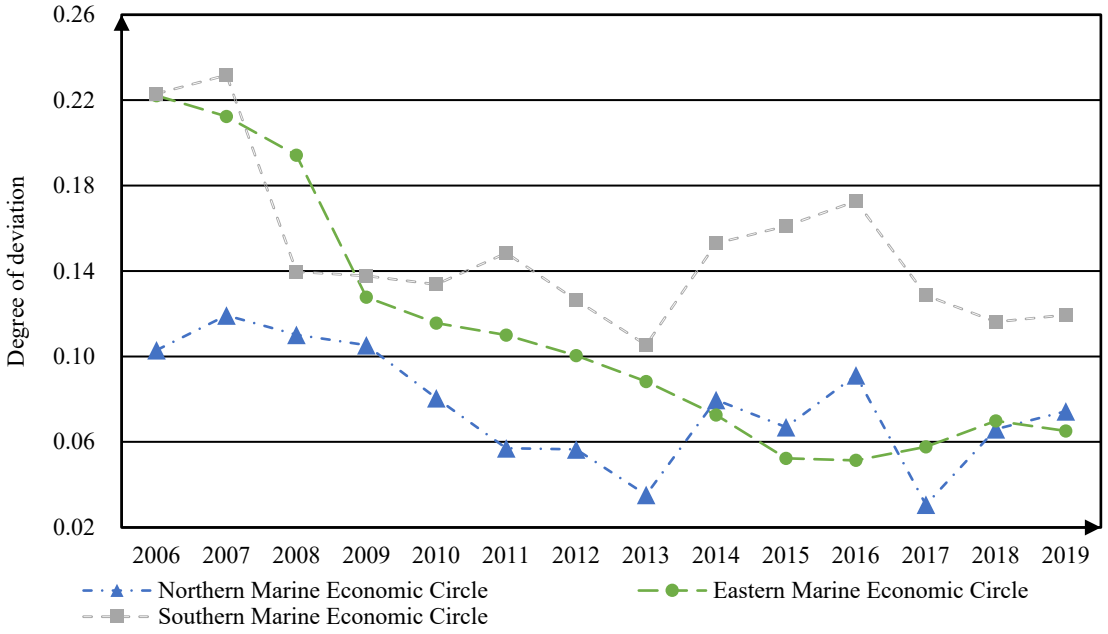


Figure 10. Degree of deviation among the industrial structures of three coastal economic circles (2006–2019).

As shown in Figure 10, an overall downward trend was observed in the degree of deviation between the structures of continental and marine industries in the three coastal economic zones; this indicates that the development of linkages and convergence in their industrial structures have strengthened over time, and the unified industrial structure is developing to a higher level. In addition, there was a consistent and substantial decline in 2008, and the effects of policies were evident. Before 2014, the deviation between the industrial structures in the Northern Marine Economic Circle was the lowest among the three regions, and the continental and marine industrial structures were the most closely linked.

Since 2009, the Eastern Marine Economic Circle has exhibited a rapid and nearly linear decline in industrial structure deviation. In 2013, the simultaneous development of continental and three marine industrial structures was achieved and the overall development of the secondary sector of the economy in the Eastern Maritime Economic Circle is relatively stable. The gap in the relative advantages of the industries is relatively small, which has resulted in a reduction in the degree of deviation between industries. Between 2014 and

2017, this region had the lowest degree of deviation in industrial structures among the three economic circles.

The absolute degree of deviation in the industrial structures of the Southern Maine Economic Circle region after 2009 was higher than that in the Eastern Marine Economic Circle. This was due to the slow speed at which this region's continental industrial structure was transformed, upgraded, and synchronized with the development of the marine industrial structure (in 2015). In addition, the tertiary continental sector developed rapidly via accumulation, resulting in a high degree of deviation between continental and marine industrial structures. In recent years, with the Chinese government promoting economic and industrial coordinated development, the gap in the industrial structures of the three marine economic zones has gradually narrowed.

4.2.3. Measuring the Coefficient of Coevolution

Accordingly, the coefficients of coevolution between continental and marine industrial structures in the three coastal economic zones were obtained (Figure 11).

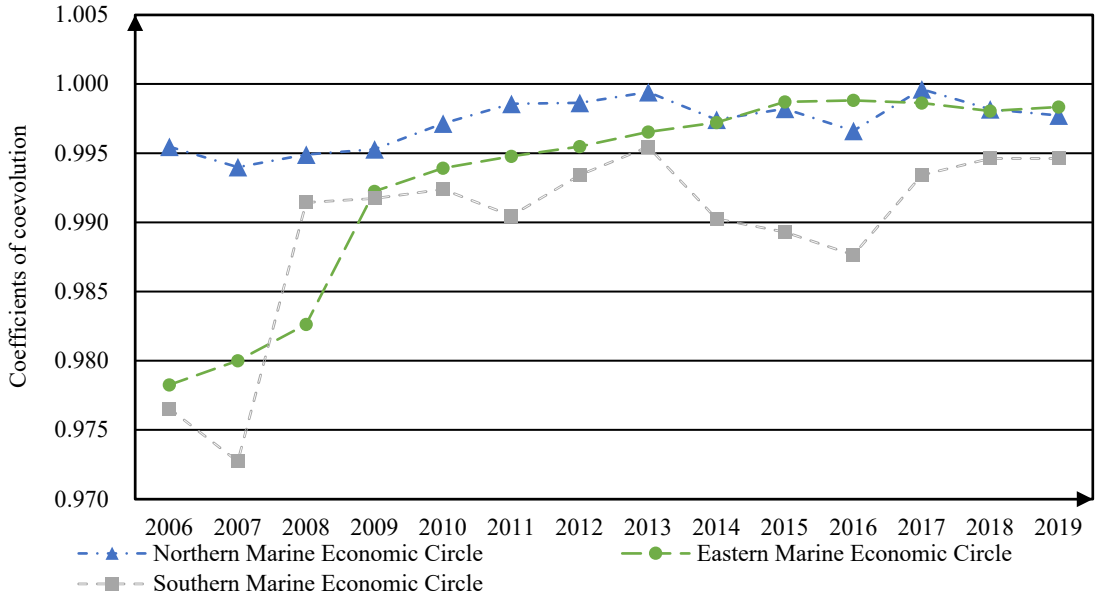


Figure 11. Coefficients of coevolution among the industrial structures in the three coastal economic zones (2006–2019).

The coordination (coevolution) coefficient of industrial structures in the Northern Marine Economic Circle revealed a high level of coordination, and the trend in linkage development from 2006 to 2019 was relatively stable. The land-sea industrial structure maintained a high level of consistency, and the layout changed from primary ("2-3-1") to advanced ("3-2-1"). After the financial crisis in 2008, both the eastern and the southern marine economic circles seized the opportunity to achieve a high degree of unity in the development of their industrial structures and an advanced ("3-2-1") layout was realized after the recovery and adjustment period. However, between 2014 and 2016, the degree of deviation in the industrial structures of the Southern Marine Economic Circle was relatively high, which made the coordination coefficients of these years change considerably and caused clear variability. With the stabilization of the deviations between industrial structures, the coordination coefficient of the land-sea industrial structure in this region gradually recovered and stabilized.

5. Conclusions

Based on the structural feature analysis of land and sea industry, statistical and gray systems methods were comprehensively applied to analyze the spatiotemporal differences in the linkages of land-sea economic and industrial structures in three coastal economic

zones. The development of linkages among three industrial structures in the three coastal economic zones of China from 2006 to 2019 was measured regarding the synchronization and lag in the development of the industrial structure itself, equilibrium and dislocation, the internal and external linkages of the industrial structure, and its coordinated evolution.

Synchronization and lag in the development of the industrial structure. The layout of the industrial structure of China's three coastal economic zones still requires improvement, and the level of development among regions differs markedly. In 2016 and 2014, the land-sea industrial structure of the Northern Marine Economic Circle changed from primary ("2-3-1") to advanced ("3-2-1"); however, the advantages of the tertiary sector were unclear. From 2006 to 2012, the continental industrial structure of the Eastern Marine Economic Circle presented a primary pattern ("2-3-1"), which gradually became advanced ("3-2-1") between 2013 and 2019. The marine industrial structure of this economic circle is in an advanced stage of development ("3-2-1"), and the overall layout is reasonable. From 2006 to 2014, the continental industrial structure of the Southern Marine Economic Circle exhibited an advanced pattern ("3-2-1"), which was transformed between 2015 and 2019. The marine industrial structure has maintained an advanced ("3-2-1") mode of development, and the overall layout is reasonable. Both the eastern and southern economic circles have been developing in dislocation for many years, while also having realized the synchronous development of continental and marine industrial structures.

Spatiotemporal differences in the internal and external linkages of China's land-sea industrial structure. Although the land-sea industrial structure of the Northern Marine Economic Circle has changed from the "2-3-1" type to the advanced "3-2-1" type, the secondary and tertiary marine industries in this economic circle were the most strongly correlated with the secondary and tertiary continental industries; however, the current level of economic development in this region has not yet given full play to the advantages provided by the tertiary continental and marine industries. While an advanced stage of synchronous development has been realized, the comparative advantages of the industrial structures are not outstanding, and the transformation and upgrade of the industrial structure and high-quality development of continental and marine industries should be improved.

The tertiary continental sector in the Eastern Marine Economic Circle has played an increasingly important role in the economic development of this region. Moreover, the primary and tertiary continental industries have had strong positive effects on the primary and tertiary marine industries. The Eastern Marine Economic Circle has formed an advanced ("3-2-1") industrial structure, especially regarding its marine economic development, which has a strong role in the developmental feedback of this economy and is suitable for use as a reference. Although the Southern Marine Economic Circle has achieved an advanced ("3-2-1") land-sea industrial structure, due to pronounced differences in regional development, the dominant advantage of the tertiary continental and marine sectors has not been given full play, and the role of the marine economy is weak.

Differences in the coevolution of industrial structures. The coordination (coevolution) coefficient of the industrial structure in the Northern Marine Economic Circle shows a high degree of coordination, and the development of economic and industrial linkages was stable from 2006 to 2019. The land-sea industrial structure has exhibited an advanced ("3-2-1") layout, but with substantial room for improvement. The Eastern Marine Economic Circle and the Southern Marine Economic Circle have both achieved a high degree of coordination in the development of their industrial structures, reaching an advanced ("3-2-1") model of industrial development. However, the Eastern Marine Economic Circle has a weak marine economy, and the development of the secondary and tertiary marine industries should be strengthened to promote the balanced development of the land-sea economy in this region.

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