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The Research on International Development Path of China's Marine Biopharmaceutical Industry

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Abstract: Under the backdrop of the Maritime Silk Road Initiative, the study on the international development of China's marine biopharmaceutical industry based on factor allocation is of great practical significance for industrial sustainability and building the industry into a leading international player in the global market. In this paper, we first identify the leading factors that influence the development of the marine biopharmaceutical industry, namely, resources, technologies, talents, investments and policies. Furthermore, the hierarchical structure model of these factors was established and analyzed using the analytic hierarchy process (AHP). The importance ranking of these constraints was identified, as follows: technologies > talents > resources > policies > investments. Then, based on the theory of comparative advantage and game theory, we analyzed the necessity of China's marine biopharmaceutical industry going global, that is, international cooperation may lay a solid foundation for the win-win outcome of this industry in countries along the Maritime Silk Road. According to the status quo of China's marine biopharmaceutical industry, based on these findings, an international factor–allocation cooperation path was designed, and the path chart of the international development of the marine biopharmaceutical industry was drawn. Finally, methods for the development of China's marine biopharmaceutical industry were proposed, which covers efforts to protect marine resources, promote R&D for core technologies, establish a strong talent pool, encourage more investments, provide policy support and promote worldwide cooperation. It is the first report to investigate the path of the sustainable exploitation of the marine biopharmaceutical industry from the perspective of factor allocation amidst the backdrop of the Maritime Silk Road Initiative.

Keywords: Maritime Silk Road Initiative; marine biopharmaceutical industry; industrial internationalization; industrial sustainability; factor allocation; AHP; theory of comparative advantage; game theory

1. Introduction

As early as the Qin and Han Dynasties, the Maritime Silk Road to a large extent made up for the limitations of the Continental Silk Road in a way that extended cultural exchanges to the sea. In 2013, under the new era backdrop, the 21st Century Maritime Silk Road Initiative was proposed, which was aimed to strengthen the economic, political and cultural exchanges between China and Western countries. As the hub of the Maritime Silk Road, Southeast Asia makes the Maritime Silk Road, which is coupled with the Continental Silk Road, a bridge for social, economic and cultural integration between the East and West, and beyond. Focused on strategic partnerships between China

and the countries from Association of Southeast Asian Nations (ASEAN), the 21st Century Maritime Silk Road Initiative promotes regional economic cooperation to strategically support the development of marine industries, particularly the marine biopharmaceutical industry. In this context, the marine biopharmaceutical industry has gradually become a key driver of the blue-economy, and its going global could promote the marine economic cooperation between China and countries along the Silk Road for the sustainable growth of the regional economy.

Among China's marine economic industries, the marine biopharmaceutical industry is the fastest-growing industry, which has a compound annual growth rate of nearly 30% in recent years. It has been estimated that the compound growth rate will be in the range of 25–30% over the next five years. In 2020, the marine biopharmaceutical industry output will go up to 16,574 billion dollars in China. However, the development of China's marine biopharmaceutical industry is still far backward from leading countries in the world. As the earliest and most developed country in the world for the marine biopharmaceutical industry, the United States, Japan and the European Union have achieved pioneering potential progress in marine biomedical research. They have included the development of marine bioresources as an important plan for building their own strategic emerging industries and safeguarding national health. The international marine biomedicine market has huge benefits of hundreds of billions of dollars, and the industry has emerged broad prospects. The research and development of marine medicine have become the key point of the structuring of the international pharmaceutical economy strategy. However, the marine biopharmaceutical industry in China has not formed an industrial cluster yet due to the following: (1) a small amount of marine bioresources with overfishing, dumping and spills in the ocean, and coastal ecosystem destruction [1]; (2) the slow development of medicine research; (3) the lack of compound talents; (4) the low conversion rate of scientific research outcomes; (5) the weak awareness of legal rights; (6) the inadequate protection of intellectual property rights; (7) the small scale of industrial development; (8) the low level of industrial development. Industrial enterprises are also confronted with some prominent problems, such as the small number of enterprises, small scale, low level, scattered layout, and lack of brand-name leading companies and brand-name products [2,3]. As a result, the development of the marine biopharmaceutical industry is slow, and the gap with leading countries in the world should not be ignored. Therefore, the research on the international development of the marine biopharmaceutical industry should be beneficial to enhance the industrial development level and promote the sustainable development of the industry by optimizing the allocation of resources and opening up the space for survival and development in the international market.

As early as the 1950s–1960s, the marine biopharmaceutical industry came into being in Europe. In the 1970s, based on studies on marine biotoxins conducted by chemical and physiological pharmacology laboratories, Southcott concluded that marine toxins may be a possible source of new drugs [4]. In the 1980s, Grant pointed out that many marine bioactive substances have been found, but only few were used to produce drugs [5]. Hence, abundant marine bioactive substances need to be further developed and clinically applied [5]. With the passage of time, more in-depth studies on marine biomedicines have been conducted, and scholars have found that marine organisms including invertebrates, algae and microorganisms tend to have bioactive natural products different from terrestrial organisms. These marine natural products, including terpenoids, alkaloids, steroids, polyketides, carbohydrates, polyphenols, polypeptides, proteins and essential fatty acids, have been proven to possess a variety of bioactivities, such as antitumor, antiviral, antibiotic, antioxidant, antithrombotic, anticoagulant, anti-inflammatory, antihypertensive, antidiabetic and other biological functions, and these could be widely applied to drug development [6–8]. For example, Chai pointed out that Marine invertebrates, such as oysters, mussels, clams, sea cucumbers and sea squirts, are sources of potent bioactive peptides [9]. In addition, antioxidant peptides have potential applications in food, pharmaceuticals and cosmetics [9]. Ruocco described the current advances in the use of marine polysaccharides (including chitin, chitosan, fucoidan, carrageenan and alginate) for nutraceutical, cosmeceutical and pharmacological applications [10]. In addition, at the beginning of the 21st century,

Molinski and Daisay pointed out that drug research on marine natural products ushers a wave of revival [11]. In 2012, Candida and other scholars believed that one of the most promising areas of marine drugs was cancer treatment [12]. As of 2016, the value of anti-cancer drugs developed from marine natural products has risen from $563 billion to $5.69 trillion [13]. Shin investigated the isolation and identification of microorganisms of sponges. All compounds were tested for anti-proliferative activity on human cancer cell lines and RANKL-induced osteoclast differentiation inhibitory effect [14]. However, many uncharted areas of marine natural products need to be developed through cooperation among biologists, organic chemists, and pharmaceutical and natural product chemists for greater breakthrough [15,16].

China's research on marine biomedicine began with the slogan, "to develop medicine out of the ocean", at the National Science and Technology Conference in 1978. After the First National Symposium on Marine Drugs held in Qingdao in 1979, China independently established a marine drug R&D base, and marine drug R&D began to become a unique emerging science major. Meanwhile, scholars also began their research, and further regarded marine drugs as a new type of drug that is significantly different from traditional terrestrial ones, and pointed out that the differences in ecological environment between land and sea led to the diversity of marine organisms that are completely different from terrestrial organisms [17]. In particular, these differences offer marine organisms with a specific potency, which brings hope to rare diseases [18]. Decades have seen great progress in China's marine biomedicine research. In the 1980s, China established a number of professional marine biomedicine R&D institutions. Thanks to these efforts, China produced fruitful results in relevant research [19]. Specifically, the first Chinese modern marine drug, propylene glycol alginate Sodium Sulfate (PSS), was invented in 1985. This not only greatly benefited society and the economy, but also initiated and promoted the development of marine drug research in China. By 2003, China has approved the production and clinical application of nearly 30 kinds of anti-tumor drugs, including 6-chondroitin sulfate, methyl sartortuoate, okadaic acid preparation and *Sargassum fusiforme* polysaccharide preparations [20]. Driven by the Chinese Academy of Sciences and other relevant institutions, industry development and the external environment have gradually been improved and continue to enjoy a strong momentum. In 2005, China granted 14 kinds of marine drugs with Chinese drug approval numbers, including more than 130 kinds of Chinese traditional patent medicines with marine biological substances [21]. As of June 2015, 725 traditional Chinese marine materia medica have been identified and documented in coastal waters, covering 1552 organisms and minerals [18]. In recent years, there have been abundant research breakthroughs in relevant marine drugs, such as synthesis and chromatography. The marine biopharmaceutical industry enjoys a new driving force and prosperous potential for future development. According to the National Marine Economic Statistics Bulletin, the added value of China's marine biopharmaceutical industry increased from 1.01 billion dollars in 2010 to 5.062 billion dollars in 2016. This industry has become a new key driver of China's marine economy, and even a strategic emerging industry that helps to achieve the modernization of China's blue economy in the 21st century.

The above scholars conducted studies mainly based on the development and utilization of marine biomedicine. Few scholars have studied this from the perspective of marine biopharmaceutical industry chain development (Han Limin) [22], industrial cluster (Huang Sheng et al.) [3] and the industrialization of scientific and technological achievements (Fu Xiumei) [23]. To date, no studies that investigated the going global of the marine biopharmaceutical industry from the perspective of factor allocation have been reported. Therefore, based on the above research, the present study investigates the topic from the perspective of factor allocation amidst the Maritime Silk Road Initiative. First, according to the development status of China's marine biopharmaceutical industry, the influential factors were identified, the hierarchical structure model was established, and the influence ranking of these factors with the analytic hierarchy process (AHP) was analyzed. Then, backed by the theory of comparative advantage and game theory, we put forward the necessity of factor allocation on the going global of China's marine biopharmaceutical industry. On this basis, the best factor allocation program

was designed. Finally, relevant suggestions were offered to provide references for decision-making in China's marine biopharmaceutical industry.

2. Identification of Factors that Influence the Marine Biopharmaceutical Industry

Factor allocation refers to the distribution of various factors among diverse economic entities in social and economic activities according to a reasonable program to achieve high socio-economic efficiency [24]. The marine biopharmaceutical industry is an emerging high-tech marine industry, and its development is not driven by a single factor, but by multiple factors combined. According to the above necessity analysis, the main influential factors could be identified as follows:

(1) Resources are the material basis for the development of the marine biopharmaceutical industry. Different from single resource-driven industries such as the steel and textile industry, the marine biopharmaceutical industry needs diverse types of marine bioresources. Marine bioresources are the main source for bioactive compounds in R&D, and the main raw materials for medicine production. The ideal marine medicinal bioresources renewable capacity, supply capacity and availability are regarded as the greatest material guarantee for sustainable development of the industry.

(2) Technologies refer to the methods, approaches, means, production techniques and instruments for the research and development of marine biopharmaceutical products. Technologies are the driving force of the marine biopharmaceutical industry. The essential characteristic of the marine biopharmaceutical industry determines technology as a very important element. A wealth of marine medicinal bioresources without advanced technology cannot achieve the rapid development of the industry, which is an inspiration we have learned from ASEAN countries. Resources are the foundation, while bioactive substance screening, drug R&D, clinical experiments, pilot production, scale production and practical application are closely correlated to technological innovation and maturity.

(3) Talents are the people who possess professional skills, technical proficiency and specific ability in marine biopharmaceutical field. Talents are the backbone of the marine biopharmaceutical industry. As one of its advanced factors, skilled talents play a crucial role in the development of the marine biopharmaceutical industry. The development of the marine biopharmaceutical industry depends heavily on technologies, while technological progress needs vast skilled talents, including professionals and management personnel equipped with basis knowledge, and versatile talents with command of skills and market. For example, in the aspect of the drug R&D call for R&D talents, drug production and business operation need management personnel, and its scientific application depends on advanced versatile talents. Merely high-quality versatile talents can effectively link all aspects of development, from raw materials collection, extraction, purification, processing and detection to marketing, in order to form a complete industrial chain.

(4) Investments are the guarantee of the marine biopharmaceutical industry. As a strategic emerging industry in the 21st century, the marine biopharmaceutical industry calls for support with a great deal of investments. Marine resource exploitation, talent training developed by research institutions, and infrastructure construction are all inseparable from these vast funds. For example, scientific and technological progress and talent training cannot be achieved overnight, and needs long-term funds for achievement.

(5) Policies are a necessity for the development of the marine biopharmaceutical industry. Policies formulated by the national government exert an overall macroeconomic control on the development of the marine biopharmaceutical industry. In order to enhance the international competitiveness and transform marine medicinal bioresources into practical economic advantages, reasonable and effective policies should be carried out, including policy orientation, implementation and regulation, in order guide the rational development and

utilization of marine medicinal bioresources, and upgrade the industrial structure of the marine medical industry, promoting the internationalization of the industry.

Therefore, the five elements of resources, technologies, talents, investments and policies are the key factors that influence the development of the marine biopharmaceutical industry.

3. Empirical Analysis

3.1. Construction of the Hierarchical Structure Model

Based on systematization, feasibility and conciseness, these relevant factors were divided into three layers: target layer (A), dimension layer (B), and index layer (C). Then, the hierarchical structure model of influential factors for the marine biopharmaceutical industry was established (Figure 1).

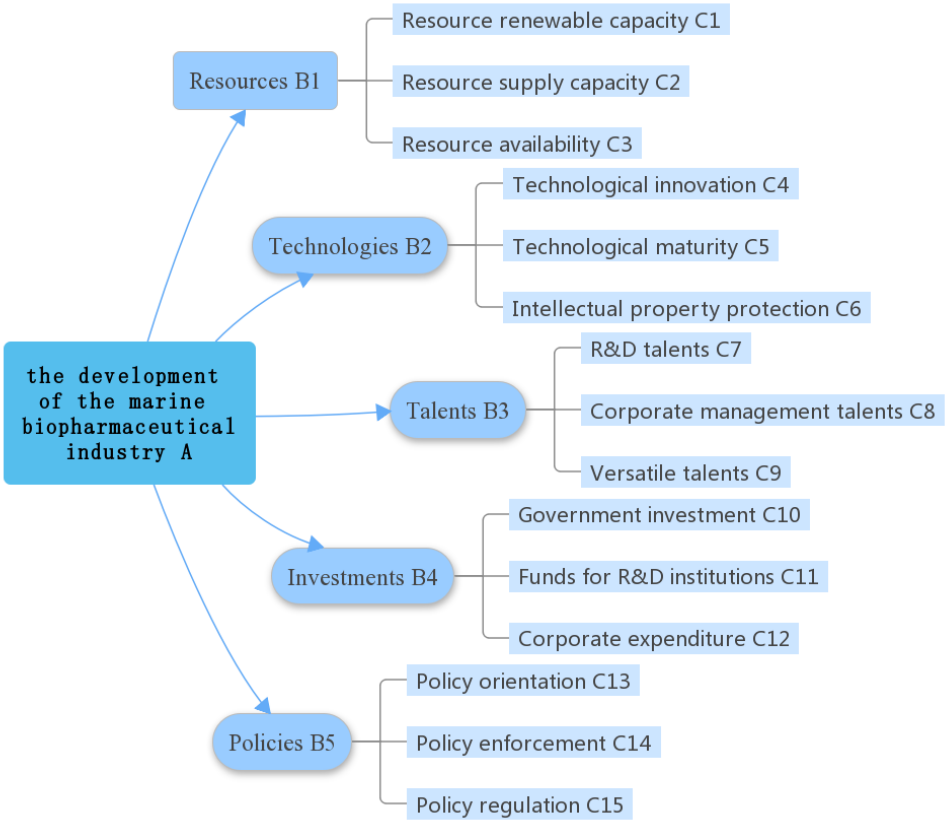


Figure 1. Hierarchical structure model of factors that influence the development of the marine biopharmaceutical industry.

3.2. Analytic Hierarchy Process Computation

Based on the constructed hierarchical structure model, domain experts were selected and invited to score the importance of the five factors (resources, technologies, talents, investments and policies) using the 1–9 scaling assignment method of AHP. Then, taking a certain element in the upper layer as a criterion, the relative importance of any two elements at the same layer was compared to construct the hierarchical matrix. Finally, the consistency of the hierarchical ordering and overall ordering of the matrix was tested (Table 1).

The calculated results indicate that all of the C.R. values were <0.1, which passed the consistency test. This shows the relative consistency of the matrix with indicators set by experts. Furthermore, these results show that the importance ranking of these factors at the dimension layer was technologies > talents > resources > policies > investments. The relative importance rankings of these factors

at the index layer were as follows: (1) resources: resource supply capacity > resource renewable capacity > resource availability; (2) technologies: technological innovation > intellectual property protection > technological maturity; (3) talents: versatile talents > R&D talents > corporate management talents; (4) investments: government investment > funds of R&D institutions > corporate expenditure; (5) policies: policy orientation > policy enforcement > policy regulation.

Table 1. Factor ranking weights of each layer.

Target Layer	Dimension Layer	Index Layer	Weight	C.W.	C.R.
Development of the marine biopharmaceutical industry	Resources (0.133)	Resource renewable capacity	0.239	0.032	0.017
		Resource supply capacity	0.625	0.083	
		Resource availability	0.136	0.018	
	Technology (0.452)	Technological innovation	0.558	0.252	0.017
		Technological maturity	0.122	0.055	
		Intellectual property protection	0.320	0.086	
	Talents (0.270)	R&D talents	0.218	0.059	0.054
		Corporate management talents	0.091	0.025	
		Versatile talents	0.691	0.189	
	Investments (0.053)	Government investments	0.683	0.036	0.025
		Funds for R&D institutions	0.200	0.011	
		Corporate expenditure	0.117	0.006	
	Policies (0.092)	Policy orientation	0.717	0.066	0.092
		Policy enforcement	0.195	0.018	
		Policy regulation	0.088	0.008	

Note: (1) C.W.: Comprehensive index weight; (2) C.R.: Consistence ratio.

According to the results of the above empirical analysis, technologies, talents and resources are the top three factors that potently affect the development of the marine biopharmaceutical industry. Simultaneously, although the influence proportion of policies and investments are relatively small compared with the former three, the development of the marine biopharmaceutical industry cannot be separated from the guidance of policies and the support of funds. Therefore, under the background of the national strategy of the Maritime Silk Road, full play should be given to the comparative advantages of technologies, talents and resources, in order to better promote the progress of the industry. Meanwhile, the supportive role of relevant policies and investments should be maximized. More importantly, active international cooperation should be carried out for the purpose of rational utilization and the optimization of international resources, realizing the win-win cooperation between China and other countries along the line.

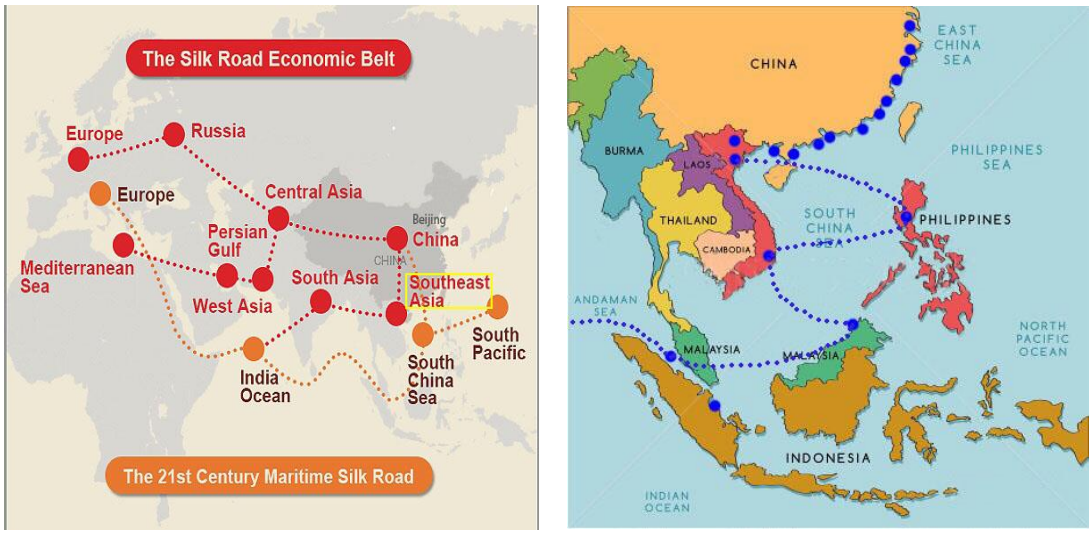
4. Necessity Analysis of the Going Global of China's Marine Biopharmaceutical Industry

The necessity analysis was conducted with the theory of comparative advantage and game theory, which lays a solid foundation for factor allocation.

4.1. Analysis of Comparative Differences in the Marine Biopharmaceutical Industry between China and the ASEAN

Among the countries along the Maritime Silk Road, China is the largest neighbor to the ASEAN (Figure 2). Ten countries in the ASEAN, except Laos, are on the verge of oceans. The total sea area of the ASEAN is more than 7.5 million km^2, accounting for 62.5% of Southeast Asia. It is mainly composed of the South China Sea, the Andaman Sea and the Malacca Strait, which are intertwined with the Malay Peninsula and Sunda Islands. Indonesia has a coastline of 35,000 km, ranking second in the world. Furthermore, Indonesia, as the largest island nation in the world with 17,499 islands, has the most marine biodiversity in the world (approximately 8500 species of fish, 555 species of seaweeds, 950 species of corals and other marine organisms) [25]. The Philippines has a coastline of 18,000 km. As one of the world's largest island countries, the Philippines, which is rich in fishery resources,

is an important fishery production country. Moreover, China is also a maritime power, which has a large sea area and long coastline. In recent years, China and the ASEAN have been committed to the development of the marine economy. It could be said that all of these countries have unique advantages in location and common interests. Therefore, the present study conducted the analysis by taking ASEAN countries as an example.



(**a**) (**b**)

Figure 2. (**a**) Map of the 21st century Marine Silk Road; (**b**) Map of Maritime Silk Road between China and the countries from ASEAN.

4.1.1. Strengths and Needs of China's Marine Biopharmaceutical Industry

In the 1970s, China put marine biomedicine R&D on the agenda, and the existing achievements are remarkable. According to the data in the Soopat [26], China's marine drug patents have ranked first in the world since 2006 (Figure 3).

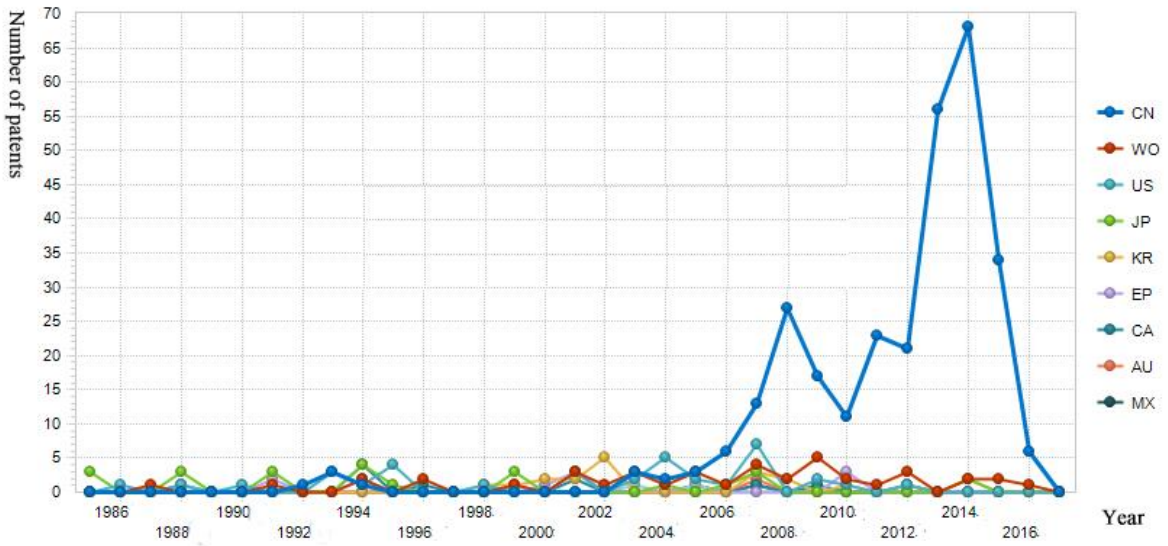


Figure 3. Patents for marine drugs among different countries.

(1) Strengths in China: In terms of technology level, the marine biopharmaceutical industry in China has made remarkable achievements. At present, the development of China's marine

biopharmaceutical industry still needs technological innovation. China possesses many R&D institutions related to marine biomedicines, such as the Key Laboratory of Marine Drugs, the Ministry of Education of China, the School of Medicine and Pharmacy, Ocean University of China, the Laboratory for Marine Drugs and Bioproducts, Qingdao National Laboratory for Marine Science and Technology, the Institute of Oceanology, Chinese Academy of Sciences, the South China Sea Institute of Oceanology, Chinese Academy of Sciences, the Shanghai Institute of Materia Medica, Chinese Academy of Sciences, the Third Institute of Oceanography, SOA, and Beijing University. Backed by these R&D institutions, China has possessed a part of related core technology, such as deep-sea sampling, extraction and separation, structural identification, molecular modification, chemical and biological synthesis, pharmacodynamic and toxicological evaluation, and microbial fermentation technology. In marine biopharmaceutical production, China has also reserved advanced technology, such as production process, quality standard, control and inspection technology. Specifically, biological separation technological systems have been established, including liquid membrane separation, field flow grading, solute system extraction, fixed membrane interface extraction, dye ligand affinity chromatography, high performance centrifuge separation system, membrane separation, supercritical fluid extraction, capillary electrophoresis separation, and countercurrent chromatography technology [27]. In 2017, three ships with different investigation capabilities, "Ocean Geology 8", "Ocean Geology 9", and "Ocean Geology 10", constitute China's deep-sea detection of three-dimensional technology system, which provides a solid technology and equipment support for China's deep-sea sampling. In addition, China has established professional R&D centers in the major coastal cities of Shanghai, Guangzhou, Qingdao and Xiamen. Thanks to these efforts, China steadily promotes technological innovation and technological maturity, and has made a great contribution to R&D and the development of China's biopharmaceutical industry. In addition, with a series of specialized research institutions, China has fostered a large number of high-quality professionals for marine biomedicine R&D in the major coastal cities, such as Shanghai, Guangzhou, Qingdao and Xiamen.

Talents, especially versatile talents, are the core factor of industry development, and the core strength for the international development of marine biopharmaceutical industry. Since China formally started the research of marine biomedicine, an independent and unique emerging marine industry has gradually come into being with certain scientific and technological talents. The number of people engaged in the marine industry in 2014 was 1.2125 million people, of which 10 thousand people mainly studied the marine biopharmaceutical industry [28]. In terms of R&D funds, the government has gradually intensified its efforts to support the industry in recent years. R&D funds have continuously been increased and have reached 34,198 million dollars by 2014, which is more than 17 times as much as 1.976 million dollars in 2009 [28,29]. Since China values the marine biopharmaceutical industry, government investment, incomes of scientific institutions and corporate expenditure are increased year by year, which provide capital support for talent training, technological development and infrastructure construction, and this further guarantees the internationalization of China's marine biopharmaceutical industry. There is no doubt that China has obvious advantages in technology and talents and funds, but especially in technology.

(2) Cooperation needs in China: As the material basis for industry development, marine medicinal bioresources guarantee the going global of the marine biopharmaceutical industry. More than 22,000 marine species have been recorded in the China Sea [23]. Among these, over 1600 species are rich in medicinal products, which provide material guarantee for the R&D and development of marine biomedicine. However, since coastal population and economic activities have increased in recent years, damages to marine bioresources are becoming increasingly serious, leading to 556 endangered species. The ecological damages caused by the extensive exploitation of marine resources in China over the years have led to the lack of marine medicinal bioresources. For example, overfishing and the abandonment of marine fishery workers seriously restrict the sustainable development of marine medicinal bioresources, improper offshore constructions occupy their habitats, and improper coastal economic activities destroy the living conditions of marine medicinal organisms.

In recent years, China has improved its related legal systems by developing a series of laws and regulations on marine ecological environmental protection. However, marine bioresources are still sharply decreasing on the aspects of its resource renewable capacity, supply capacity and availability due to the excessive exploitation of marine bioresources and the interferences of existing coastal economic activities. For the sustainable development of marine medicinal bioresources, China must implement the policy of rehabilitation for recovery. This status enhances the need for China to obtain marine bioresources through international cooperation.

4.1.2. Strengths and Needs of the Marine Biopharmaceutical Industry in Southeast Asia

(1) Strengths in Southeast Asia: Most of the ASEAN countries are located in tropical areas. Hence, the high temperature and rainy climate there produce rich bioresources. Southeast Asian countries, accounting for only 3% of the global geographical area, have more than 20% of the world's animals, plants and marine organisms. The marine region from East Asia to Southeast Asia is well-known as a hot-spot for biodiversity [30–32]. It has also been recognized as a region that contains various habitats characterized by high species richness and an abundance of habitat-forming species such as seagrass, mangroves and coral reefs [33–36]. With the attribution of 100,000 km^2 of coral reefs, the marine waters surrounding the Philippines, Malaysia and Indonesia are within the Coral Triangle Region, which is home to 3000 coral reef fishes, and this is twice the number of other world fishes all together [38]. The special and complex geographical ocean environment provides a rich biological diversity of marine organisms, compound diversity and a unique marine living resource for marine drug application, research and development. Among the global 34 hot regions with biodiversity published by the international environmental organization "Conservation International", five areas including Wallace and the Philippines are located along the Maritime Silk Road. Undoubtedly, rich and diverse marine medicinal bioresources are a major advantage in advancing the development of the marine biopharmaceutical industry along the Maritime Silk Road.

(2) Cooperation needs in Southeast Asia: Concerning industry development, Southeast Asian countries have advantages in resources and labor cost, but they are not equipped with the necessary conditions for the complete operation of the marine biopharmaceutical industry. On marine drug R&D, Southeast Asian countries, except India [39], lack professional R&D infrastructures and have not yet formed a perfect scientific research platform due to the lack of relevant experimental base and scientific research transformation platform, seriously restricting the industry in these countries. To the best of our knowledge, the development of marine biopharmaceutical industry in India is better than other ASEAN countries including Indonesia, Malaysia, Singapore, and Thailand. India, for example, has over 8000 km of coastline with clusters of marine habitats like inter-tidal rocky, muddy and sandy shores, coral reefs, and mangrove forests. The bioresources in Indian marine habitats have yet remained largely unexplored with tremendous potential for the development of new drugs and biopharmaceutical products [39–41]. Few institutions in India, such as the Ocean Exploitation Department, have initiated marine biotechnological programs to exploit new drugs and other marine derived products. In India, the development of the marine biopharmaceutical industry has started comparatively early, and in the 1990s more than 40 kinds of marine active substances were isolated [39]. However, up to date, its level of research and development of marine biological medicines is still backward to China and other advanced countries [40]. The shortage of investment has made the establishment of a R&D system more difficult, and restricted basic research. Furthermore, basic research-oriented talents remain scarce, and versatile talents are even more rare. Obviously, Southeast Asian countries require more financial support in R&D platforms, infrastructure construction and personnel training. At the 2014 China-ASEAN summit, China promised to provide economic assistance to ASEAN, that is, to provide ASEAN countries with a preferential loan of 10 billion US dollars to promote practical cooperation in different fields [42]. At the end of December 2015, all 10 ASEAN countries were members of the Asian Infrastructure Investment Bank (AIIB) [43]. The establishment and operation of AIIB may bridge the gap of facilities' investments alongside countries. Therefore, it can be expected that AIIB will be

benefit the improvement of the international cooperation environment in ASEAN countries in the field marine biopharmaceutical industry.

It cannot be denied that government policies are a crucial influential factor. The promoting effects of these policies on the going global of the industry are becoming more obvious between China and ASEAN countries. According to the findings reported by Shen [44], the contribution of relevant policies to China's marine biopharmaceutical industry accounts for 27.3%. At present, in regard to the marine biopharmaceutical industry as a strategic emerging industry, China has issued a series of macroeconomic policies to develop the marine economy with a clear overall orientation. For example, the 21st Century Maritime Silk Road and "Going Global" initiatives encourage the international development of Chinese enterprises. The friendly cooperation and exchanges among governments provide support for the going global of enterprises. The introduction and implementation of relevant policies promote international cooperation among enterprises and encourage enterprises to positively explore the international market with various supports, including preferential loans and tax incentives.

Based on the above analysis, it could be concluded that China and the countries along the Maritime Silk Road have obvious comparative advantages in the marine biopharmaceutical industry, which are mainly characterized by China's advantages in R&D technologies, capital investments and professional talents, and being alongside countries with marine medicinal bioresources. The support of government policies is a necessary condition for the development of the marine biopharmaceutical industry in China and countries along the Maritime Silk Road. Regional cooperation on marine biopharmaceutical industry between China and other countries along the Maritime Silk Road could offer each other a lot in order to achieve a win-win scenario.

4.2. Game Theory Analysis of International Cooperation of the Marine Biopharmaceutical Industry

According to the above comparative advantage differential analysis, a static game analysis was conducted using the game theory to investigate the cooperation in the marine biopharmaceutical industry between China and ASEAN countries (Table 2).

Table 2. Static game matrix of China and alongside countries.

Party B \ Party A	Cooperation	Non-Cooperation
Cooperation	$(R_c + E_c, R_m + E_m)$	$(R_c - T_c + P_m, R_m + T_m - P_m)$
Non-cooperation	$(R_c + r_c - P_c, R_m - r_m + P_c)$	(R_c, R_m)

The complete information game is the game in which each participant has accurate information about the characteristics, strategies and profit functions of all the other participants. Static game refers to the game in which two parties play at the same time or the game in which two parties choose strategies at the same time.

China and Southeast Asian countries know each other's respective development status of the marine biopharmaceutical industry, and both sides can decide on whether to cooperate at the same time. Therefore, the present study investigates the necessity of cooperation in the marine biopharmaceutical industry between China and Southeast Asian countries through the use of the complete information static game.

Assumptions:

(1) Party A is China and Party B stands for countries along the Maritime Silk Road. Both parties are rational economies. Revenues gained not through the cooperation between the two sides are R_c and R_m, and additional revenues gained through the cooperation are E_c and E_m, respectively.

(2) The method of cooperation between China and ASEAN countries is: China reveals its information and technology to ASEAN countries, and ASEAN countries open up their rich marine bioresources to China. Thus, two kinds of cooperation risks may arise: ① China is willing

to cooperate with ASEAN countries, while ASEAN countries may be not willing to cooperate with China (that is, China tends to be open to share information and technology to ASEAN countries, but ASEAN countries do not want to do common exploitation of resources with China). At this situation, the absolute value of technology losses of China's technology disclosure with the non-openness of resources in ASEAN countries and the absolute value of profit of ASEAN countries are labeled as T_c and T_m, respectively; ② ASEAN countries want to cooperate with China, while China does not (that is, ASEAN countries share marine bioresources with China, but China does not want to share information and technologies to ASEAN countries). At this status, the absolute values of China's additional revenues with no information and technology disclosure combined with the resources sharing of ASEAN countries and resources losses of ASEAN countries are marked as r_c and r_m, respectively.

(3) Both parties necessarily sign a contract stating that they will abide by the cooperative strategic agreement. If one party breaches the contract, the defaulting party will pay a fine or accept other penalties. If China fulfills the contract for cooperation and countries in Southeast Asia do not, these Southeast Asian countries will have to pay P_m liquidated damages to China. On the contrary, if China defaults, China will have to pay P_c liquidated damages to the Southeast Asian countries.

(4) $P_m = P_c$; $P_c > r_c$; $P_m > T_m$; $P_m > T_c$; $P_c > r_m$.

According to the above game matrix:

(1) When China makes a choice:

① When countries in Southeast Asia choose to cooperate, the cooperation return of China is $R_c + E_c$, and the non-cooperative return of China is $R_c + r_c - P_c$. China will definitely choose cooperation because of $P_c > r_c$, $R_c + E_c > R_c + r_c - P_c$.

② When countries in Southeast Asia do not choose to cooperate, the cooperation return of China is $R_c - T_c + P_m$. The non-cooperative return of China is R_c. Since $P_m > T_c$ and $R_c - T_c + P_m > R_c$, China will definitely choose to cooperate.

In summary, China will inevitably choose to cooperate with ASEAN.

(2) When Southeast Asian countries make their choices:

① When China chooses to cooperate, the return of cooperation between Southeast Asian countries is $R_m + E_m$, and the uncooperative return of Southeast Asian countries is $R_m + T_m - P_m$. Therefore, all countries in Southeast Asia will choose to cooperate as $P_m > T_m$ and $R_m + E_m > R_m + T_m - P_m$.

② When China does not choose to cooperate, the cooperation gains of Southeast Asian countries are $R_m - r_m + P_c$, and the non-cooperative gains of Southeast Asian countries are Rm. Therefore, all the countries in Southeast Asia will choose to cooperate, because of $P_c > r_m$ and $R_m - r_m + P_c > R_m$.

In summary, countries in Southeast Asia will inevitably choose to cooperate with China.

As China and ASEAN countries follow through strategic partnerships, cooperation is the best choice. While utilizing the rich marine medicinal bioresources in countries along the Maritime Silk Road for thorough diverse researches, China occupies a lot of market share and promotes the common development of medicine R&D in ways that obtain additional benefits. The alongside countries profits come from China's technological sharing, special investment, talents transfer and training in ways that make them more competitive in higher levels.

5. Design of the International Factor-Allocation Cooperation Path

According to the above analyses, the international cooperation was designed based on resources, technology, talents, investments and policies, in order to promote the going global of China's marine biopharmaceutical industry (Figure 4).

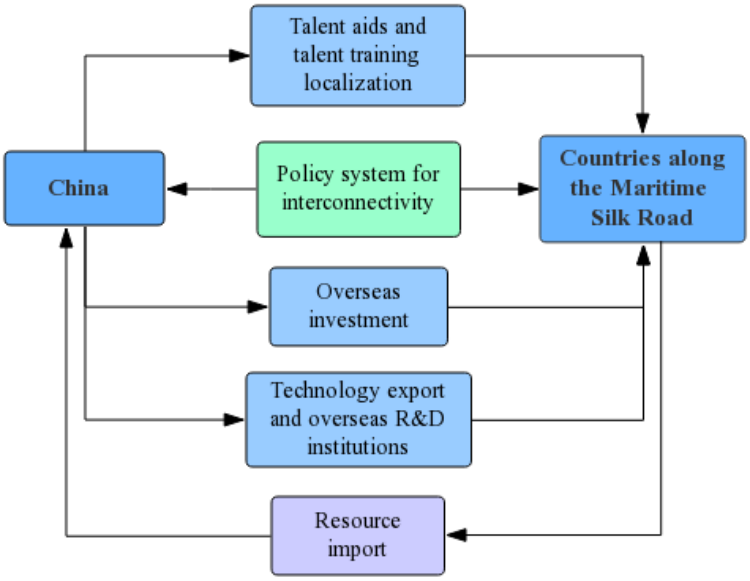


Figure 4. The path chart of the International factor–allocation cooperation of the marine biopharmaceutical industry.

5.1. Resources Allocation Path

The basic factor of industry development is marine medicinal bioresources. As the sea with the most abundant biodiversity worldwide, the Southeast Asian countries enjoy rich marine bioresources several times of those in China. China should make full use of the comparative advantages of rich marine bioresources in neighboring countries to support the cooperation among countries. The specific program could be concluded as follows:

(1) By putting disputes over territorial sovereignty aside at present, China and Southeast Asian countries could work together to exploit marine medicinal bioresources in the South China Sea and provide raw materials for marine medicinal production.
(2) China's advanced marine expedition vessels could be dispatched to the waters along the Maritime Silk Road to obtain biopharmaceutical resources in ways that complete resource gathering and screening experiments for biochemical substances at the same time, and conduct basic research efficiently.

5.2. Technologies Allocation Path

Based on the status quo, China has a comparative advantage in R&D technology for marine biomedicine. Therefore, in terms of technology factor allocation, China should take the following measures:

(1) The government and private investment would help build R&D institutions in countries along the Maritime Silk Road and explore more biopharmaceutical resources, in order to provide techniques for new drug R&D and product innovation.
(2) Accumulated processing experience over years would provide technological guidance for the production and processing of marine medicinal products in alongside countries, and accelerate cooperation.
(3) In addition to key technology and R&D institutions, China should give priority to intellectual property protection for marine medicinal products in a way that provides quality product basis for sustainable development.

5.3. Talents Allocation Path

In the process of the joint development of the marine biopharmaceutical industry with alongside countries, China's present talent allocation program is proposed as follows:

(1) Necessary personnel assistance program to transfer professionals to marine drug research institutions in alongside countries, and achieve new drug research and development combined with local resources.
(2) Establishment of overseas personnel training institutions to localize the training of R&D and corporate management talents in ways that would optimize the overall skills of countries along the Maritime Silk Road.

5.4. Investments Allocation Path

Compared with countries along the Maritime Silk Road, China has a comparative advantage in investment in the industry. In the joint development of the marine biopharmaceutical industry with neighboring countries, China's present investment allocation program is suggested as follows:

(1) China works to expand foreign investment, utilize marine medicinal bioresources in alongside countries, and strengthen the construction of R&D institutions and production infrastructures, in order to promote overseas marine biopharmaceutical production as soon as possible.
(2) Except for necessary R&D funds, capital should be used for the industrialization and transformation of scientific and technological achievements to production in ways that would benefit mankind with marine drugs.

5.5. Policies Allocation Path

As a factor that guarantees industrial development, the policy is the pilot link of the industry's going global. Amidst the 21st Century Maritime Silk Road, China and neighboring countries should give full play to the positive role of policies, in order to provide a broader and free-policy environment for the development of the marine biopharmaceutical industry.

(1) China and neighboring countries introduce marine biopharmaceutical industry-related policy systems, and strengthen policy implementation with effective policy regulation.
(2) Policy orientation interconnects marine drug production and sales channels within the cooperated countries along the Maritime Silk Road, and eliminates technical trade barriers. The recognition of China's marine biomedicine production technology regulations, standards and certification systems, including health, quarantine, safety, environmental protection, product quality and certification, through alongside countries would help smoothly carry out international cooperation in production.

6. Strategies for the Development of China's Marine Biopharmaceutical Industry

In order to speed up the international development of China's marine biopharmaceutical industry and ensure the effective implementation of the designed allocation program, the following suggestions were offered based on technology, talents, resources, policies and investment.

(1) Promotion of R&D of core technologies

Technologies are the main driving force of the marine biopharmaceutical industry. At present, it is urgent for China to strengthen the basic research on marine bioactive substances, explore marine drug mechanisms, improve technological innovation and maturity, and ensure follow-up product innovation, clinical experiments and other activities. At the same time, it is suggested to improve innovation capacity in the process of industrial development, open up horizons, develop new methods and processes, and improve production efficiency.

(2) Value talent training

It is important for China to continuously carry out R&D and management talent training, and focus on versatile talent training equipped with pluripotentiality, in order to balance the talent structure of China's marine biopharmaceutical industry. It is suggested that the marine education level should be improved in existing institutions, and the marine education capacity of other comprehensive institutions should be expanded in ways that expand the marine knowledge of high-quality talents nationwide. In addition, marine courses or knowledge lectures should also be arranged in primary and secondary education before higher education, developing marine consciousness among juvenile, establishing China into a marine power in the new era.

(3) Protection of marine bioresources

With the upgrading of science and technology and the rise of green conviction, it is a prerequisite for the sustainable development of the marine biopharmaceutical industry in China to change its extensive development models, and effectively recover the resource supply capacity and renewable capacity of marine medicinal bioresources. Furthermore, it is crucial to introduce more detailed marine laws and regulations to improve the existing marine legal system. All sea-related activities should be based on sustainable development by prohibiting excessive fishing and over-exploitation of offshore areas. The awareness of citizens on marine natural ecological and environmental protection should be enhanced, in order to improve the availability of marine medicinal bioresources and achieve the sustainable development of the marine biopharmaceutical industry.

(4) Strengthening policy support

Strong policies could support the rapid rise of the marine industry. At present, "the Belt and Road" strategy and "Going global" initiative positively promotes China's marine economic development. Macro-policies have been put in place, and the Chinese government should introduce more detailed policies for the marine biopharmaceutical industry, such as encouraging domestic investment, strengthening international investment, simplifying R&D pilot redundant procedures, authorizing preferentially industrial facility lands, and standardizing drug regulations, providing a guarantee for the going global of the industry.

(5) Expanding investments

The combination of government investment and social enterprise investment with stable supply to marine biopharmaceutical R&D institutions would help China keep up with the times, accelerate the optimization of industrial structure and achieve the going global of the industry. Meanwhile, the investment mechanism and industry structural upgrading pattern should be introduced from the international leading countries, sticking to the right path and narrow the gap among China, European and American countries in ways that would further promote the industry development of countries along the Maritime Silk Road.

(6) Deepening international cooperation

Backed by the Maritime Silk Road Initiative, China should selectively establish strategic fulcrums in countries along the Maritime Silk Road, in order to allow them to play a crucial supporting role for the rapid development of the marine biopharmaceutical industry. These fulcrums may fully be driven and stimulate the surrounding areas and other parties to more actively give full play to their comparative advantages, and equip various resources optimally, in order to achieve the upgrading and sustainable development of the marine biopharmaceutical industry.

It should be noted that due to different national characteristics and conditions, the Southeast Asian countries may not react as one group in international cooperation and their reactions may

also be affected based on their own bilateral or multilateral ties. This factor can strongly impact the international cooperation between China and Southeast Asian countries. To face this factor, China should firstly improve the confidence and willingness of cooperation by conducting more exchanges and communication in order to make sure greater understanding and mutual trust among all countries exists. On this basis, China and Southeast Asian countries may carry out effective and substantive cooperation for common interests by playing their respective advantages to achieve the sustainable development of marine biopharmaceutical industry in countries along the Silk Road.

7. Conclusions

This study is the first report to investigate the sustainable exploitation of marine biopharmaceutical industry based on factor allocation under the backdrop of the Maritime Silk Road Initiative. Amidst the Maritime Silk Road Initiative, according to the status quo of China's marine biopharmaceutical industry, the present study investigates the factors allocation of the development of the marine biopharmaceutical industry in China by using AHP, the comparative advantage theory, and game theory. The main conclusions are as follows:

(1) Through analyzing the status quo of China's marine biopharmaceutical industry, the identified main factors were investments, technologies, talents, resources and policies.
(2) The analysis with AHP revealed the importance ranking of these factors: technologies > talents > resources > policies > investments. These results revealed that technologies, talents and resources are the top three factors that affect marine biopharmaceutical industrial development. Simultaneously, although the proportion of policies and investments is relatively small compared with the former three, the development of the marine biopharmaceutical industry should be guided by policies and supported by funds.
(3) Based on the comparative advantage and game theory, according to our studies, as China and Southeastern countries are interested in the partnership, international cooperation should be considered as the best choice for developing the marine biopharmaceutical industry. Supported by the 21st Century Maritime Silk Road Initiative, the international development of China's marine biopharmaceutical industry will necessarily lay a win-win foundation for the rapid development of the industry in neighboring countries.
(4) According to the results of the empirical analysis, the path of factor–allocation cooperation in terms of resources, technology, talents, investments and policies were designed and the factor–allocation cooperation path chart for the international development of marine biopharmaceutical industry was planned.
(5) The strategy and pathway for the going global of China's marine biopharmaceutical industry were proposed, as follows: to focus on R&D of core technologies, to value talents training, to protect marine bioresources, to introduce supporting policies, and to invest more and strengthen international cooperation.

It should be believed that with the frequent exchanges and the increase of mutual trust, the cooperation among China and the countries along the Silk Road will be further deepened. Therefore, in the future, the research on the basic characteristics of each country should be carried out. In this way, cooperation scheme and the realization path between China and a specific country from Southeast Asian could be put forward. This will promote the healthy, rapid and sustainable development of the marine biopharmaceutical industry.

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