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Exploring Driving Forces of Sustainable Development of China's New Energy Vehicle Industry: An Analysis from the Perspective of an Innovation Ecosystem

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Received: 12 November 2018; Accepted: 14 December 2018; Published: 18 December 2018

Abstract: The sustainable development of the new energy vehicle (NEV) industry is receiving increasing attention worldwide. However, as a "catch-up" country in the automobile industry, China has made remarkable achievements in NEV industry development. To explore this phenomenon, this paper develops an "innovation-demand-policy" (IDP) framework to investigate the driving forces of sustainable development of the NEV industry from the perspective of an innovation ecosystem. Based on a comprehensive data collection and processing of interviews, patents, industry reports, and policy documents, the findings showed that technological innovation, market demand, and government policy drive NEV industry development together, and policy can play an effective role of coordination only when it follows an innovation process and market demand selection mechanism. Specifically, technological grafting, potential market demand, and supply-side policy create a minimum viable ecosystem and the embryonic form of the NEV industry. Technological breakthroughs, public demand, and demand-side policy enhance the NEV industry's ability to grow via a platform ecosystem. Additionally, total innovation, private demand, and environmental-side policy upgrade the NEV industry through expanding and reconfiguring the innovation ecosystem. This study also provides suggestions for policymakers and industrialists to promote sustainable development of the NEV industry in the future.

Keywords: new energy vehicle industry; sustainable development of industry; driving forces; innovation ecosystem; government policy

1. Introduction

The motor vehicle population in China increased from 159 million in 2007 to 310 million in 2017, almost doubling in the last decade [1]. Traditional fuel vehicle exhaust has become a severe source of air pollution in China, especially in Beijing, Shanghai, other large cities, and more populated areas. This exhaust is responsible for 20%~40% of PM2.5 [2]. The rapid expansion of motor vehicle ownership has also caused the dependence on oil in China to increase from 47% in 2007 to 67% in 2017 [3]. Undoubtedly, China is expected to become the world's largest oil-consuming country in the near future. China laid the foundation for the automobile industry through a "trading market access for technology" strategy and has been the largest automobile producing and marketing country since 2009 [4,5]. However, China is in an awkward position because its automobile industry is large rather than powerful and has not changed because of the lack of core technologies and independent famous brands.

The sustainable development of the NEV industry is receiving increasing global attention. In China, the NEV industry was declared to be one of seven strategic emerging industries tasked with reducing environmental pollution, reducing fossil energy consumption, and upgrading the automobile industry and related supporting industries [6]. NEVs are defined as vehicles using unconventional fuel power sources or new power devices, and we focus on pure electric vehicles (PEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell vehicles (FCVs) in this paper.

Since 2015, China has ranked first in the world in terms of NEV ownership [7]. By the end of 2017, NEV ownership reached 1.53 million [1], which is equivalent to 50% of the global total. A number of domestic automobile enterprises—such as BYD, BAIC, Geely, and CHANA—are devoted to developing and producing national NEVs. For example, BYD has been number one in world NEV sales for the last three years, and both BAIC and CHANA declared that they will stop selling traditional fuel automobiles before 2025. China has been a catch-up country in the traditional fuel automobile industry, so it is unclear why China can achieve the sustainable development of the NEV industry. A more comprehensive and systematic theoretical investigation needs to be conducted

Presently, the innovation paradigm has been changing and upgrading from an engineering and mechanical innovation system towards an ecological and organic innovation ecosystem [8]. An innovation ecosystem is a typical socioeconomic system that makes innovation happen [9]. The theoretical concept and practices of the innovation ecosystem suggest that innovation is the most important driver of socioeconomic change [10]. Emerging industry development is not only derived from technological change or other single factors, but also depends on the imbedded innovation ecosystem [11–13]. As a typical emerging industry, the sustainable development of the NEV industry in China could be attributed to multiple dominant factors from the perspective of innovation ecosystem. Thus, this paper focuses on this research object and attempts to solve two issues: identifying the key driving forces and the ways these drivers affect the sustainable development of the NEV industry via an evolving innovation ecosystem.

The remainder of the paper is arranged as follows: The second section provides the literature review and research framework. The third section describes the data collection and analysis methods. We analyze the driving forces of the NEV industry development in China in the fourth section and discuss the driving mechanism in the fifth section. In the last part, we summarize the conclusions and propose practical implications.

2. Literature Review and Research Framework

2.1. Theoretical Concept of the Innovation Ecosystem

Studies on the interdependences among industrial subjects using the metaphor of an ecosystem were published as early as 1993, when Moore proposed the business ecosystem, and later studies used an innovation ecosystem to highlight co-innovation activities [14]. Recently, it has become increasingly important for emerging industries that are driven by innovation to cultivate and manage multiple sub-ecosystems connecting science, technology, and commerce activities [13].

What is an innovation ecosystem? The more common definition was proposed by Adner [11,15] and Fransman [9,10]. Adner defines an innovation ecosystem as "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize," and Fransman's definition is that "an innovation ecosystem consists of a group of interdependent players and processes who together, through their interactions, make innovation happen." Their theoretical concept of the innovation ecosystem includes four specific aspects:

- All the players embedded in the innovation ecosystem have a focal value proposition and can create and obtain sufficient value together; additionally, the symbiotic producer-user of value creation, distribution, and transmission among these players form a value adoption chain.

- This co-innovation changes the products and services produced by the ecosystem via sharing complementary knowledge [10]. The success of an innovative product or service relies on the technical maturity and feasibility of upstream components and downstream complements, and the close innovation interdependence among these technologies forms a co-innovation chain.
- The co-innovation chain is helpful for realizing a focal value proposition based on the value adoption chain, and the value adoption chain guarantees the enthusiasm of the co-innovation chain. Thus, the co-innovation chain and the value adoption chain formed by the "internal" alignment structure of the multilateral set are the two cores of an innovation ecosystem [11,15].
- An innovation ecosystem exists in a broader socioeconomic environment. Path-breaking innovation activities that occur within an innovation ecosystem essentially challenge the existing mainstream socioeconomic regime. In other words, the "external" viability of the innovation ecosystem and the socio-tech environment are as important as the "internal" alignment of both chains within the innovation ecosystem [12]. Thus, "over time the innovation ecosystem as a whole evolves, as do its players and processes, as the variety of new products and services produced are subjected to various selection forces." [10]

2.2. Innovation Ecosystem Evolution and Sustainable Development of Industry

Digital innovation pressures traditional industry to cultivate and manage an innovative ecosystem during the process of innovation [16]. In addition, the innovation ecosystem is the core of the sustainable development strategy of emerging industries driven by science, technology, and commerce innovation, which are closely connected [13]. The NEV industry is a typical ecosystem based on a series of new technological changes and involves all kinds of stakeholders in the process of developing and commercializing these technologies [17,18]. The evolution of the innovation ecosystem is a process not only of technological change, but also of continuous coordination of the main subjects, tasks, and structures with market and policy, all of which can effectively enhance sustainable development of industry [19,20]. Therefore, developing the NEV industry is, in essence, cultivating and developing an industrial innovation ecosystem with high performance; conversely, to promote the synergistic evolution of the co-innovation chain and the value adoption chain (internal alignment), as well as the evolution of the innovation ecosystem and external environment (external viability), can lead to sustainable development of the NEV industry [12].

2.3. Key Drivers of Affecting NEV Industry Development

Scholars are concerned about the drivers of sustainable development of the NEV industry, and the majority of their studies mainly focus on the effects of technological innovation, market demand, and government policy on NEV industry development; these drivers are in line with the classification of driving forces proposed by Nemet [21].

2.3.1. Technological Innovation

As a typical emerging industry, the rise of the NEV industry is due to new technological breakthroughs in the fields of energy batteries, motors, electric controls, and so on. Recent studies suggest that technological innovation remains the bottleneck factor affecting sustainable development of the NEV industry [22,23]. Although China has been the largest NEV production base and the largest consumer market in the world since 2015, it lacks competitive core technologies [24]. Zhang, et al. even noted that among the factors influencing the diffusion of NEVs, technological performance is the most relevant [25].

Battery technology is a major obstacle to the popularization of PHEVs [26], and the technical support needed for the charging infrastructure, particularly for fast chargers [27], is the most important factor affecting consumers' decisions to buy PEVs [28]. Therefore, overcoming the technological bottlenecks and determining the scientific technological paths will help promote the sustainable development of the NEV industry [23,24].

In contrast to the business ecosystem, the innovation ecosystem emphasizes interdependence among technological innovations [29], which is the logical starting point for exploring the inner motives of the innovation ecosystem. Innovation is the most important driver of socioeconomic change via creating and injecting novelty into it [10]. The focal enterprise location [14,30], player diversity [31], complementary resource availability [32,33], and symbiotic relationships affect the evolution of the innovation ecosystem [9,34]. Complex technological co-innovation among manufacturers and the suppliers of components and complements promotes the formation, expansion, and reconstruction of the NEV co-innovation chain in the innovation ecosystem and drives sustainable development of the NEV industry.

2.3.2. Market Demand

The explicit development of the NEV industry indicates that NEVs are widely adopted by consumers. Encouraging all stakeholders to innovate commercially rather than to research and develop pure technologies can speed NEV industry development [18,35]. The market demand, consumer adoption, and the market penetration of NEVs have attracted the attention of scholars. Consumers adopt NEVs instead of traditional fuel vehicles due to both rational and perceptual factors [36]. Consumption preferences result in differences in the development of PEVs, and both Chinese and American consumers maintain their respective demand preferences for different NEV models regardless whether subsidies exist [37]. Consumers that are more concerned about energy saving and environmental protections are more likely to consider selecting compact PHEVs than those that are less concerned about these issues [26].

Most existing studies have focused on the factors affecting consumers' adoption of NEVs, but overlooked how consumer demand drives NEV industry development. NEV adoption involves various stakeholders [17,18], and the demand of different consuming sectors (such as public sector and private sectors) also attracts and coordinates different players to join the innovation ecosystem to offer corresponding innovation solutions of NEVs.

Demand preferences can shape the different evolution processes of the innovation ecosystem [38]. The layered value adoption chain, which forms around value creation, as well as the distribution and transfer of value to the customer, is based on the multilateral interdependence of players and reflects the willingness and enthusiasm of the innovation ecosystem to provide customers with total innovation solutions [11,15,39,40]. The innovation ecosystem, which is different from the traditional innovation system, is always considering the realization of innovation value [29]. Market selection can provide players with important feedback that serves as an input into their subsequent rounds of innovation, and over time, the innovation ecosystem further evolves and changes [10]. Therefore, consumer satisfaction with the value creation and delivery efficiency of the innovation ecosystem determines the sustainable development of the NEV industry.

2.3.3. Government Policy

In the current literature, most of the scholars have discussed the effect of the NEV industry policies; some scholars have even noted that, globally, China ranks first in the use of NEVs due to the distinctive force of its policy [41].

China's NEV policies aim to encourage the development of core technologies and reduce the price of NEVs [42]. Both national and regional policy incentives have played a significant role in jump-starting the PEVs [43]; however, national policies mainly guide the formulation and rely on the implementation of local policies, while local policies respond to specific regional challenges [41]. NEV policies have experienced dynamic transformation from government selection to market selection and have transformed from being production-oriented to being consumption-oriented [34]. The bottom-up policy formulation path is more likely to improve policy outcomes [44].

Clearly, the focal policies support key components, power systems and highly reliable and recyclable electric vehicles at the national strategic level [24]. Additionally, new policies are urgently needed to accelerate the network development and construction of fast chargers for these vehicles [27]. Tax incentives and demonstration policies are of low importance but result in high satisfaction, while subsidies, as well as technical and infrastructure supports are of high importance, but result in low satisfaction in China [45]. In addition, the policy of "no traffic restrictions for NEVs" is more influential [28], and the Chinese government should enhance the standards of the charging infrastructure in the future [41].

The innovation ecosystem highlights the importance of external viability, which is determined by the socioeconomic environment [12]. Specifically, enterprises with resource constraints should ensure that their business model innovation strategies align with the goals of national policies [19,32]. The success of India's renewable energy innovation ecosystem is also attributed to the national support of infrastructure construction [20]. Policy is an important part of the development environment in which the emerging industry innovation ecosystem operates and can guide every innovation subject (or community) to coordinate its innovation strategy with the pace of government policies to achieve success [19,46]. The NEV industry has inherently helped to solve a series of problems characterized by public externalities, such as environmental pollution and the energy crisis. Furthermore, public policy needs to focus on the coordination of complementary players and their interactions within the sector innovation ecosystem [10]. Especially considering the background of China's strong administrative intervention, government policies have become a significant force coordinating the synergistic evolution of the co-innovation chain and the value adoption chain, subsequently accelerating NEV industry development.

2.4. Research Framework

To determine why China, as a "catch-up" country in the automobile industry, has made remarkable achievements in the sustainable development of the NEV industry essentially involves exploring key forces and their driving mechanisms. Based on the literature review above, by applying the theoretical concept of the innovation ecosystem [9–12] and the classification of the key incentive forces [21], we propose our research framework for the "innovation-demand-policy" (IDP) driving the sustainable development of the NEV industry (see Figure 1).

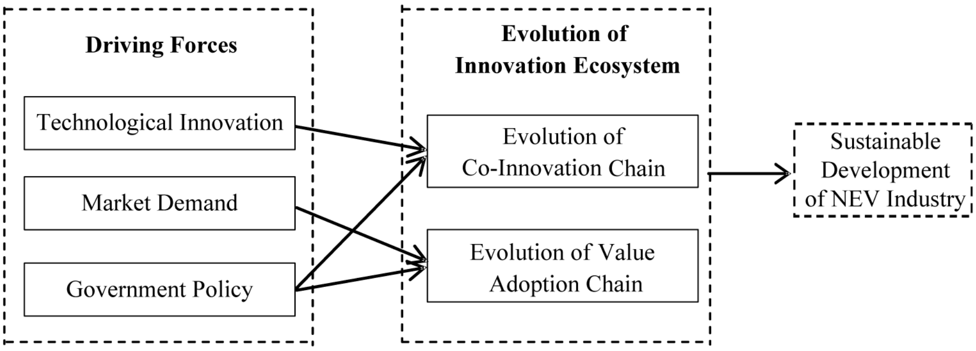

Figure 1. Research framework for the IDP driving the sustainable development of the NEV industry.

3. Materials and Methods

We use a comprehensive data collection and processing to investigate the key driving forces and their driving mechanism of sustainable development of the NEV industry in China. The research data consists of interviews, invention patents, marketing data, and policy documents.

3.1. Interviews

First, interviews were conducted using a semi-structured questionnaire; the main questions used for the semi-structured interviews are provided in Appendix A. We interviewed managers, officials and experts in China's NEV industry from 2017–2018 (see Table A1). Each interview lasted 40–60 min, and the interview records included approximately 50,000 words that described the key events, the technological changes, the marketing status, the effects of policies, and so on. Second, an analysis of interview data identified the main players, symbiotic relationships, the socioeconomic environment and the evolution process of the NEV innovation ecosystem in China, based on the time sequence and logic of the case study [47,48].

Based on the interviews and analysis mentioned above, we propose the basic structure of the NEV industry innovation ecosystem (see Figure 2). The main innovation players in the NEV industry innovation ecosystem include manufacturers and the suppliers of components and complements, all of which take part in value creation, transmission, and distribution, and finally deliver value to consumers. The successful manufacturing of NEVs depends on high complementarity of other players, specifically, having the necessary and feasible component technologies (such as batteries, electric motors, and electronic controls) and convenient and feasible complement technologies (for example, charging facilities). Overall, three types of innovation players offer value-added total innovation solutions to customers together through both the co-innovation chain and the value adoption chain.

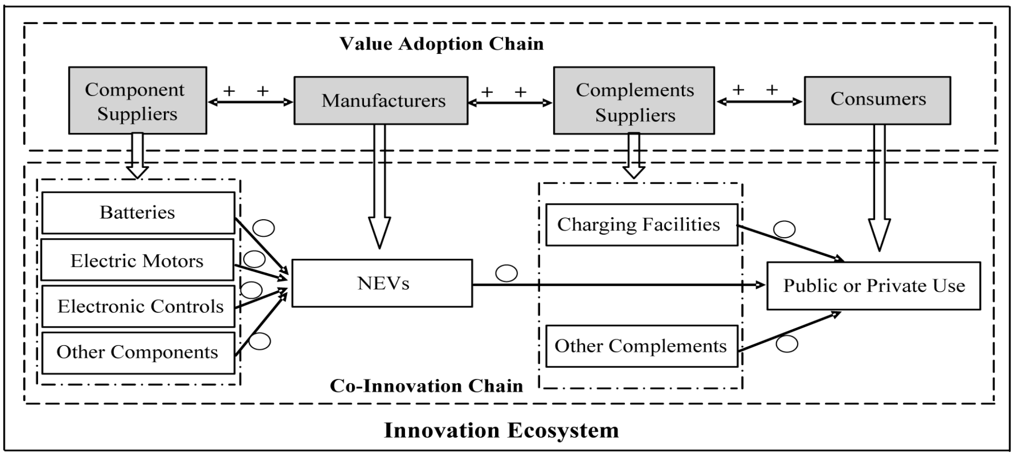

Figure 2. The basic structure of the NEV industry innovation ecosystem. "o" indicates that the corresponding technologies are feasible, and the double "+" indicate that the complementary players can create and obtain value together.

3.2. Patents

Invention patent applications reflect innovation vigor and performance [49], and we followed three steps to collect these data. The first step was selecting the database and the index method. The Patent Information Services Platform contains the most complete and comprehensive patent data of ten major industries [50]. The use of keywords is the most common tactic for searching the patent index [51], and we selected search keywords related to the classification of NEVs in China, including "Abstract = (new energy vehicle or battery electric vehicle or plug-in hybrid electric vehicle or fuel cell electric vehicle) and Application date = (1991 to 2017)" (China started to develop electric vehicles during the 8th Five-Year Plan in 1990). The search was conducted on 22 February 2018.

The second step was data cleaning and classifying the technological fields. We removed the uncorrelated and redundant data through a careful analysis of the abstract of each innovation patent. In total, we identified 16,187 patent applications for China's NEV industry from 1991 to 2017. According to International Patent Classification (IPC) rules and expert consultation, Table 1 shows the classification of core components and complements that form co-innovation chains of NEVs into the corresponding technological fields. The last step was a time series analysis. The patent applications of the overall industry, three core components, and the charging infrastructure from 1991 to 2017 were statistically analyzed.

Table 1. IPC of the core composition of the co-innovation chain of NEVs.

Core Composition of Co-Innovation Chain		IPC
Three core components	Battery	H01M
	Electric motor	H02K
	Electronic control	B60W
Charging infrastructure	Charging system	B60L11/00
	Charging unit	H02J7/00

3.3. Marketing Data

We collected research reports regarding the NEV industry in China. China's NEV industry reports include auto sales reports compiled by the China Association of Automobile Manufacturers, the China Strategic Emerging Industries Reports (2013–2018) compiled by the Chinese Academy of Engineering and Tsinghua University, and the Annual Report of New Energy Vehicle Industry in China (2013–2018) compiled by the China Automotive Technology Research Center, Nissan (China) Investment Corporation, and Dongfeng Motor Company. In addition, professional network media reporting data for the NEV industry were collected, for example, from the literature [52]. Then, we obtained data on the production-sale trends and market share from 2006 to 2017 and data on the market adoption performance of the demonstration projects of NEVs in China.

3.4. Policy Documents

First, policy documents were collected. A document list was obtained from the literature [36], which focused on policy transformation; this list included 67 documents spanning from 1991 to 2015, and we searched for these documents using official websites of the Ministry of Finance of China, the Ministry of Science and Technology of China, the Ministry of Industry and Information Technology of China, and the National Development and Reform Commission of China. In addition, 52 documents created in 2016 and 2017 were added after they were compared with the policy data in the report published by the China Association of Automobile Manufacturers. Ultimately, 119 policy documents were identified.

Second, policy instruments were extracted through a text analysis of the policies. A policy instrument can be seen as a means to achieve policy goals or results and should explicitly contain policy targets, methods, and objectives, if a policy instrument was aimed at different targets or objectives, or had been adjusted, then it was regarded as multiple policy instruments. According to the policy typology proposed by literature [21,53], we divide the NEVs policy instruments into three categories: supply-side instruments, demand-side instruments, and environmental-side instruments or institutional-side instruments [36]. These three types of policy instruments are specifically defined so that the supply-side instruments focus on NEV technology development, product improvement, production cost reduction, and output increases; the demand-side instruments aim to increase the purchase quantity, reduce use costs, and improve the convenience of product usage; and environmental-side instruments optimize the development environment of the NEV industry, including industry admittance, product standards, trade barriers, traffic control, and industry supervision. Table A2 shows the categorization of the main NEV policy instruments in China. It is worth noting that two researchers analyzed the policy contents at the same time to make sure the results were consistent; if these researchers obtained inconsistent results while extracting, coding, and classifying the same policy instrument, then a third researcher judged the policy instrument again. Ultimately, we ensured that two of the three researchers agreed on the results of the analysis of the same policy tool.

4. Results and Analysis

4.1. Driving Forces and Innovation Ecosystem Evolution

4.1.1. Technological Innovation and Co-innovation Chain Evolution

Patent applications for NEVs in China comprise patents for the three core components, charging infrastructure patents, and other complementarity patents. Figure 3 shows that the number of patent applications has increased since 1991, including the total number of patents, patents for the three core components, and patents for the charging infrastructure. Before 2007, the patents were mainly for the three core components, while after 2007, patent growth was significant, especially after 2014, when more patent applications were seen for the charging infrastructure than for the three core components. Thus, we can see that China's NEV technology innovation trend has three stages.

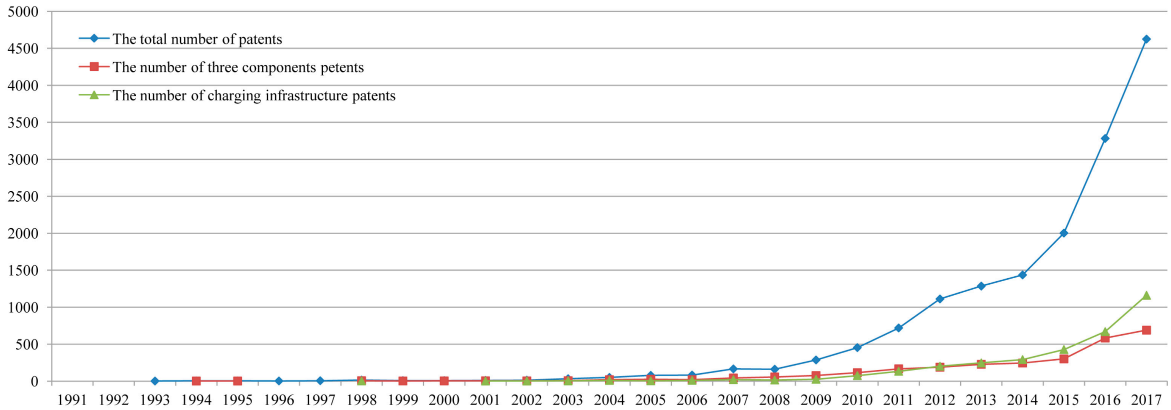

Figure 3. Invention patent applications for NEVs in China from 1991 to 2017.

Technological Grafting

During the 16 years from 1991 to 2007, the number of China's NEV patents grew slowly, and the majority of the patents were for battery, electric motor, and transmission device innovations. During this period, some NEV manufacturers with a certain amount of technology accumulation formed the co-innovation chain composed of components, vehicle manufacturing and necessary complements by grafting the new battery, electric motor, and charging device technologies onto the technology system of traditional fuel automobiles with success. This development was a driver of the emergence of the initial NEVs in China. For example, BYD made the first PEV, named F3e, though grafting its battery technologies onto the F3, which was a classic mass-production fuel vehicle.

Technological Breakthroughs

After some manufacturing pioneers launched their first NEVs, their technological innovation focus turned to the technologies of the three core components. Until 2013, the three core components occupied the largest proportion of innovation patent applications. The technological breakthroughs related to the three core components composed the industrial innovation platform. In addition, increasing numbers of vehicle manufacturers established their own NEV innovation platforms on this basis and carried out the serialization development of NEVs. For example, BYD constructed its NEV innovation platform earlier, as showed in Figure 4.

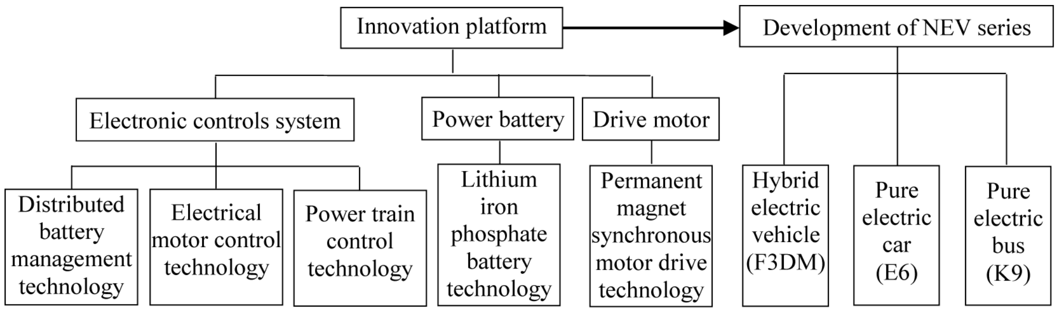

Figure 4. Innovation platform and NEV serialization development of BYD in 2011.

The technological breakthroughs related to the three core components induced the co-innovation chain to upgrade from technological grafting to establishing a specialized NEV industry innovation platform, which is independent from the traditional fuel vehicle industry. In this stage, technological breakthroughs and the specialized manufacturing of the three core components also drove the technological innovation of the NEV industry upstream battery, new materials, motor components, and electronic control units. Meanwhile, NEV serialization development involved the technological innovation of other parts, the assembly and the manufacturing process.

Total Innovation

After 2014, there were two explicit changes in the invention patent application. First, the total number of applications apparently grew faster than that for the three core components and the charging infrastructure. Second, there were more patent applications for charging facilities than for the three core components. The State Grid Corporation of China, which focuses on charging facility technologies, exceeded manufacturers such as BAIC and BYD and ranked first in NEV industry for the number of patent applications by 31 December 2017. Hence, the technological innovation of NEVs in China has entered the full-speed stage since 2014, which can also be called the period of total innovation [54]. These technological innovations expanded the co-innovation chain from components to complements in order to strengthen convenience of NEV facilities.

Especially in 2016 and 2017, the comprehensive penetration advantage of "Internet plus" technologies boosted artificial intelligence development in NEV industry in China and caused NEV to become an important carrier of mobile Internet and artificial intelligence. Table 2 shows that the top Internet companies, Baidu, Alibaba, and Tencent (BAT), in China started their plans of "making NEVs" one after another. NIO is a new NEV joint venture founded by China's top Internet companies and entrepreneurs and launched its first mass-production vehicle the ES8 in 2017; in addition to having the same product performance as other NEVs, this model also includes Internet-based driving, power, and service systems, cloud computing, and artificial intelligence technologies. Thus, the co-innovation chain of the NEV industry innovation ecosystem was reconfigured by "Internet plus" technologies.

Table 2. Strategic layout of Internet companies in the NEV industry in China.

Internet Companies	Strategic Actions	Partner Companies	Joint Ventures
Baidu	Apollo plan Carlife system	Dongfeng, FAW Group, BAIC, and Daimler	WM Motor and NIO
Alibaba	Automatic drive research plan AliOS system	Ford, Honda, SAIC, and Volvo	Xiaopeng Motors
Tencent	Automatic drive research plan AI in car system	CHANA and GAC MOTOR	WM Motor, NIO, and Tesla

Data source: the literature [55].

4.1.2. Market Demand and Value Adoption Chain Evolution

China's first local NEV was made in 2006, but market demand was very small at that time. In 2011 and 2012, NEV sales increased due to public demand. NEV sales in the public sector continued to increase rapidly after 2013; however, in 2016 and 2017, the growth rate of private demand increased from 32% to 57%. Figures 5 and 6 illustrate that the market demand for NEVs in China has distinct phases.

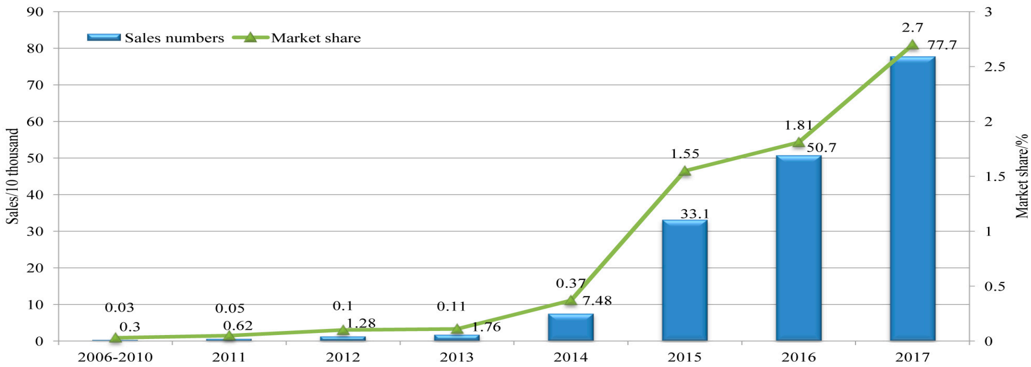

Figure 5. Sales and market share of China's NEVs

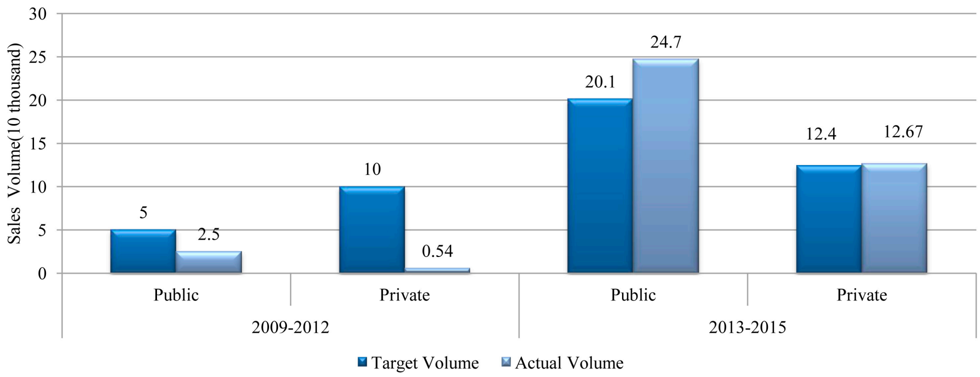

Figure 6. Target and actual sales of the public and private sectors during the demonstration program. Data source: China Association of Automobile Manufacturers.

Potential Demand

Simple substitution for traditional fuel vehicles represented the potential demand for NEVs under the rapidly increasing pressures of environment pollution, oil safety, and the upgrading of the traditional fuel automobile industry. Although the potential demand was very high, it induced some manufacturing pioneers to contribute to the initial NEVs, which, to some extent, involved complementary players launching the so called "concept car", aiming to concentrate on market testing and feedback. Before 2007, there were only a few sales of NEVs; for example, few customers purchased the F3e, which was made by BYD. However, the vast potential demand induced some pioneering companies to form a focal value proposition, and the initial research and development input from these vehicle-manufacturing pioneers became the source of early value. Due to the simple value proposition and small source of value, several pioneers formed the limited value chain of the NEV industry in China.

Public Demand

Public demand for taxis, buses, and official and special vehicles was easier to supervise and control than private demand [56]. Figure 6 shows that in the first round of the demonstration program (2009–2012), this program expected to sell 50,000 vehicles to the public sector and sold half that number.

In contrast, the target for sales to the private sector was 100,000 and ultimately, just 5400 were sold. In the second round of the demonstration program (2013–2015), public sales became vigorous and exceeded the expected target. For example, 29,658 electric buses and other special electric vehicles were sold in the global market; of these, 25,858 were sold in the Chinese market, which represents 87.19% of the global market in 2014 [57]. In contrast to private consumption, the needs of the public market included vehicles with a single purpose, a clear route, and a centralized facility. Public demand for NEVs, which became the first explicit market, pulled and coordinated automobile manufacturers, component suppliers, and operators to form a value adoption chain.

Private Demand

In the second round of the demonstration program (2013–2015), the growth rate of private demand was higher than that of public demand, and potential demand quickly became explicit in the private sector. In the field of traditional fuel vehicles, the market share of the private sector accounted for up to 98%; Nevertheless, NEVs had been purchased by less than 1% of private consumers by 2017. Thus, rigid demand transformed from extremely high potential private substitution demand, which increasingly became the key driver pulling NEV adoption in China.

Private consumers have specific requirements regarding the price, cost and convenience of NEVs for the whole product life cycle, and they especially focus on differentiation and diversification [25]. Therefore, private demand attracted and coordinated more players of different types to join the innovation ecosystem to realize the innovation value [18]. For example, the construction of charging facilities for private consumers induced an increasing number of players—including community builders, property companies, construction administration committees, charging equipment suppliers and battery operators—to join the value adoption chain.

Increasing the knowledge of consumers about the emerging technologies and products in the NEV industry is a gradual process. The shift from potential demand to realistic rigid demand (see Figure 7) has resulted in the continuous evolution of the NEV adoption chain. As the potential alternative market demand gradually shifts to real public demand and private demand, the types and number of players attracted to the industry both increase. Meanwhile, the complexity of the value adoption chain configuration continues to increase.

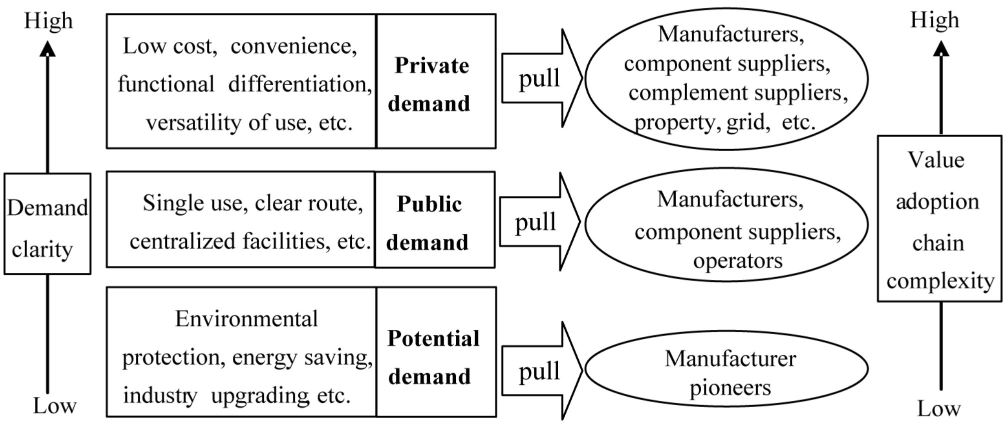

Figure 7. Evolution of the value adoption chain of the NEV industry caused by a shift in market demand.

4.1.3. Government Policy and the Evolution of the Two Chains

The number of policy instruments has increased yearly since 1991. Figure 8 shows the annual distribution of policy instruments based on time, while each type of policy had its own emphasis at the different stages. Supply-side policy instruments were a priority in the early stage; then, they kept pace with the demand-side policy instruments. Subsequently, the number of environmental-side policy instruments increased, and have done so steadily for the last two years.

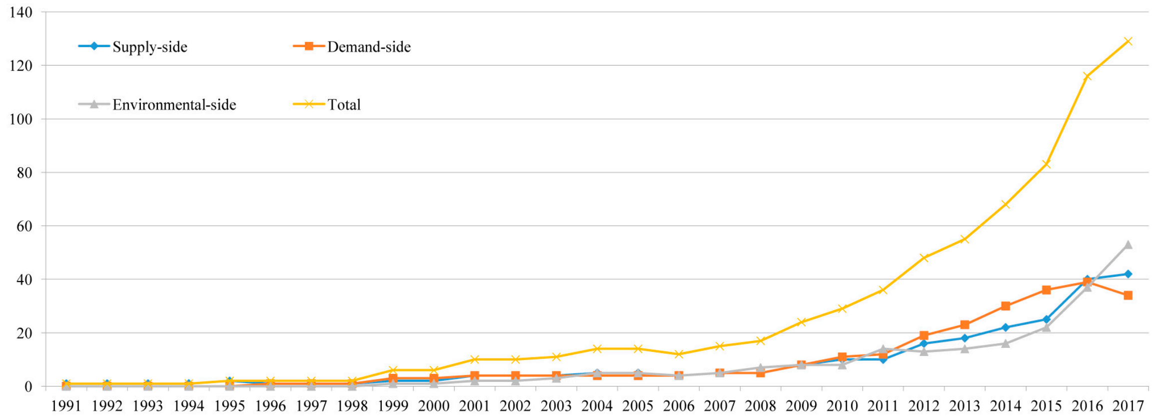

Figure 8. The annual distribution of policy instruments from 1991–2017.

Supply-Side Policy

During the period from 1991 to 2005, the technological research and development plans for NEVs were included in the National Key Scientific and Technological Projects of the "8th", "9th", and "10th" Five-Year Plans in China. In particular, the research and development program named the "Three Transverses, Three Longitudes" (the term "Three Transverses" refers to PEVs, PHEVs, and FCVs; the term "Three Longitudes" refers to multi-energy power control system, drive motor, and power battery) was listed in the 863 Program (a high-tech research program started in March 1986 in China.) in 2001. Therefore, technology support programs and related financial subsidies were the focus of China's NEV policies during this period, which provided strong support for research and development for battery, electric motor, and electronic control technologies. Without doubt, the Chinese government continued to invest in NEV technologies, and research and development subsidies were more generous in the 863 Program for the "11th" and "12th" Five-Year Plans, which promoted the technological innovation and transformation of PEVs, PHEVs, and FCVs and ensured the continuous upgrading of the related core technologies. In a word, the supply-side policy focusing on technological innovation supported the systematic deployment of basic science, generic key technology and system integration and continuously improved the co-innovation chain of NEVs in China. Meanwhile, financial support for technological innovation from the government became the early value source; these funds were assigned and delivered to complementary innovators embedded in the co-innovation chain, which resulted in the emergence of the early value adoption chain.

Since 2009, policy instruments, such as marketing size planning, emission controls, and consumption tax waivers had been successively issued, which caused supply-side policy to change its focus from technology research to the production scale, quality and performance of NEVs. Notably, the number of supply-side policy instruments for NEVs increased greatly in 2016 and 2017; these policy instruments were included in the policy documents of "Internet plus" intelligent energy development, manufacturing upgrading and light industry development to extend the co-innovation chain by promoting the combination of NEVs and the emerging complementary knowledge and technologies of "Internet plus".

Demand-Side Policy

Demand-side policy initially began with infrastructure planning and the demonstration program in 1995 that supported the basic use facility development and stimulated demand. Similar policy instruments were introduced in the National Key Scientific and Technological Projects of "10th" and "11th" Five-Year Plans, which also promoted consumer adoption of NEVs. However, the policy instruments that explicitly stimulated demand began with the NEV demonstration program "Ten Cities, Thousand Vehicles" in 2009, which included a purchase rebate, government procurement and demonstration subsidies. The Chinese government created public demand and constructed the initial adoption chain to deliver value to consumers. In 2010, the number of pilot cities expanded, and the demonstration subsidies were issued to stimulate private consumers to adopt NEVs. In 2014, the government procurement plan and the purchase subsidies for private consumers continued; in 2016, it was declared that these subsidies would be extended until 2020, which has been greatly stimulating private demand. The increasing subsidies from the government for private car purchases and charging facilities have encouraged more complementary players to engage in infrastructure construction and operation to further expand the value adoption chain.

Remarkably, the number of demand-side policy instruments has increased significantly and has even exceeded the number of supply-side instruments after 2011. This increase occurred because the government has paid more attention to improving consumers' convenience of NEV use through the addition of more infrastructure plans and subsidy policy tools. The range of supply-side policy instruments from infrastructure plans to the demonstration programs, government procurements, operation subsidies, private purchase subsidies, and infrastructure subsidies helped to connect the NEV product with both public demand and private demand and strengthen the close producer-user interaction, further promoting the establishment and improvement of the value adoption chain of NEVs in China.

Environmental-Side Policy

Environmental-side policy for NEVs was used later than the other two types mentioned above. The earliest environmental-side policy can be traced back to the NEV entry regulation included in the Guidelines of Foreign Investment in High-Tech Fields in 2003. In 2007, the National Development and Reform Commission of China promulgated the Management Rules on NEV Enterprises and Production Entry, which stipulated that any qualified NEV enterprise must have independent intellectual property rights on one of the three core components. In 2009, NEV product entry standards and various product standards were introduced, which had a positive impact on improving the quality of NEVs. The number of environmental-side policy instruments increased rapidly after 2011. On the one hand, industry access and product standards were continuously improved and special entry policies and standards for batteries and infrastructure were introduced; on the other hand, trade barriers and the number of traffic control policy instruments increased. In particular, a series of industry supervision policy instruments were added in 2016 and 2017, such as automobile sales management and safety supervision. The Ministry of Industry and Information Technology and the Standardization Administration of China promulgated the Construction Guidelines of National Car Networking Industry Standard System, in which the key standards and technical requirements of intelligence networks were proposed. With the scale development and the maturity of the industry, environmental-side policy instruments were oriented to shape a fair and orderly socioeconomic environment to coordinate the more complex innovation process full of substitution and complementarity effects and close producer-user interaction [10] to promote the synergistic evolution of the co-innovation and value adoption chains.

4.2. Innovation Ecosystem Evolution and Sustainable Development of the NEV industry in Phases

Technological innovation, market demand and government policy promoted the continuous evolution of the co-innovation chain and the value adoption chain of the NEV innovation ecosystem in China, which then drove the formation, growth and upgrading of the NEV industry. In general, the timing of the transformation of the three driving forces was roughly the same and basically corresponded to the initial launching of NEVs, public sector promotions, and private sector adoption in China, which is also in line with the stages identified by Xu et al. [36].

4.2.1. Minimum Viable Ecosystem and the Embryo Form of the Industry

Due to the support of various technological innovation plans made by the government of China, some manufacturing pioneers grafted traditional fuel vehicles with improved batteries and electrical motor technologies to form the co-innovation chain, aiming to develop the initial NEVs in China. Meanwhile, the very high potential alternative demand became the basis for some pioneering companies to form a focal value proposition. The plans of the government to financially support technological innovation and the initial research and development input from some vehicle-manufacturing pioneers became the sources of early value. Driven by these three driving forces, the small but relatively complete co-innovation chain and limited value adoption chain constituted the minimum viable ecosystem of China's NEV industry [58]. This period was roughly from 1991 to 2007, during which some domestic companies such as BAIC, BYD, Geely, Chery, etc. launched their initial NEVs and started the embryonic form of the NEV industry based on the minimum viable ecosystem in China.

4.2.2. Platform Ecosystem and Industry Growth

Under the guidance of China's technology road map "Three Transverses, Three Longitudes", manufacturing pioneers with accumulated innovation ability made technological achievements in the core components of batteries, electric motors and electronic controls to build the co-innovation chain, which had the characteristic of an independent industrial innovation platform. At the same time, increasing adoption of NEVs by public consumers expanded the value source, which induced the formation of a more complete value adoption chain. In addition, the government's demonstration and promotion programs, and operational subsidies functioned as value sources. Technological breakthroughs, increasing explicit public demand and the government's strengthened demand-side financial subsidies supported the construction of the innovation platform ecosystem of the NEV industry in China and induced the parallel development of PEVs, PHEVs, and FCVs [33,59].

This period was roughly from 2008 to 2012, during which China's NEV industry grew rapidly based on the platform ecosystem. Notably, the NEV industry was selected as one of the seven strategic emerging industries with potential growth in China. Increasing numbers of traditional fuel vehicle manufacturers moved into the NEV field, and both the number and the specialization degree of the component suppliers increased. At this point, China became the fastest growing country in terms of the production and sales of NEVs.

4.2.3. Expanded-Reconfigured Ecosystem and Industry Upgrading

The increase in total innovation expanded the co-innovation chain of NEVs to include the development and application of charging pile, station and tower technologies. Meanwhile, a group of companies that focuses on emerging complementary knowledge and technologies—such as the Internet, the Internet of things, and artificial intelligence—had begun plans for "making NEVs" to support "the realization of pure electric driving and intelligent development of NEVs" [60]. Increasing numbers of NEVs were adopted by private consumers with more stringent requirements regarding the convenience of complements, which increased the value source and attracted many complementary players to join the value adoption chain. The increasing subsidies from the government for private car purchases and charging facilities encouraged and coordinated more players to engage in infrastructure construction and operation, which expanded the value adoption chain further. In recent years, environmental-side policies and regulations have been strengthened to support the synergistic expansion of the co-innovation and value adoption chains of NEVs in China.

Under the three driving forces above, the expanded-reconfigured stage [58] of the NEV innovation ecosystem in China started in approximately 2013 and continues to the present. During this period, the development of the NEV industry has the characteristics of upgrading. Specifically, private demand has been effectively met, and new demand has been created by adding many emerging complementary technologies. More innovation subjects and stakeholders are involved in the NEV industry. Thus, NEVs are no longer limited to simply replacing the technical performance and demand of traditional fuel vehicles, but can subvert the automotive industry, and even the existing NEV field. China is in the lead position to promote the innovation and development of the NEV industry in the current period.

5. Discussion

5.1. Low-Risk and High-Efficiency Innovation Path for Complex Technologies and Sustainable Development of the NEV Industry

In contrast to relatively simple innovation ecosystems with a small number of technologies that have been investigated in the previous literature [14,30,40], an NEV is comprised of tens of thousands of parts and involves a series of complementary facilities for its application. The complex technology of NEVs prolongs the time to "wait for finishing the last piece of the building block". This complexity explains why this process has taken a long time, from 1991, when the Chinese government declared it would encourage NEV development to 2006, when BAIC launched the first NEV. This process also reflects the complexity of innovation processes happening in the innovation ecosystem, which is in line with Fransman's research [10]. In terms of reducing the number of challenges posed by the high technological complexity of building a new innovation ecosystem, NEV manufacturing pioneers tried their best to make the initial NEVs using existing batteries, motors, etc., with minimal technological adjustments to the traditional fuel vehicle architecture. Whether BAIC learned to improve the DODGE electric car or BYD grafted its battery technologies into the classic model of a traditional fuel car, the minimum viable ecosystem of NEVs driven by technological grafting was successfully constructed to achieve much from little. Thus, a good start is to note that "the imagined deemed viable" [10] realizes, through a few complementary companies coordinated by the focal company, a co-innovation based on existing complementary knowledge.

The minimum viable ecosystem is fragile, and research and development input-driven industry development is unsustainable; thus, an innovation platform is the key to supporting the industry innovation ecosystem [33,59]. An innovation platform has a significant advantage of pooling and sharing more new complementary knowledge and information, and more complementary innovators can be easily coordinated to create variety to deal with uncertainty during the innovation process [61]. The automobile manufacturers' tendencies to innovate the three core components supported the NEV innovation ecosystem rather than the complements, which also suggests that the backward integration strategy is more helpful for enhancing the performance of focal companies (NEV manufacturers) in the innovation ecosystem [30]. Notably, developing countries can compete in emerging technologies, and emerging industry development continues to be faced with the unavoidable mission of developing technological breakthroughs in key components. The only way to shorten innovation time and reduce innovation risks for "catch-up" countries is to rely on a clearer innovation strategy to align more excellent innovation subjects and innovation resources. This implication also reflects the advantages of an innovation ecosystem strategy for developing complex technologies.

The total innovation achieved further highlights the commercial innovation of NEVs [35,62]. The number of patent applications for charging facilities exceeded those of the three core components after 2013, and the co-innovation chain was extended to infrastructures, such as charging devices, which improved the use convenience of using NEVs. At the same time, and more importantly, NEVs were combined with emerging technologies, including artificial intelligence, cloud computing, and big data. Internet companies, such as BAT, etc., joined the "making NEVs" action. Faced with the double challenges of complexity (technological innovation process) and uncertainty (continuous emergence of new technologies), the total innovation achieved by an increasing number of complementary players drove the NEV industry co-innovation chain to expand and reconstruct simultaneously.

In summary, the technological innovation carried out by the players in the innovation ecosystem is the inner driver of sustainable development of China's NEV industry. The co-innovation chain was driven to form, grow, expand and reconfigure along the technological innovation path of "technological grafting→technological breakthrough→total innovation". This path was also the innovation process in which an increasing amount of complementary knowledge to share requires that complementary undertakings be coordinated to co-innovate. As technological innovation continues to shift, the NEV industry develops with relatively low risk and innovation takes less time. Thus, this innovation path may also be the innovation path for other emerging industries driven by complex technologies with innovation uncertainty.

5.2. Awareness and Adoption of Emerging Products with Public Externality and NEV Popularization

Market selection is the ultimate selection mechanism for the variety of new products and services produced by the innovation ecosystem [10]. The wide adoption by consumers is the key indicator of sustainable development of the NEV industry [63]. The market demand of NEVs is particular, and the adoption decision-making of consumers depends on rational, as well as perceptual, factors [36].

The initial market demand stemmed from the intensification of environmental pollution, the increasing depletion of fossil fuel resources and the automobile industry upgrading in China. However, the ambiguous potential alternative demand to replace traditional fuel vehicles attracted and selected only the pioneers with great vision to obtain first-mover advantage [58]. Therefore, some national companies, such as BAIC, BYD, and Geely, which are committed to challenging the competitive landscape of the automobile industry dominated by foreign multinationals, launched their initial NEVs.

For the market selection mechanism, the close producer-user interaction is the key to the innovation process. As the initial NEVs were launched, these NEVs were also tested and selected by the actual market demand. At the same time, the emergence of NEVs caused potential demand to shift to actual demand, and public demand was clearly first [64]. Public demand could be met only by coordinating a small number and limited types of players, such as vehicle manufacturers, component suppliers, and specific operators, to form a simple value adoption chain to provide NEV products. Although the nature of the public sector is such that all taxpayers pay for energy conservation and environment protection, the government played a greater role in the adoption decision. This government intervention explains why public demand arose first and is more sensitive to supply-side policy than private demand.

As public demand was gradually satisfied, core and supporting enterprises had to shift to meet new demands to increase revenue. In contrast, private demand was complicated [36,65,66] since offering total innovation solutions involves coordination stakeholders [18]. Private need could be satisfied only by the joint efforts of vehicle manufacturers, component and complement suppliers, properties, urban construction companies, grids, gas stations, etc., some of which had to offer public goods or services during this innovation process. Thus, the adoption of NEVs by more private consumers depends on an extensive and intensive value adoption chain that can satisfy and balance the interests of more player embedded in the innovation ecosystem

In short, an NEV is an emerging product with certain attributes of public goods [41], and consumers' awareness and adoption of NEVs is a gradual process. Meanwhile, with the help of feedback from the different market needs, a variety of "innovation hypotheses" regarding NEVs were tested and selected. Thus, the different market demands of NEVs induce various players to shape different value adoption chains, which, essentially, is realizing the focal value proposition of stakeholders and effectively solving the public externalities.

5.3. Government Policy Rationality and the Evolution of the NEV Industry Innovation Ecosystem

Government policy plays an important role in coordinating complementary players to form interdependent relationships. Due to the sustainable development of the NEV industry, the number of government policy instruments did not decrease but increased (see Figure 6). This increasing trend was, to a large extent, due to the need to support the continuous evolution of the innovation ecosystem.

The technologies of the NEV industry are complex, may need to be combined or rapidly updated, and face new bottlenecks regularly. Thus, various plans to support innovation which are classified as supply-side policy, coordinated new knowledge with high complementarity dispersed among different players to gather and share in an open context. This process supported the NEV technology grafting, breakthroughs in core component modules, and cross-convergence; then it promoted the continuous evolution of the co-innovation chain. Similarly, to translate the very high potential demand into real rigid demand, the government increased the number of demand-side policy instruments—including purchase, operating, and convenient use subsidies—to coordinate the producer-user interaction and attract more players to form a more complete adoption value chain. In addition to policy tools oriented to manufacturers and consumers [36], environmental-side policy instruments turned to shape the orderly competitive and cooperative socioeconomic environment to coordinate interdependence within or across the different layers of the innovation ecosystem [10]. These environmental-side policy instruments were vital for promoting the synergistic evolution of both the co-innovation and value adoption chains. As the number of three types of policy instruments continued to increase and together coordinate the process, the innovation ecosystem evolved from simple to complex, and its boundary continued to expand, so China's NEV industry achieved sustainable development. In general, emerging industries based on new frequently-changing technologies (innovation uncertainty) are more strongly dependent on government policies, especially under the transformation background in China.

Although the frequency with which the three kinds of policy instruments were used continued to increase, the guidance emphasis varied at the different stages of sustainable development of the NEV industry innovation ecosystem. The innovation ecosystem relied on supply-side policy at the beginning, and the NEV industry was a typical emerging industry driven by research and development investment in the early stage. Then, a series of demand-side policy instruments, such as demonstration subsidies, government procurement, and operating subsidies were issued by the government to stimulate public demand [67]. However, these demand-side policy instruments were not effective for private demand [25,36] until the introduction of infrastructure construction planning, private car purchase waivers, purchase subsidies, and so on. Environmental-side policies are more effective for helping the NEVs innovation ecosystem to expand.

It can also be said that government policy, regarded as the "rules of the game", enhances the complementarity of the whole innovation ecosystem [10], and the phased evolution of the innovation ecosystem more accurately reflects the rationality of the number and focus of NEV policy instruments in China.

5.4. Combination of the Three Driving Forces and Sustainable Development of the NEV Industry

The precondition for technological innovation's playing a role is that every innovation activity follows ultimate selection mechanism of market demand. Only when NEVs are widely adopted by consumers can the focal value proposition by the players who participate in the co-innovation be realized. The initial potential and vague alternative demands of the consumers were awakened by the first NEV made by the pioneers. Meanwhile, the innovation was tested by the market, and subsequent market feedback also helped identify the next emphasis of co-innovation. Public demand and subsequent private demand required the serialization development based on the innovation platform and the differentiation development based on total innovation, respectively. Therefore, the interaction between technological innovation players and market demand consumers is essentially the process of promoting the synergetic evolution of the co-innovation and value adoption chains. Finally, the NEV industry was driven to develop rapidly.

Government policy aims to coordinate the innovation process and connect technological innovation and the market demand of NEVs. Take National Key Scientific and Technological Projects as an example; on the one hand, the major scientific and technological plans of the government coordinate more innovation pioneers to create and share new knowledge with high complementarity to solve the key technological problems together and to form the initial co-innovative chain. On the other hand, the government played a role as a value source through research and development plans and subsidies in the early stage of the innovation ecosystem. More pioneers benefited from the government's financial support, which solved the externalities and spillovers of complementary knowledge among the players, reduced collective innovation costs and risks, and allowed even some research and development institutions to increase their revenue. Thus, this process included value adoption chain formation, which was driven by the government's innovation input. Conversely, demand-side policy, which is crucial for improving the adoption enthusiasm of consumers [45], can also indirectly coordinate more players to become involved and innovate. As consumers became the major value source, the government also shifted the focus of the policy instruments to create an orderly competitive and cooperative socioeconomic environment for the synergetic evolution of the co-innovation and value adoption chains.

Government policy should follow the different laws of the technological innovation process and market demand selection mechanism. Supply-side policy instruments highlight the coordination functions of innovation strategies for the future, while demand-side policy instruments adjust according to consumer demand over time, and environmental-side policy instruments create a fair and normative environment that aligns with the large-scale development of the NEV industry. Government continues to learn [36] and plays a role through bottom-up policy selection [62]; furthermore, the importance of the top-level design and strategic guidance of government policy has been highlighted.

According to the horizontal and vertical analysis and a discussion of the three driving forces and their driving mechanism of sustainable development of China's NEV industry, it is clear that the combined effects and the transformation of technological innovation, the market demand and the government policy can drive the synergistic evolution of the industrial innovation ecosystem and promote the sustainable and rapid development of the NEV industry in China. The model of the driving mechanism is shown in Figure 9.

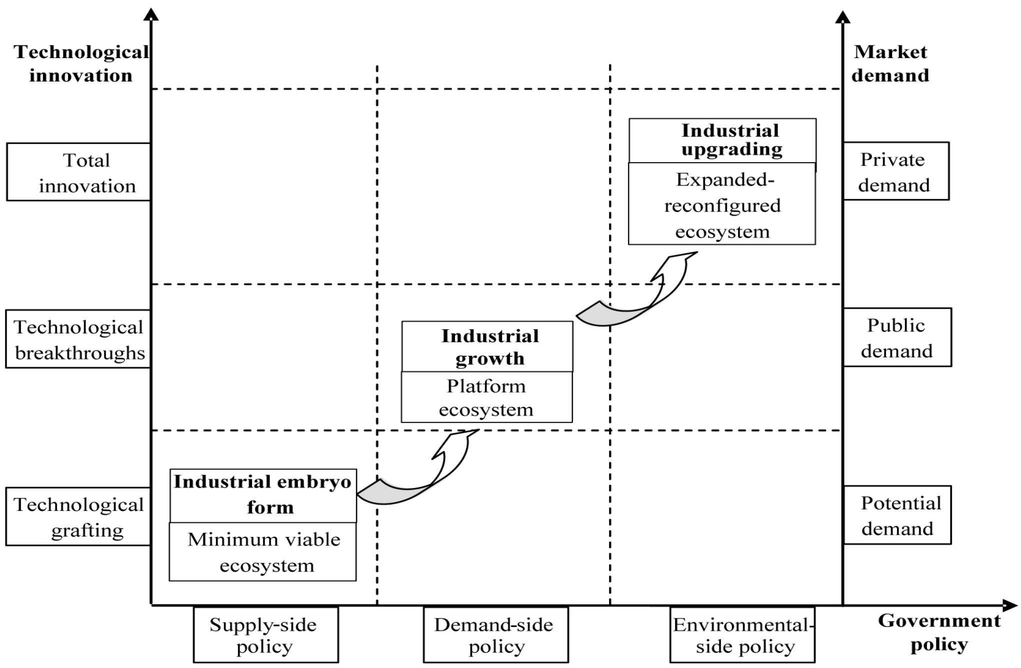

Figure 9. The model of the three forces driving sustainable development of China's NEV industry via the evolving innovation ecosystem.

6. Conclusions and Implications

6.1. Conclusions

China established the foundation of the traditional fuel vehicle industry through "trading market access for technology", but abandoned this development logic of overemphasizing technologies in the NEV industry. By the combined effect of technological innovation, market demand, and government policy, the innovation ecosystem of the NEV industry has been nurtured and has evolved; thus, the sustainable development of the NEV industry has been achieved.

It is not doubted that technological innovation is an important internal driver that induced the sustainable development of the NEV industry. Local enterprises in China followed the principle of "minimum footprint" and the path of "technological grafting→technological→total innovation" to carry out co-innovation. Both the principle and the path can truly coordinate creating and sharing new complementary knowledge, reduce the cost and risk of innovation, increase the pace of technological innovation, and continuously perfect the co-innovation chain. Market demand selection drives the transformation from a variety of technological innovation achievements to value realization. As the potential alternative demand was transformed into real public demand and then private demand, increasing numbers of participants were attracted to the innovation ecosystem and were coordinated to create, distribute and transfer value, and then to form and evolve the value adoption chain. The sustainable development of China's NEV industry also depends on the three categories of policies in general, and the focus of policy instruments continuously varied from the supply-side to the demand-side, and then to the environmental-side, responding to the evolutionary stages of the innovation ecosystem.

Three forces combine to drive China's NEV industry to develop sustainability in phases via an evolving innovation ecosystem. The technological grafting conducted by manufacturing pioneers, the potential alternative market demand and the innovation plans and subsidies of the government created a minimally viable ecosystem and the initial NEVs. The technological breakthroughs of the core components, the gradual transformation from potential to real public demand, and the various demand-side policy instruments drove the innovation ecosystem into the platform ecosystem stage, which supported serialization development of the NEV industry. Total innovation, high realistic and rigid private demand and government environmental-side policy have expanded and reconfigured the ecosystem, then upgraded the NEV industry.

When technological innovation meets market demand, then value creation can be realized, and the close interaction of technology innovation players and market demand consumers promotes the synergistic evolution of the co-innovation and value adoption chains. The policy formulation of the government follows the rules of the technological innovation process and market demand selection mechanism. Government policy with bi-directional mechanisms of a top-down strategic design and the implementation of bottom-up dynamic learning and adjustment guides the synergistic evolution of the innovation ecosystem and the sustainable development of the NEV industry.

6.2. Practical Implications

The kind of policy used by the government to coordinate the development of emerging industries characterized by complex new technologies and high public externalities depends on the evolutionary stage of the industrial innovation ecosystem. At the stage of a minimally viable ecosystem system, supply-side policy, such as research and development plans and subsidies, should be issued and implemented as early as possible. The nation's top-down technological breakthrough strategy can stimulate pioneering enterprises, institutions, and universities to jointly address problems related to complementary knowledge and technologies for key components. For the platform ecosystem stage, demand-side policy instruments—including demonstration projects, pilots and government procurement—should be applied to promote the public consumption sector. During the stage of an expanded-reconfigured ecosystem, government policy should turn to fair and normative industrial regulation and adjust policy tools from the bottom to the top in a timely manner, following the market discipline. Specifically, China's current NEV industry is at the expanded-reconfigured stage and is combined with emerging "Internet plus" technologies, while private demand is expanding. Therefore, environmental-side instruments, such as standards and supervision, are the main instruments used to support the standardized and sustainable development of the NEV industry. Meanwhile, supply-side policy tools need to be strengthened to coordinate new complementary knowledge and technologies scattered across a wider range of players to share, combine, and integrate.

The players, who are characterized by different layers and types, need to choose the appropriate time to join, considering the evolutionary stage of the emerging industry innovation ecosystem. The core enterprises, including the vehicle manufacturers and the core component suppliers, can obtain first-mover advantage to challenge or even subvert the monopoly status of the multinationals. Changing new technologies and emerging industries open the window of opportunity for pioneer enterprises in developing countries. The suppliers of complements, as followers, should join the innovation ecosystem after the formation of the platform ecosystem to reduce the innovation risks and research and development input, and to ensure sufficient adoption of the technology. For enterprises with a lack of previous knowledge in this technology, such as some Internet platform enterprises or enterprises committed to cross-domain diversification, becoming involved in the innovation ecosystem is more favorable at the stage of an expanded-reconfigured ecosystem. This fact has been proven from the success of NIO, which was a latecomer and who came from behind to win the race.

Author Contributions: Conceptualization, J.W.; data curation, J.H.; formal analysis, H.W.; investigation, H.W.; methodology, Z.Y.; validation: X.H.; writing—original draft: J.W. and Z.Y.; writing—review and editing, X.H.

Funding: This research was supported by the National Natural Science Foundation of China (no. 71503061, no. 71473062).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Main questions for managers are as follows:

1. When and how did your firm start conducting business in the NEV industry? When and what did your firm extend to other NEV business segments during its development? What is your firm's NEVs business currently?
2. What and when did your firm make greater achievements in terms of technological innovation or market sales in the NEV industry? What were the key forces that drove your firm to do so?
3. What are the main advantages of your firm compared with other NEVs firms, especially international competitors?
4. Which types of firms or institutions are your firm's main cooperative partners? What is their main cooperative business?
5. How do you assess the degree of interdependence of technological innovation between your firm and its cooperative partners? How did your firm balance the interests with its cooperative partners to satisfy the consumers?
6. What are the main challenges your firm faced during its development in the NEV industry? How did your firm overcome these challenges?
7. What types of government policies helped your firm to develop rapidly? What did not? Why?
8. Did the rapid emergence of the "Internet plus" NEV technologies bring opportunity or challenge for your firm? How does your firm prepare to deal with this trend?

Main questions for officials and experts are as follows:

1. When and why did China decide to develop NEV industry? What phases did China's NEV industry undergo?

2. What achievements did the China's NEV industry make in technological innovation and market sales during its development?
3. What strategies did China's NEV industry use to conquer the technological bottlenecks during its development? What is the specific interdependence among these technologies?
4. How the main subjects in the China's NEV industry cooperate and balance their interests to offer different consumers with attractive total innovation solutions?
5. How did the government policy to promote or hinder the China's NEV industry to develop?
6. What are the advantages of China's NEV industry compared with other countries'?
7. What path did China's NEV industry follow to develop on your opinion? To what extent is this path different from "trading market access for technology" of traditional fuel vehicle industry in China?
8. What kinds of "Internet plus" technologies and other emerging technologies are more influential for China NEV industry? How do they affect the NEV industry?

Appendix B

Table A1. List of interviewees.

Type	Number of Interviewees	Location
Managers from NEV manufactures and suppliers	15	Beijing, Changchun, Hefei and Harbin, China
Officials from central and local governments	8	Beijing, Changchun and Harbin, China
Experts from research institutes and universities	10	Beijing, Changchun and Harbin, China

Table A2. Categorization of main NEV policy instruments in China.

Policy Instruments	Supply-Side	Demand-Side	Environmental-Side	Reason
Consumption tax waiver	★			Reduce production cost
Demonstration subsidy		★		Increase the purchase quantity
Emission control	★			Improve quality of NEVs
Entry regulation			★	Regulate market order
Government procurement		★		Stimulate public consumption
Infrastructure subsidy		★		Improve the convenience of product usage
Infrastructure planning		★		Improve the convenience of NEVs usage
Infrastructure standard			★	Regulate market order of infrastructure construction
Market size planning	★			Stimulate production
Operation subsidy		★		Reduce usage cost
Product R&D program	★			Improve production technology
Product standard			★	Regulate market quality through standard
Product R&D tax credit	★			Reduce production use cost
Product technology planning	★			Identify technology trajectories for reducing production cost
Purchase rebate		★		Increase the purchase quantity
Purchase tax waiver		★		Increase the purchase quantity
Trade barrier removal			★	Optimize competitive environment
Traffic management policy			★	Optimize usage environment
Industry supervision			★	Optimize development environment

Notes: The naming of policy instruments references the literature [36]. The symbol "★" stands for the categorization of policy instruments.

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