

Resilience Evaluation of Innovation Ecosystem of High-tech Enterprises in Liaoning Province

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Abstract: With the increasingly fierce global competition, the innovation ability of high-tech enterprises has gradually become an important manifestation of national competitiveness as an inexhaustible driving force for national development. Similar to traditional ecosystems, resilience against external environmental disturbances which ensures operation stability is also necessary to innovation ecosystems of high-tech enterprises. This paper proposes four-dimensional indicators that affect the resilience of innovation ecosystems of high-tech enterprises after taking resilience of traditional ecosystems as the starting point and considering higher requirements of high-tech enterprises innovation ecosystems. The resilience evaluation system of high-tech enterprises innovation ecosystems are also improved in this paper. Based on the specific development of Liaoning Province in recent years, key problems of resilience in high-tech enterprise innovation ecosystem of Liaoning Province are proposed combined with the proposed resilience evaluation indicators, and specific solutions are given. This research provides a reference for resilience construction of high-tech enterprise innovation ecosystems and ideas for the innovative development of high-tech enterprises in Liaoning Province.

1. Introduction

With the advent of the global digital era, the international economic market environment is gradually fiercely competitive. In this context, the dominant role of national technological innovation capabilities has become increasingly prominent. The word "innovation" frequently appears in China, which clearly emphasizes that innovation is the primary driving force leading development and an important goal on the way to accelerate the construction of an innovative country. Traditional innovation management regards each enterprise as an independent innovation unit, emphasizing the game between the enterprise and its competitors and upstream and downstream partners^[1], in order to strive for a higher market share. However, this method excessively occupies the internal resources of the enterprise, restricts its circulation to a large extent, and hinders the development and improvement of the innovation ability of high-tech enterprises to a certain extent. In recent years, with the change of national environment and the

diversification of innovation forms, the driving force of innovation has changed greatly. In addition to the three innovation drivers of co-working spaces, open sources communities, or non-profit organizations, the innovation ecosystem, as the fourth innovation-driven model, has gradually gained the attention of many scholars at home and abroad^[2]. Compared with the traditional innovation management method, this innovation-driven model emphasizes the complementarity and synergy between innovative enterprises and their stakeholders, and the mutual competition and cooperation among the innovation entities in the whole process of innovation from idea generation, R&D, to marketization^[3,4], so as to jointly enhance the overall innovation capacity.

Since Moore first introduced the ecosystem into the enterprise management field and proposed the concept of enterprise ecology^[5], researches on the function and mechanism of innovation ecosystem have gradually emerged at home and abroad. The embryonic form of enterprise ecosystem has been gradually established^[6-8]. Evaluation system^[3,7,9] is also improving day by day. Liu Xielin et al.^[11] put forward a theoretical framework for the management of innovative ecosystems based on the analysis of the coexistence, dependence and evolution mechanism of ecosystems. Similar to traditional ecosystems, innovative participants interact around common value propositions, and are arranged by core enterprises in the innovation ecological network, which directly or indirectly affects the system innovation capabilities. On this basis, Wang Kaixia^[10] proposed a strategy for building an enterprise innovation ecosystem by analyzing the evolution process of the innovation ecosystem, and emphasized the importance of establishing a sound and perfect evaluation system to the operation effect of innovation ecosystem. Analogous to natural ecosystems, in the case of fluctuations in external conditions, a good ecosystem needs to have a certain degree of resilience to resist the impact of changes in the external environment. Liang Lin et al.^[11] proposed an innovation ecosystem resilience evaluation system based on four-dimensional resilience characteristics, which fully considered the impact of system diversity, evolution, mobility and buffering on innovation ecosystem resilience. On this basis, Yang Wei^[12] adjusted and enriched the resilience evaluation system based on the characteristics of the regional digital innovation ecosystem, and analyzed the effect of different governance niche configurations on improving system resilience by using the fsQCA method. Fan Decheng^[13] used the improved entropy-DEMATEL-ISM combination algorithm to evaluate the health of the technological innovation ecosystem of high-tech industries in mainland China comprehensively, and analyzed the important factors affecting the health of the system.

However, at present, a large number of studies mainly focus on the operating mechanism, evaluation system and optimization strategy of innovation ecosystem. The definition of innovation ecosystem resilience is still not clear, and the influencing factors and evaluation system are still relatively generalized. Analysis that targeting specific region are still less. In view of this, this paper constructs an innovation ecosystem resilience evaluation system based on the innovation status of high-tech enterprises in Liaoning Province, and comprehensively uses a variety of data to evaluate the innovation ecosystem resilience of high-tech enterprises in Liaoning Province, which serves as a reference in the innovative development of high-tech enterprises in Liaoning Province.

2. Innovation Ecosystem Resilience and Its Evaluation Indicators

2.1. Innovation Ecosystems and Their Resilience

Building an innovation ecosystem is the only way for China to explore innovative development models and promote the scientific and technological revolution of high-tech enterprises. From the perspective of ecology, the evolution mechanism of innovation ecosystem is the response process of innovative species, populations and communities within the system to external environmental changes and disturbance^[11]. Individual enterprise is the main innovation subject in the innovation

ecosystem of high-tech enterprises. Institutions of higher learning, scientific research institutes, financial institutions and government support groups play a role in assisting innovation. Various groups, populations and the external environment interact, depend on each other, cooperate and coexist, forming a unified whole of the innovation ecosystem.

Similar to natural ecosystems, innovation ecosystem resilience is expressed in the system's ability to buffer external shocks. Ecosystem resilience plays a key role in determining ecosystem viability during the process of external shocks and the recovery period after system damage. When the system is subjected to external shocks, the functional level of the ecosystem will decline to a certain extent. At this time, a resilient ecosystem has better performance in terms of resistance stability and restoration stability. After internal adjustment, it can return to the normal working state of the ecosystem after a period of time. However, ecosystems with lack of resilience or insufficient resilience have poor resistance stability after receiving external shocks, which may lead to the extinction of ecosystems after external shocks. Even if the non-resilient ecosystem does not die immediately during the shock, due to its weak resilience stability and poor ability to repair the shock, it will take a long time for the ecosystem to recover to the normal working range and the level of ecosystem function will be relatively low compared to the resilient ecosystem. By analogy with the natural ecosystem, for the innovation ecosystem, by improving the internal structure of the innovation ecosystem, making the system better adapt to changes in the external environment, enhancing its anti-interference ability and post-damage repair ability, the stability of innovation ecosystem and the sustainable development of the system can be greatly improved.

2.2. Resilience Evaluation Dimensions

2.2.1. Diversity of Innovation Subjects

For natural ecosystems, biodiversity is a key factor affecting the stability of system resistance. For the innovation ecosystem, the diversity of innovative organisms is an important basis for ensuring stable connections between the various subjects of the system under external shocks. On the one hand, diversity is reflected in the variety of innovative subjects in the system. The more types of innovation subjects, the more complex the relationship network between subjects, the smaller the impact on the system when the single chain got the external shocks, the higher the fault tolerance rate of the system, and the stronger the resistance to external shocks. Diversity, on the other hand, is reflected in the order of magnitude of innovative agents within a single population of the system. With the increase in the number of innovative subjects of the same group, the rate of system innovation will also accelerate. In addition, the greater the number of innovation entities of the same kind, the less likely a single species will be destroyed by external shocks, and the greater the space for trial and error in the innovation system, which can improve the success rate of system innovation to a certain extent.

2.2.2. Buffering

The buffering of the innovation ecosystem is an important basis for responding to external shocks, playing an important role in weakening the negative impact of external shocks on the system, maintaining the organizational structure of the system, and resisting stress^[14]. The strength of buffering is mainly reflected in the complexity of the internal structure of the system and the advantages of the system resource endowment. The more complex the system structure, the stronger the internal support capacity, the more obvious the external resistance ability. The system resources are rich, and innovative resources that exceed the demand can be used as a backup to cope with the short-term collapse of the system caused by excessive external shocks.

2.2.3. System Vitality

For the innovation ecosystem, the diversity of subjects and the strength of system buffering are mainly reflected in the stability of the system's resistance when it is subjected to external shocks, while the advantages of system vitality are prominently reflected in the restoration of the system after it is damaged by shocks. The vitality of the system mainly includes the vitality of the main body of innovation, and the mobility of internal resources and technology. The evolution of the innovation subject is the main factor affecting its vitality. Whether the innovation subject can gradually evolve through self-adjustment and self-adaptation under the conditions of rapid changes in the external environment and restore its own vitality to restore the vitality and function of the ecosystem has a great impact on the resilience of the system. Each innovation subject maintains the normal operation and function of the system by realizing the interactive flow of innovation elements such as talent, information, technology, and capital through interconnection. The flow effect of various innovation elements within the system affects the response speed of the innovation ecosystem to short-term shocks, and also it has a greater impact on the material and resource mobilization ability of the system during the restoration period, which is an important threshold for improving the system repair ability and repair speed.

2.2.4. Sustainability

Sustainability reflects the co-evolution capability of the innovation ecosystem and the environment^[15]. It is reflected in the environmental friendliness, resource conservation, social security and economic sustainability of the innovation ecosystem. The sustainability of the innovation ecosystem ensures the ability of the system to operate stably for a long time. To a certain extent, it can weaken the intensity of external interference, which helps the system to achieve internal enhancement of support, improvement of repair power, external risk avoidance, reduction of interference probability, internal and external coordination, and exert the best state of system resilience.

3. Resilience Evaluation of Innovation Ecosystem in Liaoning Province

3.1. Development of High-tech Industries in Liaoning Province

Liaoning Province, located in the southern part of the Northeast Region, is an important junction of the Northeast Economic Zone and the Bohai Rim Economic Zone^[16]. This unique geographical location and resource endowment are a good foundation for promoting the development of high-tech industries in Liaoning Province. At present, the high-tech industry in Liaoning Province generally shows a trend of continuous growth. In 2020, Liaoning Province plans to identify 2,044 high-tech enterprises, forming an overall structure with Shenyang and Dalian national high-tech zones as the core and multi-point radiation^[17]. All high-tech enterprises work together continuously improve the overall high-tech development level of Liaoning Province.

The overall development trend of high-tech in Liaoning province is good. However, there are still some problems. For example, compared with those provinces with strong scientific and technological innovation capabilities, Liaoning Province has insufficient investment in R&D of innovative industries; although the number of high-tech zones is considerable, the industrial scale is relatively small and the nationwide competitiveness is relatively weak; the lack of professional and technical personnel, the loss of universities and scientific research personnel; the internal construction of the innovation ecosystem of high-tech enterprises is not perfect, and the development is relatively backward, etc.. This series of problems has affected the resilience of the

innovation ecosystem of high-tech enterprises in Liaoning Province to a certain extent, reducing their anti-interference ability and weak buffering capacity for external shocks.

3.2. High-tech Enterprise Innovation Ecosystem Resilience Evaluation Indicators

Based on the innovation ecosystem resilience evaluation indicators, combined with the current situation of high-tech enterprises in Liaoning Province, this paper proposes an innovation ecosystem resilience evaluation system, as shown in Table 1. The four dimensions of innovation ecosystem resilience evaluation are first-level indicators, and second- and third-level indicators are proposed according to regional characteristics and actual conditions to ensure the accuracy and comprehensiveness of the evaluation.

Table 1: High-tech enterprise innovation ecosystem resilience evaluation system

First-level Indicators	Second- level Indicators	Second- level Indicators	Direction
diversity of innovation subjects	talent diversity	proportion of employees with bachelor's degree or above	positive
		proportion of technicians	positive
	enterprise diversity subject order of magnitude	proportion of enterprises with R&D institutions	positive
		number of R&D institutions	positive
		number of high-tech enterprises	positive
buffering	internal structural complexity	enterprises innovation activities	positive
		number of internal departments	positive
		proportion of innovation-related departments	positive
	resource endowment advantage	invest in adsorption capacity	positive
		talent adsorption capacity	positive
		university distribution	positive
system vitality	innovation capital investment	scientific research expenditure	positive
		expenditure on research and test equipment and instruments	positive
	innovation output	number of SCI papers	positive
		CSSCI paper number	positive
	talent flow	university talent connectivity	positive
	information flow	"Internet +" index	positive
	technology stream	technology market technology contract inflow amount	positive
		technology market technology contract outflow amount	positive
	cash flow	fixed asset investment	positive
		foreign investment	positive
sustainability	environmental friendliness	industrial pollutant gas emissions	negative
	resource conservation	enterprise project energy consumption	negative
	social security degree	cumulative endowment insurance per capita	positive
		administrative monopoly level	negative
	economic	proportion of registered social organizations	positive
		per capita year-end deposit balance of financial	positive

	sustainability	institutions	positive
		end-of-year loan balance of financial institutions per capita	

Source: Improved on Liang Lin et al. (2020)

At present, most of the research and analysis methods such as the TOPSIS entropy weight method^[18], the improved entropy method^[13], and the qualitative comparative analysis method^[12] are used to evaluate the resilience of innovation ecosystems and get the measurement results in provinces or cities.

3.3. Analysis on the Resilience of the Innovation Ecosystem of High-tech Enterprises in Liaoning Province

For high-tech enterprises in Liaoning Province, the resilience of their innovation ecosystems is currently at an intermediate level in the country, and there is still much room for improvement in the specific indicators under the resilience evaluation system of some innovation ecosystems.

As of 2019, there were a total of 17,969 R&D institutions in the country, mainly located in Guangdong Province and Jiangsu and Zhejiang provinces, accounting for 38.0%, 19.4% and 10.1% respectively. In Liaoning Province, there are only 99 innovative R&D institutions for high-tech enterprises, accounting for only 0.5%. In addition, there are 78 enterprises with R&D institutions in Liaoning Province, accounting for about 0.5% of the whole country, and there are relatively few technical personnel in the enterprises. There is still much room for improvement in the diversity of talents and enterprises. The diversity of innovation subjects of in Liaoning Province is relatively weak.

Data show that in 2019, 33.1% of high-tech enterprises in Liaoning Province carried out innovation activities, of which about 61% of enterprises carried out technological innovation activities. However, in eastern regions of China, such as Jiangsu and Zhejiang provinces, the proportion of high-tech industries carrying out innovation activities in the province can reach 55.5% and 51.9%, and the proportion of technological innovation activities can reach about 80%. Compared with such areas, the types of innovation activities of high-tech enterprises in Liaoning Province are relatively simple, and the innovation activities are not extensive and universal enough. Furthermore, 34.7% of the province's industry-university-research cooperation enterprises carry out innovation cooperation enterprises, and the degree of integration between enterprises, universities and scientific research institutions is not strong, which also affects the buffering ability of the innovation ecosystem of high-tech enterprises in Liaoning Province.

China's technology export market is mainly concentrated in the eastern region. In 2019, the eastern region accounted for 63.62% of the total export contract value of the national technology market, while the north-eastern region accounted for only 5.65%. In recent years, the total output of the technology market in Liaoning Province has continued to increase, showing a good trend. In 2019, the total output contract value of the technology market reached 55,759,040,000 RMB yuan, accounting for 2.49% of the national total, which was at an upper-middle level. However, for the vitality of the innovation ecosystem of high-tech enterprises in Liaoning Province, there is still a room for improvement.

4. Future

4.1. Strengthening the Government's Macro-guidance in Liaoning Province

Government's Macro-guidance provides assurance for optimizing the innovation ecosystem and improving its resilience by creating a good external environment for the innovation ecosystem of

high-tech enterprises. The government promotes the aggregation of innovation resources to the innovation ecosystem of high-tech enterprises through fiscal policies such as tax credit or tax leverage, and so on, to improve the allocation efficiency of innovation resources. Relying on key scientific research institutes, research institutions and key universities in Liaoning Province, we can effectively integrate scientific and technological resources and solve the key problems that restrict the development of high-tech enterprises in Liaoning Province. Promulgate legal provisions to limit resource monopoly behaviour, strengthen investment supervision, improve risk exit mechanisms, establish and improve social security systems, etc., to create a stable external environment for the high-tech enterprises innovation ecosystem.

4.2. Promote Industry-University-Research Joint Mechanism in Liaoning Province

Improve the innovation system of Liaoning Province and promote the joint mechanism of production, education and research. Optimize the existing system of high-tech enterprise innovation ecosystem in Liaoning, including enriching the types of enterprise innovation ecological activities, increasing the frequency of technological innovation activities, broadening the audience of enterprise innovation activities, and strengthening Liaoning's high-tech enterprises resilience by improving internal buffer of innovation ecosystems. In addition, explore a new mechanism for the joint development of production, education and research in the province with high-tech enterprises in Liaoning Province as the core, accelerate the integration of innovation resources in the province and speed up the flow of scientific and technological elements across industries. It forms a new model with high-tech enterprises to take the lead and scientific research institutions and universities as follow. It promotes the stable development of the province's innovation ecosystem.

4.3. Increase the Attractiveness of High-tech Talents in Liaoning Province

Emphasis on personnel training, and improve the attractiveness of high-tech talents in Liaoning Province. Scientific and technological talents are the cornerstone of the development of high-tech enterprises and one of the key elements affecting the innovation level of the province. Improve the talent training system in Liaoning Province, and increase investment in talent training in universities and research institutes in response to the shortage of urgently-needed professional in high-tech innovative enterprises. In addition, learn from international and domestic advanced experience, optimize the management measures for high-tech talents, and attract high-tech talents from all over the country and even overseas through a more relaxed work and employment system, more flexible salary and welfare system, to improve the talent training and adsorption capacity of Liaoning Province. In this way, the resilience of the innovation ecosystem of high-tech enterprises in the province will be promoted.

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