Innovation ecosystem innovation coordination management of Chinese shipbuilding enterprises

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Abstract. The shipbuilding industry is an important basis for China's strategy of becoming a marine power. Promoting the innovative development of the shipbuilding industry is important means for China to build a marine power. Based on the analysis of the mechanism of the innovation ecosystem of shipbuilding enterprises, this paper studies the level of the coordinated development of the coupling between the internal innovation and the external environment of shipbuilding enterprises, quantitatively measures the overall coupling coordination degree of the innovation ecosystem of shipbuilding enterprises, and analyzes the coordinated development of the innovation coupling of various shipbuilding enterprises. The innovation and development of shipbuilding enterprises not only depend on their own innovation investment, but also have an important relationship with the external environment of the enterprises, and then give relevant enlightenment from the enterprise itself and the government.

1 Introduction

At present, the international ship market is getting better and better, entering a new round of industry adjustment period. The new international maritime rules guide ships to green, intelligent technology and other directions, bringing new historical opportunities for China's shipbuilding industry to achieve a higher level of development[1]. The great changes in the shipbuilding industry and the new round of industrial technology revolution require the shipbuilding enterprises to have stronger innovation ability and international competitiveness, and the innovative development of shipbuilding is particularly important[2].

With the introduction of the "ecosystem" theory into innovation research[3], the research on innovation system has gradually transformed into the research on innovation ecosystem[4]. Innovation is the problem of coupling and collaborative innovation between innovation subjects and innovation environment[5]. The innovation competition among enterprises evolves into the competition of enterprise innovation ecosystem[6]. Jiang Shimei and others sorted out the innovation platform formed and gave the concept of enterprise innovation ecosystem from a micro perspective[7,8]. Zhou Quanquan believed that the main body of the innovative enterprise and the external main body of the enterprise should be integrated into a value creation system with a common innovation mission[9]. Liu Gang believes that building a business ecosystem based on the needs of enterprises is the key to improving the competitiveness of enterprises[10]. Wu Jianlong obtained the conclusion that the boundary of enterprise innovation ecosystem can be expanded through case analysis, and that platform functions can promote collaborative innovation of subsystems[11,12]. Xu Yinna et al. studied coupling and coordination scheduling based on enterprise production, innovation and ecology, and carried out empirical measurement and analysis[13]. Cheng Zhang et al. demonstrated the driving force of technological innovation on the overall development of manufacturing service-oriented by using the coordination degree of technological innovation and manufacturing service-oriented[14]. Theyel pointed out that coupling refers to a phenomenon in which two or more subsystems interact and cooperate with each other. Good coupling can promote common development[15,16]. Suseno believed that the enterprise interacted with its innovation stakeholders in terms of resources, and that enterprise innovation was related to both its own and external resources[17].

To sum up, the research results related to the development of enterprise innovation ecosystem are very rich. From the perspective of research objects, most scholars have studied innovation ecosystems such as industrial enterprises or platform enterprises and less research on shipbuilding enterprises. China's shipbuilding enterprises are facing the dilemma of green and intelligent technology in the global industry, and high-tech shipbuilding technology is still lacking[18]. Therefore, it is of great strategic significance to promote the innovation and development of shipbuilding enterprises through empirical research on the coupling and coordination development of the innovation ecosystem of China's shipbuilding enterprises and the maximum use of innovative environmental resources.

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2 Mechanism

The concept of coupling originated from physics, which means that two or more systems interact and influence each other. The final result is to make the original attributes of each subsystem enlarge or reduce[19]. The innovation ecosystem of shipbuilding enterprises includes two subsystems, namely, the internal main body innovation and the external environment innovation. There is a complex coupling and coordination relationship between the two. The innovation ecosystem of shipbuilding enterprises is a complex process of internal and external system coordination. With the improvement of technology innovation level in the overall environment of the shipbuilding industry, it promotes the coupling and coordination of enterprise innovation and innovation environment, provides policy support, innovation resources, support funds, etc. for internal innovation of shipbuilding enterprises, improves the external environment level of enterprise research and development, and then improves the internal technology research and development efficiency of enterprises. At the same time, the improvement of the enterprise's R&D level further affects the technological innovation level of the entire shipbuilding industry, and realizes the internal promotion of innovation through the enterprise's innovation input, achievements and transformation. The development of coupling and coordinated innovation of shipbuilding enterprises is a process of mutual influence. In the process of mutual influence and joint innovation, a dynamic innovation whole of coupling and coordination between internal innovation and external environment of the enterprise is formed. The coupling and coordinated development enable the enterprises to develop in a coupling and coordinated manner, thus improving the overall technological innovation performance of the enterprise.

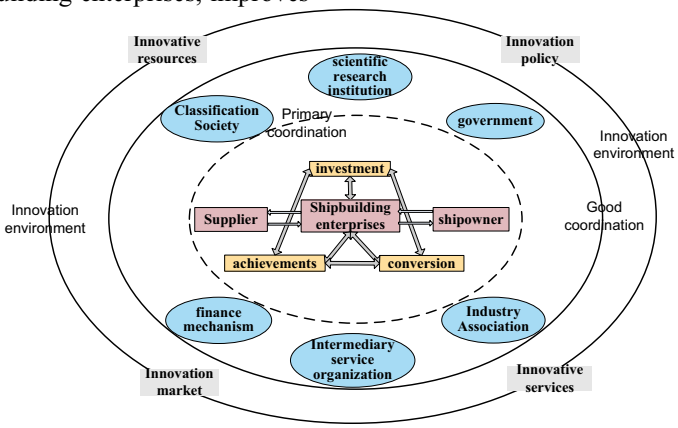

Fig.1. Coupled and coordinated development model

3 Model building

3.1 Evaluation model

Set the innovation collaboration subsystem of the shipbuilding enterprise innovation ecosystem as X_i, Y_i. X_i, $Y_i \in [0,1]$. Enterprise internal innovation is X_i and enterprise external environment is Y_i.

$$Xij = (xij - bij)/(aij - bij) \quad (1)$$

$$Yij = (yij - bij)/(aij - bij) \quad (2)$$

Using linear weighting method:

$$X = \sum Vij * Xij, \sum Vij = 1 \quad (3)$$

$$Y = \sum Wij * Yij, \sum Wij = 1 \quad (4)$$

Using the model research of Lu Jin[20] for reference, build a coupling coordination model:

$$C = 4[X * Y] / [X + Y]2 \quad (5)$$

$$D = [C * T]1/2 \quad (6)$$

$$T = \alpha X + \Phi Y, T \in [0,1] \quad (7)$$

In Formula (5), C refers to the coupling degree of the innovation ecosystem of shipbuilding enterprises. In Formula (6), D represents the coupling and coordinated scheduling of the innovation ecosystem of shipbuilding enterprises. The closer the value of D is to 1, the higher the contribution of the internal innovation and the external environment of the enterprise to the entire innovation ecosystem, the stronger the coupling and coordinated innovation, and vice versa.

3.2 Indicator system

The innovation coupling coordination system of the enterprise innovation ecosystem involves many parameters of the subsystem. The order parameters of the subsystem are determined according to the synergetics theory to reduce the complexity of studying the enterprise innovation ecosystem[16]. The internal innovation of shipbuilding enterprises mainly considers the indicators of enterprise innovation ecosystem from three aspects: innovation input, transformation and output[21-23], studied and built the evaluation index system of innovation coupling coordinated dispatching of China's shipbuilding enterprises:

4 Empirical analysis

The entropy method is used to calculate the weight of each evaluation index of innovation subject and innovation environment, and the actual collected data of each index is substituted into each formula for calculation. The results are shown in **Table 2**.

4.1 Comprehensive analysis

4.1.1 Overall fluctuation rising trend

The overall fluctuation of shipbuilding enterprises in 2019-2021 has a trend of rising convergence. From 2012 to 2021, the coupling coordination degree of the innovation ecosystem of shipbuilding enterprises showed a fluctuating increase. The overall coupling coordination degree of the selected enterprises decreased in 2019, and the innovation coupling coordination increased in 2020 and 2021.

Table1. Index System Table

Enterprise internal innovation	investment	R&D investment intensity	Proportion of total R&D investment in operating revenue (%)
	conversion	Proportion of R&D personnel	Proportion of the number of R&D personnel (%)
		Proportion of marketing personnel	Proportion of enterprise marketing personnel (%)
		Number of patent applications	Total number of independent patent applications (item)
	achievements	Net profit	Net profit attributable to shareholders (yuan)
		Main business income	Enterprise main business income (yuan)
External environment of the enterprise	government	Government support	Proportion of government R&D subsidy (%)
	market	Export volume of shipbuilding industry	Total exports of shipbuilding industry (100 million US dollars)
		Total profit of shipbuilding industry	Total profit of shipbuilding industry (100 million US dollars)
	industry	Shipbuilding completion in China	Shipbuilding completion in China (10000 dwt)
		Order quantity of new ships	Order volume of new ships undertaken (10000 dwt)
		Order quantity of handheld ships	Hand held orders of ships nationwide (10000 dwt)
	resources	Number of shipbuilding enterprises	Number of shipbuilding enterprises
		Number of R&D institutions	Number of R&D institutions in the shipbuilding industry

Table2. Coordination Index Table

Enterprise code / Year	600150	600764	600072	601989	300516	300527	300065	601890	002552	300008	300320	mean value of *T*
2012	0.5368	0.3144	0.3860	——	0.3759	——	0.7948	0.7942	0.7079	0.3971	0.5192	0.3550
2013	0.5388	0.5729	0.5852	——	0.5523	——	0.8734	0.7966	0.7848	0.3640	0.4299	0.2130
2014	0.6066	0.5405	0.4441	——	0.6189	——	0.8413	0.8446	0.5538	0.3326	0.5173	0.1708
2015	0.5241	0.5718	0.4226	——	0.5259	——	0.5595	0.7267	0.6491	0.4101	0.6390	0.3196
2016	0.4991	0.5271	0.6260	0.4997	0.6541	0.8494	0.5951	0.5630	0.6293	0.2937	0.5857	0.3450
2017	0.5787	0.6634	0.6215	0.6052	0.6384	0.4832	0.6103	0.5628	0.4988	0.3214	0.5498	0.3018
2018	0.7134	0.7525	0.5277	0.6168	0.6244	0.5034	0.5806	0.5842	0.4847	0.3049	0.5948	0.3343
2019	0.7029	0.5429	0.3683	0.4593	0.3948	0.4146	0.4692	0.3835	0.4424	0.3815	0.4006	0.5569
2020	0.5822	0.5580	0.7530	0.4876	0.2583	0.5154	0.5009	0.3598	0.3877	0.3454	0.4642	0.6926
2021	0.7024	0.7267	0.6658	0.6915	0.6333	0.6266	0.6650	0.6311	0.6180	0.6388	0.6344	0.5863

Table3. Coordination Level Table

Cate-gory	Enterprise code	2012		2015		2018		2021	
		D	level	D	level	D	level	D	level
I	600150	0.5368	Primary coordination	0.5241	Primary coordination	0.7134	Good coordination	0.7024	Good coordination
	600764	0.3144	Mild maladjustment	0.5718	Primary coordination	0.7525	Good coordination	0.7267	Good coordination
II	600072	0.3860	Mild maladjustment	0.4226	On the verge of maladjustment	0.5277	Primary coordination	0.6658	Intermediate coordination
	601989	——	——	——	——	0.6168	Intermediate coordination	0.6915	Intermediate coordination
	300516	0.7948	Good coordination	0.5595	Primary coordination	0.5806	Primary coordination	0.6650	Intermediate coordination
III	300527	——	——	——	——	0.5034	Primary coordination	0.6266	Intermediate coordination
	300065	0.3759	Mild maladjustment	0.5259	Primary coordination	0.6244	Intermediate coordination	0.6333	Intermediate coordination

601890	0.7942	Good coordination	0.7267	Good coordination	0.5842	Primary coordination	0.6311	Intermediate coordination
002552	0.7079	Good coordination	0.6491	Intermediate coordination	0.4847	On the verge of maladjustment	0.6180	Intermediate coordination
300008	0.3971	Mild maladjustment	0.4101	On the verge of maladjustment	0.3049	Mild maladjustment	0.6388	Intermediate coordination
300320	0.5192	Primary coordination	0.6390	Intermediate coordination	0.5948	Primary coordination	0.6344	Intermediate coordination

4.1.2 The average level has risen.

From the perspective of the whole enterprise time development process, all enterprise innovations coexist in the same innovation environment, and are coupled, promoted and coordinated with each other. The innovation coupling coordination degree of all shipbuilding enterprises is fluctuating and growing, laying a foundation for the innovation development and further development of enterprises.

4.1.3 Differences in the level.

After analysis, the development level of coupling and coordinating innovation of shipbuilding enterprise innovation ecosystem is divided into three categories. To further clarify the level of coupling and coordinating innovation of enterprise innovation ecosystem, **Table 3** and **Fig. 2.** are drawn (four typical representative years are selected equally).

(1) The first type of enterprises mainly carry out innovation activities by means of independent innovation and research and development of ship technology. Such enterprises have a relatively complete manufacturing innovation R&D chain of the shipbuilding industry, and rely on R&D advantages to form scale effect, agglomeration effect and other advantages. At the same time, the cooperation between upstream and downstream enterprises across the shipbuilding industry chain is characterized by multi-party cooperation, and it is more prominent in its own innovative research and development and integration of environmental innovation advantages to promote innovative development.

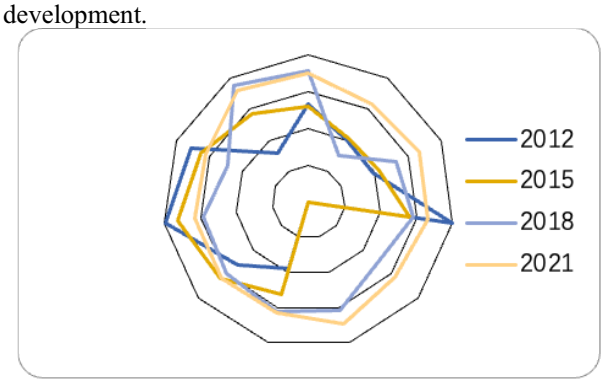

Fig.2. Radar Chart of Coupling Coordination Degree

(2) The coupling and coordination degree of the second type of enterprise innovation ecosystem is at the upper level of the overall level. There is a small gap in the degree of coupling and coordination with the first class of shipping enterprises, and the gap in the degree of coupling and coordination of innovation ecosystem is caused by differences in business development focus and innovation resource cooperation. Have a good foundation for innovation and development, which can quickly improve the core competitiveness of enterprises.

(3) The coupling and coordination degree of the third type of enterprise innovation ecosystem is below the average level. From the perspective of the main business of the enterprise, it is mainly the supporting enterprise of the core shipbuilding enterprise, engaged in the supporting service of shipbuilding, focusing on the cooperative development with large shipbuilding enterprises, with little demand for enterprise innovation and insufficient enterprise size to support its long-term innovation research.

4.2 Analysis of external environment

4.2.1 Increased internal innovation coordination

From the perspective of internal innovation coordination of shipbuilding enterprises, the internal innovation coordination of enterprises is on the rise. In combination with the coordination degree of subsystems, from 2012 to 2021, the coordination degree of internal innovation investment of enterprises has increased. The internal innovation input of the enterprise has basically increased from about 0.1 to more than 0.7, and the overall data is rising, which is consistent with the development trend of the coupling and coordination degree of the ship enterprise ecosystem.

4.2.2 Declining in external environment coordination

From the perspective of the coordination degree of the external environment of shipbuilding enterprises, the coordination degree of the external environment of enterprises is declining. The coordination degree of the external environment subsystem of shipbuilding enterprises decreased from 2012-2021 on the whole, and there was a significant recovery in 2019. However, after this year, the coordination degree of the external environment of all shipbuilding enterprises decreased and the data showed significant changes, which was consistent with the changes in the coupling coordination degree of the innovation ecosystem of shipbuilding enterprises as analyzed above.

5. Conclusion and revelation

5.1 Conclusion

5.1.1 Important role of external environment

Shipbuilding enterprises are Industrial enterprises. The technological innovation of ship enterprise plays an important role in the strategy of manufacturing power. The environment composed of governments and other external entities plays an important role in the foundation and facilitation. The external environment of shipbuilding enterprises brings new development to shipbuilding industry. Measures such as supply-side reform and the restructuring of the three central shipbuilding enterprises have driven the innovative development of shipbuilding enterprises. In recent years, the economic situation and epidemic situation of the world shipbuilding industry are grim. Competition among shipbuilders is fierce. The demand for ship technology is getting higher and higher. The innovative development of shipbuilding enterprises needs to improve the external environment.

5.1.2 Enterprise's own innovation ability

The internal innovation capability of an enterprise determines its innovative development. Ship enterprises include core ship enterprises, supporting enterprises, ship related enterprises, etc. The internal innovation of enterprises requires the joint efforts of all entities of the innovation ecosystem, while the innovation and development of ship enterprises themselves are determined by the driving force of their innovation and development. At the same time, ship enterprises are involved in military secrecy and other issues, so the development of their own innovation ability is particularly important.

5.1.3 Joint innovation and development inside and outside the enterprise

Enterprise internal innovation and enterprise external environment jointly promote the overall innovative development. The internal innovation of shipbuilding enterprises can achieve a certain degree of innovation, but the coordination between most enterprises and the external environment is not obvious. The innovation and development of enterprises cannot achieve the effect of "1+1>2". Limited by the characteristics of long innovation cycle and large capital occupation of shipbuilding enterprises, it is essential for enterprises to jointly develop and innovate in the external environment.

5.2 Revelation

5.2.1 Enterprise's own innovation and development

When the large market environment cannot be changed, enterprises should first innovate and develop themselves. Then, promote joint innovation with external environmental resources.

The first type of shipbuilding enterprises must always pay attention to the development trend of international technological innovation frontier. Follow the development trend of international ships. Focus on industrial hot spot technological innovation and combine relevant scientific research frontier achievements to form an innovation system of coupling and coordination between shipbuilding enterprises and the environment. Finally, Chinese shipbuilding industry can realize the innovation and transformation of Chinese shipbuilding technology. And the enterprise realizes the further development of technological innovation.

Ship enterprises in the second stable period must follow the steps of China's leading ship enterprises and focus on promoting enterprise technology innovation. The industry concentrates all kinds of resources to consolidate core technology, and speed up the ranks of Class I ship enterprises.

The third type of growing shipbuilding enterprises should actively carry out restructuring, mergers and acquisitions of shipbuilding enterprises to achieve the transformation and upgrading of the enterprise. They should expand the cooperation and innovation model with other shipbuilding enterprises and institutions such as government, enterprises, universities and research institutes in resource technology. Enterprises optimize the division of resources in the ship industry chain. Enterprises work together for common development.

5.2.2 The government provides R&D subsidies

The government promotes R&D innovation and development of shipbuilding enterprises through R&D subsidies, tax incentives and other relevant policies. Shipbuilding enterprises need a lot of money and time to innovate. The government continues to provide preferential policies in terms of innovation subsidies and corporate taxes to promote the research, development, transformation and application of innovative achievements of shipbuilding enterprises.

5.2.3 China Shipbuilding Industry Association Building Platform

The China State Shipbuilding Association and other organizations are actively involved in improving the environment for innovation. Improving internal innovation is not enough. Innovation support base and innovation resources are also crucial. The government should actively promote the optimization of the structure of the entire shipbuilding industry. The government and industry associations will jointly promote the establishment of a mechanism for sharing resources, information and funds in the shipbuilding industry. The government promotes the openness of basic technical resources and concentrates shipbuilding resources. At present, the government and financial institutions provide innovative financial support to shipbuilders. The government guides shipping enterprises and research

institutes to work together on key and high-end shipping technologies. The government and other entities will promote technology transformation and application, and break through barriers to enterprise R&D and innovation. Finally, the ship enterprise realizes the collaborative development of innovation.

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