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Development Status and Evolution Analysis of Cooperative Innovation Network in The New Energy Vehicle Industry

Chunyu Wang

School of Management, Xi'an Polytechnic University, Xi'an, Shaanxi, 710048, China

Abstract: As a strategic emerging industry, new energy vehicles are very important to the economic development of a country. The new energy vehicle industry has entered a new stage of accelerated development. However, at present, there is still a gap between the driving force of technological innovation in China's new energy vehicle industry and developed countries, and the cooperation and innovation of enterprises in the industrial chain still need to be improved in terms of complementarity and closeness of cooperation. Based on the cooperative patent data of enterprises in the new energy vehicle industry from 2010 to 2020, this paper divides it into three stages, and uses the spatial analysis tool of ArcGIS software to systematically analyze the spatial distribution characteristics of cooperative innovation networks in various provinces. The results show that more and more enterprises are choosing collaborative innovation. The conclusions of this study can put forward relevant policy suggestions for enterprises in China's new energy vehicle industry to achieve high-quality technological innovation.

Keywords: New energy vehicle industry; Enterprise cooperation network; Technological innovation.

1. Introduction

At present, the world is experiencing a new round of scientific and technological revolution and industrial transformation, and accelerating the development of key core technologies, which is an important tool for the country, is of great significance to promoting the high-quality development of China's economy. As a strategic emerging industry, new energy vehicles are crucial to a country's economic development. The new energy vehicle industry has entered a new stage of accelerated development, and the "New Energy Vehicle Industry Development Plan (2021-2035)" clearly states that collaborative innovation is very important for the future development of the new energy vehicle industry, and it is also the key for the industry to overcome market barriers and form industrial competitive advantages. The development of the industry itself requires the linkage development of upstream raw material enterprises and key parts enterprises in the midstream related to the industrial chain, as well as downstream vehicle enterprises and charging equipment enterprises, so as to promote the overall improvement of the industrial chain. However, at present, there is still a gap between the driving force of technological innovation in China's new energy vehicle industry and developed countries, and it is difficult to break through key core technical barriers, such as power batteries and engine transmissions in the new energy vehicle industry [1], and the zero-whole cooperative relationship between enterprises needs to be improved urgently.

Enterprises in different positions in the new energy vehicle industry, as technology demanders, it is often difficult to achieve technological innovation only by relying on internal research and development [2], while enterprise cooperation and innovation in the industrial chain can achieve resource sharing, provide enterprises with more comprehensive technical information, and facilitate technological innovation. However, the cooperation and innovation of enterprises in the new energy vehicle industry still need to be improved in terms of complementarity and closeness of cooperation, so the cooperation and innovation of enterprises on the chain has become an urgent problem to be solved. Although some studies have examined the cooperation network of new energy vehicles at the micro level, there are still the following shortcomings. Firstly, although the evolution of the collaborative innovation network of the new energy vehicle industry is analyzed [3], it does not focus on the cooperative innovation network of enterprises, and secondly, the influence of the position of the cooperative innovation network of enterprises is ignored, and how to achieve high-quality technological innovation by enterprises in different positions of the industry needs to be further demonstrated.

To this end, this paper attempts to explore the problem of enterprise cooperation and innovation in different positions of the new energy vehicle industry, focusing on the enterprise level, and exploring the dynamics of the cooperation network of the participants in the enterprise cooperation and innovation network in the new energy vehicle industry and its significance to the innovation and development of enterprises in the industrial chain.

2. The Composition and Development Status of The New Energy Vehicle Industry

2.1. Composition of the new energy vehicle industry

The new energy vehicle industry refers to an emerging industry with new energy vehicles as the core, involving the production and follow-up services of new energy vehicles, covering the entire industrial chain. New energy vehicles refer to vehicles that use on-board power supply as power, use new energy instead of traditional fuels (such as gasoline and diesel) as power sources, and integrate advanced technologies into vehicle power control and drive to form automobiles with advanced technical principles and the characteristics of adopting new technologies, new processes and new structures.

New energy vehicles aim to reduce dependence on fossil fuels, reduce tailpipe emissions, reduce environmental pollution, and promote the transformation and sustainable development of the energy structure. As an important carrier of cross-industry and cross-professional innovation and integration, new energy vehicles are promoting far-reaching changes in the form of automobile products, urban transportation modes, energy conservation and environmental protection concepts and social development models, and providing new ideas and new solutions for exploring between the popularization of automobile use and solving social problems such as natural environment, power energy, and transportation, which involve a wider range of links in the industrial chain.

The new energy automobile industry is a huge and complex industrial system, nested with a number of small cycle of growth industry, its industrial chain is composed of many scattered industrial nodes, through the vehicle manufacturing will be integrated into a whole, the whole and interconnected parts of the industrial chain is the way of existence, with integrity, relevance, synergy of the main characteristics. The overall industrial structure of new energy vehicles is more complex than the general automobile industry structure, with hundreds of related industries, which are mainly extended on the basis of the traditional automobile industry, thus giving birth to a new huge industrial chain.

The structure of the new energy vehicle industry consists of three parts: upstream, midstream and downstream. Among them, the upstream mainly includes all kinds of non-ferrous metals and chemical raw materials and other production enterprises, and the midstream refers to the vehicle manufacturing and core parts processing of new energy vehicles, the technical level and production capacity of these enterprises directly affect the performance and quality of new energy vehicles, and at the same time need to continuously promote technological innovation and product upgrading to meet the needs of consumers and market changes. Downstream refers to the sales and service channels of new energy vehicles, including car dealers, charging pile operators, power companies, etc. These companies need to continuously improve service quality and user experience to provide consumers with more convenient and efficient services.

(1) Upstream: non-ferrous metals and chemical raw materials

In the industrial chain of new energy vehicles, the upstream part mainly focuses on the supply and primary processing of raw materials. Among them, key mineral resources such as lithium, cobalt, nickel, graphite and rare earths are mined, screened and preliminarily processed and converted into core components such as cathode and anode materials, electrolytes and separators for batteries. These mineral resources are the core elements of the power battery, drive motor and electronic control system ("three-electric system") of new energy vehicles. Their stable supply plays a crucial role in the production of core components.

(2) Midstream: component manufacturing

The midstream segment is mainly involved in the manufacture of parts and components. With the intensification of market competition and the rapid iteration of technology, many enterprises in the fields of batteries, motors and electronic control have realized the importance of establishing in-depth cooperative relations with raw material suppliers. By working closely with high-quality suppliers in materials, equipment and other links, enterprises can not only reduce losses caused by fluctuations in raw material prices, but also ensure the continuity and stability of product production. Therefore, the raw material link and the core component link are increasingly inseparable.

(3) Downstream: vehicle manufacturing, service and downstream applications

The downstream links mainly cover vehicle manufacturing, charging services, aftermarket services, etc. The product system of the whole vehicle product is extremely complex, and it has significant advantages in terms of technology development and mass production. At the same time, emerging car manufacturers have broken through the traditional automobile production ideas with a sense of technology and cost performance as the core, focusing on meeting the changing travel needs and driving experience of consumers, and the market recognition of this innovative product concept is also increasing. With the popularity of new energy vehicles, charging services have become a huge market. This includes everything from charging equipment, battery swapping equipment, and battery recycling. At the same time, aftermarket services are also a non-negligible part of the new energy vehicle industry chain. This includes auto finance, auto insurance, car rental, second-hand car trading, auto repair, and auto teardown and recycling. With the continuous expansion of the new energy vehicle market, these service areas will also usher in huge development opportunities.

To sum up, the supply of raw materials and primary processing in the upstream of the new energy vehicle industry chain, the manufacturing of parts in the midstream, and the vehicle manufacturing and service in the downstream are closely linked, which together constitute a complete ecology of the new energy vehicle industry. With the continuous progress of technology and the continuous expansion of the market, this industrial chain will continue to deepen and improve, providing solid support for the popularization and development of new energy vehicles.

2.2. Development status of new energy vehicle industry

With the increasing attention to environmental protection and sustainable development around the world, the new energy vehicle industry has become the focus of competition for development in various countries. As the world's largest automobile market, China attaches increasing importance to the new energy vehicle industry. From the initial exploration to today's rapid development, the new energy vehicle industry has shown a steady and strong momentum of development.

In the initial development stage of the new energy vehicle industry, the development speed of power battery, as the core technology, has played a decisive role in the entire industry. Initially, due to technical bottlenecks, the performance and cost of power batteries have become the key factors restricting the development of the industry. However, with the continuous progress of technology, China has made significant breakthroughs in battery technology, such as the energy density and life of lithium-ion batteries have been greatly improved, laying a solid foundation for the rapid popularization of new energy vehicles. In 2010, the government listed the new energy vehicle industry as one of the seven strategic emerging industries, bringing unprecedented development opportunities to the entire

industry. In order to accelerate the development of the industry, the central and local governments have introduced a series of policies, including car purchase subsidies, tax exemptions, charging infrastructure construction, etc., which have greatly stimulated the vitality of the market. Driven by policies, China's new energy vehicle industry has shown explosive growth since 2015. Not only the production and sales volume has been rising year after year, but also the technical level is constantly improving. Today, China's new energy vehicle industry chain has been initially formed, covering battery manufacturing, motor manufacturing, electronic control systems, charging facilities and other fields. Especially in terms of battery technology, China has a complete industrial chain from raw materials to battery recycling, and has become an important pole of the global battery industry.

However, despite the remarkable achievements of China's new energy vehicle industry, it still faces many challenges. Among them, the most prominent problem is the independent and controllable key core technology. At present, China still relies on imports in core technologies such as batteries, motors, and electronic controls, which not only increases costs, but also limits the development space of the industry. In addition, issues such as the cruising range and charging time of new energy vehicles are also important factors restricting their popularity. In order to overcome the above challenges, it is necessary to strengthen the coordination and cooperation between the upstream and downstream enterprises of the industrial chain, form a close industrial chain cooperative relationship, etc., promote the collaborative promotion of technology research and development among the main bodies of the new energy vehicle industry, jointly overcome key core technologies, and promote the upgrading of the industrial chain.

3. Retrieval and Collection of Patent Data in The New Energy Vehicle Industry

This paper uses the cooperative patent application data of China's new energy vehicle industry to construct a patent cooperation network and analyzes its evolution law. Patents are the product of technological innovation and are often used to measure the level of innovation ability. In particular, the data of joint patent applications can clearly reflect the cooperative interaction between innovative subjects [4]. The CIN data is derived from the "Applicant" section of the Access to Patent data. Since the purpose of this paper is to explore the impact of the location of the cooperative innovation network on key core technology breakthroughs, only the "applicants" of enterprises and enterprise types are considered. In the final cooperative innovation network diagram, each enterprise is used as the node, and the connection between the nodes represents the cooperation between the two enterprises. Therefore, this paper chooses to use the data of joint patent applications from 2010 to 2020 to study the patent cooperation network of enterprises in China's new energy vehicle industry.

The data obtained in this paper for joint patent applications in China's new energy vehicle industry are from the Dawei Innojoy patent database. According to the IPC classification number of key technologies in the industry determined in the Reference Relationship Table of the National Strategic Emerging Industry Classification and the International Patent Classification, a total of 80,610 invention patents were retrieved with the keywords of "new energy vehicles", "pure electric vehicles", "fuel cell vehicles", "plug-in hybrid electric vehicles" and "electric vehicles". Then, clean and screen the data, delete the data that do not meet the research requirements, such as the invention patent of the applicant as a non-enterprise, the patent information is incomplete, the repeated invention patent and other data, and retain the effective data with the publication (announcement) date of "20100101:20201231", and at the same time, in order to facilitate network analysis, sort out some patent data, such as enterprises that have changed their names between 2010 and 2020, and unify their names. Finally, if two or more companies appear in the "Applicant" field of the same patent together, they are considered to have a cooperative relationship. This approach largely reflects the exchange and interaction of knowledge between firms, and the partnerships captured through patents are real and more objective and reliable. In the end, the number of joint patent applications for China's new energy vehicle industry from 2010 to 2020 was 1,283, and a total of 402 entities participated in cooperative innovation.

4. The Overall Situation of The Cooperative Innovation Network of The New Energy Vehicle Industry

From 2010 to 2020, the number of cooperative patent applications and the number of applicants in China's new energy vehicle industry showed an upward trend as a whole, as shown in Figure 1. First of all, from the perspective of the number of cooperative patent applications, from 2010 to 2013, the number of jointly applied patents increased rapidly, from 38 in 2010 to 116 in 2013, and there was a slight downward trend in the next two years, and after 2016, the number of patents jointly applied by enterprises showed a fluctuating upward trend, but the number of cooperative patent applications was more than 100, and in 2020, it reached the level of 203 applications. Secondly, from the perspective of the number of applicants, the number of entities participating in joint patent applications has increased from 22 in 2010 to 161 in 2020, and the number of cooperative entities has increased several times in just ten years, which shows that cooperative innovation has become an important trend of enterprises, and the nodes of cooperative innovation networks are increasing and the scale of the network is expanding.

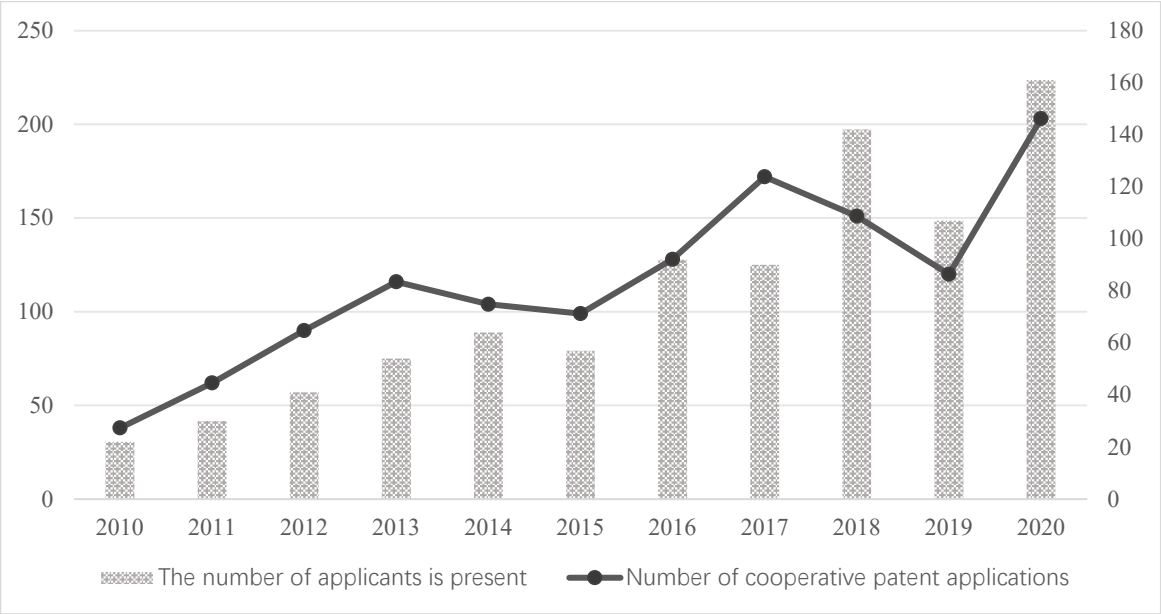

Figure 1. Trend of the subject and number of patent applications in the new energy vehicle industry

As shown in Figure 1, through analysis, it can be found that the number of invention patents jointly applied for by China's new energy vehicle industry is generally increasing, which can be roughly divided into three stages: the first stage from 2010 to 2014, the second stage from 2015 to 2017, and the third stage from 2018 to 2020.

In the first stage, in 2010, the "State Council on accelerating the cultivation and development of strategic emerging industries" in the new energy vehicle industry included in China's seven strategic emerging industries, after 2010, China's new energy vehicle industry entered a period of rapid development, this stage lasted until 2014. In the second stage, before 2015, new energy vehicles were in their infancy, and most of them were "oil-to-electricity", that is, transformed from traditional fuel vehicle platforms. In 2015, the State Council issued the plan "Made in China 2025", which proposed a new development direction of "improving the collaborative innovation capabilities of core technologies such as advanced transmissions, hybrid systems, and intelligent control, forming a complete innovation system from key components to vehicles, and promoting the development of collaborative innovation networks in the new energy vehicle industry" [5]. The government has gradually reduced the subsidy policy for new energy vehicles, major automobile manufacturers have successively launched new energy vehicle platform development plans, and joint R&D and sharing platforms between enterprises have become common. Until the third stage, in 2018, in order to further increase the energy density threshold requirements of pure electric vehicles, non-fast charging pure electric buses, and special vehicle power battery systems, the application of high-performance power batteries was encouraged. The state has adjusted and optimized the subsidy standards for new energy vehicles, and reasonably reduced the subsidy standards for new energy vehicles. As a result, new energy vehicle industry enterprises have once again entered a new stage of development.

This paper measures the cooperative innovation network of large and small enterprises in the new energy vehicle industry from 2010 to 2020, in which 2010-2014 is the embryonic stage, 2015-2017 is the growth stage, and 2018-2020 is the mature stage, in the embryonic stage, the network scale is 100 enterprises for cooperative innovation, and it has increased to 135 enterprises in the growth stage, and finally has reached 264 enterprises in the mature stage。 At the same time, the network density decreased from 0.023 in the embryonic stage, to 0.016 in the growth stage, and finally to 0.009 in the mature stage, showing a significant downward trend, indicating that although the number of network subjects and connections increased, the connection between nodes was not close. The average path length and clustering coefficient in the budding stage were 2.124 and 0.789, respectively, and the average path length and clustering coefficient in the growth stage were 1.194 and 0.886, respectively, and in the mature stage, the average path length and clustering coefficient were 2.294 and 0.781, respectively, with slight fluctuations, indicating that with the development of the new energy vehicle industry, the cooperative innovation relationship between enterprises tends to be stable, and there is a certain degree of clustering phenomenon, that is, the proportion of enterprise cooperative innovation activities in the new energy vehicle industry is gradually increasing.

5. Patent-based Collaborative Innovation Cyberspace Evolution Analysis of The New Energy Vehicle Industry

According to the three stages of the enterprise cooperation network of the new energy vehicle industry, this paper uses ArcGIS software to visualize and analyze the spatial pattern of the cooperative innovation network of enterprises in China's new energy vehicle industry from 2010 to 2020. The results show that from 2010 to 2014, the cooperative innovation activities among enterprises are mainly concentrated in large cities: Beijing, Tianjin, Shanghai, and Jiangsu have a higher frequency of cooperative innovation activities. In the embryonic stage, a total of 15 provinces participated in the cooperation, with Beijing and Jiangsu having the highest number of cooperation, with 10 cooperation, followed by Beijing and Shanghai with a total of

7 cooperation. In the growth stage, there was a slight change in the number of cooperative provinces, with a total of 16 provinces being connected, Beijing and Henan cooperating 9 times, Tianjin cooperating 7 times, and Hainan and Shanghai cooperating 8 times, which shows that in addition to the cooperation carried out with Beijing as a node, the number of cooperation between other provinces has also begun to increase significantly. In addition, the number of cooperation between Hainan and Henan reached 14 times, the number of cooperation between Beijing and Tianjin reached 12 times, the number of cooperation between Zhejiang and Sichuan reached 11 times, and the number of cooperation between Jiangsu and Guangdong reached 10 times. More importantly, the provinces and cities with more frequent cooperation are all regions with strong innovation ability and more developed economy, and this spatial distribution pattern also reflects that enterprises maintain a more cautious attitude towards cooperative innovation, and the regions with poor innovation ability are less involved in the cooperative innovation network, and the overall spatial distribution pattern spreads outward in the network with Beijing as the core.

6. Conclusions and Recommendations of the Study

6.1. Research Implications

Taking the enterprise cooperation network in the new energy vehicle industry as an example, this paper focuses on specific industries, breaks through the limitations of previous broad research that only focuses on the impact of industry-university-research collaboration on technological innovation, opens up new ideas of enterprise cooperation and technological innovation to a certain extent, and makes up for the shortcomings of existing research that only focuses on industry-university-research cooperation mode. In the new era of fierce competition, the cooperative innovation network structure of enterprises in the new energy vehicle industry is gradually becoming complex and balanced. The connections between network nodes in the cooperative innovation network are constantly enriched, and more and more node provinces occupy an important position in the cooperative innovation network. At the same time, the network structure has been continuously optimized, more and more enterprises have participated in the cooperative innovation network, the number of cooperation between enterprises has increased year by year, and the number of patents for cooperative inventions has also increased significantly. In addition, there are more and more connections between provinces, not only between enterprises in the same province to cooperate and innovate, but more and more enterprises have begun to cooperate across provinces. It shows that in the development process of the new energy vehicle industry, enterprises pay more and more attention to participating in the cooperative innovation network and promoting their own development while sharing resources.

6.2. Research Recommendations

The above conclusions provide important enlightenment for the cooperative innovation network of enterprises in the industrial chain to improve their core competitiveness and realize technological innovation. First of all, in order to promote the cooperation of enterprises in the new energy vehicle industry to achieve technological innovation, local governments should play a role in attracting high-quality and further opening up to the outside world by improving the innovation policy system and implementing targeted financial subsidies, and encourage enterprises in the industrial chain to cooperate and innovate, so as to activate the overall situation from point to area. Secondly, the incumbent enterprises should learn to make full use of the superior resources of different enterprises in the industry, strengthen the management of innovation openness, introduce external knowledge and technology through an open innovation model, and strengthen the accumulation, integration and application of existing knowledge within the enterprise, and promote knowledge intersection and integration, so as to cope with the complexity and diversity of new energy vehicle industry technology, so as to better promote technological progress.

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