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Measuring China's new energy vehicle patents: A social network analysis approach

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Due to increasing concerns on climate change, air pollution, and associated public health, China's new-energy-vehicle (NEV) industry has received great support and experienced rapid development. Many patents have been approved and applied in this field to support its rapid development. However, few studies investigated the evolution of these patents. Under such a background, we measure China's NEV-related patents by using a social network analysis approach. The top 38 organizations with the most NEV-related patents were chosen as the study targets. Patent numbers, technological innovation and development, and the geographical distribution of patents were examined. The cooperation network of NEV-related patents was also investigated, including its features and performance during different stages of the NEV growth. The results show that China's NEV-patents cooperation network has evolved smoothly with a growing network density, stable structure, and more cohesive subgroups. Policy recommendations were raised by considering the Chinese realities, such as the encouragement of cooperation, the creation of NEV-related patents pools, and the roles of various stakeholders.

1. Introduction

The global energy crisis and increasing transportation pollution has led to an urgent need to transfer fossil fuels-based vehicles to new energy vehicles (NEVs) [1,2]. Since the beginning of the 21st century, the NEVs industry has experienced unprecedented development. Different from traditional diesel or gasoline-based vehicles, new energy vehicles (NEVs) generally refer to hybrid electric vehicles (HEVs), especially plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs). Due to their significantly less emissions, NEVs have received wide acceptance worldwide. Many countries released preferable policies to support their application, such as free vehicle plates, governmental subsidies, rapid development of charging stations, cheaper insurance fees, etc [3]. In particular, as the world's largest vehicle market, China has endeavored to support NEVs to address air pollution, climate change and public health concerns. In 2001, China launched a national major research project to solve some fundamental problems related to electric vehicles. In 2009, with the strong governmental support, the NEVs industry was listed as one of the seven strategic emerging industries. To date, China has been the largest stock of NEVs in the world, with cumulative sales of over 1.7 million units until December 2017, including passenger cars and heavy-duty commercial vehicles such as buses and sanitation trucks.

As a representative of emerging industry, NEVs adopt emerging technologies and the core of their industrial competitiveness depends on technological innovation (Ruan et al., 2017; Song et al., 2017) [4,5]. One direct output of technological innovation is patent, which reflects the latest technology progress and can serve as an effective measure on one enterprise's research and development (R&D) capacity. These patents can be classified and integrated for data analysis so that valuable information can be obtained. Such information is valuable for analyzing technological development trend, position of the investigated enterprise in the whole sector

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and cooperation between different patentees. However, several academic questions still remain and need to be further addressed. For instance, what patent strategies should be adopted in order to protect the innovation achievements in this new field? What type of cooperation model should be supported to protect the benefits of patentees and promote the development of the NEVs industry? This paper attempts to answer these questions by applying a social network analysis method.

In recent years, industrial innovation has become a hot research topic. Baum et al. simulated how companies choose partners by building a network evolution model and concluded that knowledge complementarity plays an irreplaceable role and might be the real driving force for cooperative alliance [6]. Based on the dynamic analysis of two competitive innovation networks, Blundel investigated the different roles played in the innovation network by technological capability and industry dynamics [7]. Jiang et al. discussed the dynamic evolution of techno-innovation network structure from the viewpoint of network embeddedness [8]. Based on Motorola's innovative network, Chen and Vang examined the status and evolution of developing countries in the global innovation network of transnational corporations [9]. Battke found that, compared with peripheral knowledge, core knowledge is more likely to adapt to the flow of knowledge within the technology, and it is unlikely to penetrate into other technologies [10]. Geerts et al. discussed the role of the geographical dimension in explaining the ambidexterity-performance relationship and evaluated the benefits of geographic proximity between technology exploitation and exploration [11]. Binz and Truffer proposed a framework to analyze technological innovation processes in transnational contexts [12]. In addition, Hao et al. quantitatively evaluated the impact of stepped pattern of fuel consumption rate targets on automaker's lightweighting innovation strategy based on China's domestic automotive market data [13].

With regard to the development of the electric vehicle industry, several studies focused on patents and technological innovation for NEVs. For instance, taking Japan as an example, Ahman discussed the relationship of government policy and the development path of electric vehicles [14]. Brown et al. studied the role and importance of standards in an emerging market for electric vehicles [15]. Christensen argued that sharing components of power-transmission systems, such as battery power systems, hybrid power, and fuel systems, helped to implement the modular strategy [16]. Based on a comparative analysis of the entire invention patents and joint patents, Wang and Zhu examined patents development in China's NEVs industry from the perspective of industry-university-institute cooperation [17]. Bär made a comparative study of the two major NEVs countries (China and Germany) [18] and found that the development patterns of the two countries are entirely different. While China chose a government-fostering pattern, Germany adopted a market-oriented strategy. Moreover, Bär also mentioned China's strength in lithium-ion-battery technology. Based on patent data for electric vehicles, Yang et al. investigated the correlation between the relevant policies concerning electric vehicles in China and the trends in the associated technological development [19]. Yuan et al. presented a comprehensive and critical review of the policy framework for NEVs in China and discussed the development of NEVs for a sustainable future [3]. Zhang et al. analyzed how EVs will penetrate in the market, and estimated the resulting impacts on energy consumption and CO_2 emissions up to 2030 [20]. Furthermore, Ou et al. analyzed the life cycle energy consumption and GHG emissions of China's current and future multi vehicle energy technologies [21].

In general, NEVs battery technology has developed relatively slowly compared with other NEVs fields. For example, Van den Hoed gave an example of fuel-cell technology in the automotive industry [22]. Yang and Chen introduced the concept of the transnational patent and used a patent-comparative-advantage index to compare the advantages of electric vehicles in China with other NEVs power sources [23]. They concluded that the development of China's NEVs industry is imbalanced. Liu and Kokko argued that government support is needed to balance the cost advantages of traditional cars while private firms fall outside the alliances and rely on foreign collaborations [24]. Gong et al. found that lead-acid battery technology is a substantial factor in the high-volume sales of top NEV car models because of the constraints imposed by price and technological maturity [25]. In addition, Wang et al. assessed the energy reduction associated with NEVs compared with conventional vehicles (CVs) for real-world driving conditions in Beijing, China [26]. Zhao et al. evaluated the life-cycle cost and emissions of NEVs in China [27]. Chen et al. used data mining to analyze the patent-cooperation network of the top 100 patentees with the most low-carbon-vehicle patents and examined their overall characteristics [28]. Oltra and Jean analyzed the competition between the various technologies for NEVs as well as the innovative strategy of car manufacturers [29]. Frenken et al. analyzed R&D portfolios in environmentally friendly automotive propulsion including alternative fuel options [30]. Haslam et al. did a bibliometric analysis for FCV technology based on the theoretical framework of Rogers' innovation diffusion curve [31]. Finally, Sakthivel et al. introduced the current and future scenarios of Indian transportation, petroleum oil, and bio-fuel sectors including global progress on using ethanol as an alternative transportation fuel in spark-ignition vehicles [32].

These studies mainly focus on the direct analysis of patent data, such as the distribution of patent numbers and patent applicants and other preliminary descriptive statistics. Social networks and other methods were used to study the evolution of the NEV patent-cooperation network. However, few scholars measured the potential of the patent pool based on China's NEV patent data. By establishing patent cooperation network and evolution analysis, this study aims to uncover the potential of the NEVs industry's technological innovation and patent-pool construction in China.

The remainder of this paper is structured as follows: Section 2 depicts research methods and data, Section 3 presents the research results, Section 4 presents policy recommendations and Section 5 draws research conclusions.

2. Methods and data

2.1. Data sources

The patent data used in this paper are derived from the patent retrieval and analysis system built by the State Intellectual Property Office of China (SIPO). Scholars usually use the international patent classification number (IPC) or keywords search method, or combine the two methods when searching for new energy vehicle technology patents. One drawback of this IPC retrieval is that the determination of classification number is controversial, which may cause omissions. The keywords search method can be combined to retrieve the technology of different patent classifications by defining key words. It can overcome some shortcomings of the IPC retrieval method and ensure the accuracy of the patent information. However, the IPC classifications for some emerging industries have some problems. For example, a number of IPC classifications may exist in one patent. In order to solve such a problem, we adopt keywords search method to avoid omissions [29–31].

The keywords used in this study include hybrid electric vehicle, electric vehicle, plug-in electric vehicle, and fuel vehicle. All of them were defined by Ministry of Industry and Information Technology of the People's Republic of China in 2009. The investigation