A Sectoral Innovation Ecosystem Perspective on China's Rise in New Energy Vehicles

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ABSTRACT

The rise of China's New Energy Vehicles (NEVs), particularly electric vehicles (EVs), in the global automobile industry represents an intriguing case of an emerging technology-intensive sector in a latecomer country. Methodologically, the study employs an inductive case research design, integrating data from government policies, market analysis, and interviews with key stakeholders. The findings reveal that the success of China's NEV sector stems from the interplay between top-down policy interventions and bottom-up entrepreneurial activities. This interplay has facilitated a shift from a firm-centric, vertically integrated value chain to a sectoral supply chain ecosystem, highlighting the crucial role of adaptive policy frameworks and platforms in fostering collaboration and competition in innovation. The study underscores the importance of value co-creation at the sectoral level. By synthesizing policy-driven sectoral systems of innovation (SSI) frameworks and firm-driven innovation ecosystem (IE) frameworks, an integrated sectoral innovation ecosystem (SIE) framework is proposed. This framework enriches the theoretical understanding of innovation by connecting macro-level policy insights with micro-level entrepreneurial dynamics in the emergence of a new sector. The SIE framework offers practical implications for managers and policymakers in other latecomer countries seeking to navigate similar paths of industrial development.

Keywords: policy intervention; sectoal innovation ecosystems; electric vehicle; meso-level; China

INTRODUCTION

The rise of China’s New Energy Vehicles (NEVs)[1] sector presents a significant phenomenon,

[1] The 'Regulations on the Administration of Access to New Energy Vehicle Manufacturers and Products,' implemented by the Ministry of Industry and Information Technology on July 1, 2009 (No. 44), explicitly defined NEVs for the first time. According to these regulations, NEVs refer to automobiles that use unconventional automotive fuels as a power source (or conventional automotive fuels with new onboard power devices) and incorporate advanced technologies in vehicle power control and drive

illustrating a latecomer country's rapid ascent in a technologically complex and competitive industry. The NEV industry is characterized by large-scale investment requirements, high R&D expenses, intensive resource consumption, fierce market competition, strong liquidity, and diminishing profit margins (Song & Aaldering, 2019). The rise of China's NEV sector has garnered global attention, providing a compelling case study for understanding the mechanisms behind technological catch-up in latecomer countries (Zhang et al., 2022).

Existing literature on sectoral systems of innovation (SSI) and innovation ecosystems (IE) provides frameworks for analyzing such phenomena. The SSI framework emphasizes the role of institutions, policies, and interactions among firms and non-firm institutional actors in driving innovation within specific sectors (Malerba, 2002). The SSI framework builds on evolutionary economics, the innovation systems approach, and industrial organization, highlighting the importance of learning, knowledge accumulation, and the interactive nature of innovation (Nelson & Winter, 1982; Lundvall, 1992; Edquist, 1997). Some scholars argue that a country's institutions and industrial policies are particularly important in latecomer countries' catch-up, where the government is more likely to have the upper hand in addressing constraints arising from their weak indigenous technological capabilities and under-developed domestic markets (Choung, Hwang, & Song, 2014; Schott & Schaefer, 2023). Conversely, the IE framework focuses on the collaboration among diverse actors, including focal firms, entrepreneurial ventures on the value chain, complementors, users, and competitors, to foster innovation through co-specialization and co-adaptation, knowledge sharing, and resource recombination in value co-creation (Adner & Kapoor, 2010; Nambisan & Baron, 2013). However, both these frameworks have limitations in explaining the rapid

systems. NEVs include various categories such as hybrid electric vehicles (HEVs), battery electric vehicles (BEVs, including solar vehicles), fuel cell electric vehicles (FCEVs), hydrogen engine vehicles, and other new energy vehicles. In this paper, we use EV to cover both BEVs and plug-in hybrid electric vehicles (PHEVs). However, we do not cover fuel-cell electric vehicles (FCEVs), which transform hydrogen, methanol, natural gas, or gasoline into energy in fuel cells and provide power to the vehicle. Therefore, the terms NEV and EV are used interchangeably.

and complex development observed in China's NEV sector.

Traditional SSI frameworks often adopt a top-down, policy-centric approach, overlooking the micro-level dynamics of entrepreneurship-driven innovation and the intricate interplay between enterprises and their policy environments (Lundvall, 1992; Malerba, 2002; Edquist, 2005). Similarly, IE frameworks may neglect the role of formal institutions and policies, focusing predominantly on firm-level interactions (Adner & Kapoor, 2010; Nambisan & Baron, 2013). This paper seeks to bridge these gaps by synthesizing insights from both frameworks at the meso level to provide a more comprehensive understanding of the dynamic interactions and feedback loops between policy-centric and firm-centric approaches that characterize the rise of China's NEV industry (Zhang, 2023).

To address these gaps, this study poses the following research questions:

1. How do macro-level policy interventions interact with micro-level entrepreneurial activities to drive technological and industrial advancements?

2. What role do micro-level dynamics of entrepreneurship-driven innovation play in this process?

3. How have meso-level public policies facilitated the rise of China's NEV sector?

This paper employs an inductive case study approach, focusing on China's NEV sector from 2006 to 2023. Data collection includes a comprehensive analysis of 153 policy documents, market data on NEV manufacturers and key component suppliers, and interviews with key stakeholders, including policymakers, industry experts, investors, and executives from NEV firms. The analysis combines qualitative methods with quantitative techniques to explore the correlation between policy support and NEV sales revenues.

Based on the findings, we propose an integrated sectoral innovation ecosystem (SIE) framework. Central to this framework is a pragmatic policy regime that connects macro- and micro-level factors in a feedback loop, allowing policymakers to adjust policies in response to technological and market developments. In this framework, the meso-level mechanism plays an instrumental role between policies and market dynamics, enabling not only the co-creation of value but also the development of ecosystem-level goods, such as the supply chains and the infrastructure for the NEV sector, which can be shared by all actors. The study underscores the significance of adaptive policies and the interplay between government interventions and entrepreneurial activities in driving innovation and industry growth.

This paper is structured as follows. Section 2 provides a theoretical background, discussing the SSI and IE frameworks and identifying their limitations. Section 3 outlines the research design and methods, detailing the data collection and analysis procedures. Section 4 presents the findings, highlighting the key themes and patterns identified in the policy and market data. Section 5 discusses the theoretical logic of the integrated SIE framework and its implications, and directions for future research. Section 6 concludes with a summary of the findings and contributions.

THEORETIC BACKGROUND

A Sectoral System of Innovation (SSI) Framework

The concept of sectoral systems of innovation (SSI) provides a comprehensive framework for understanding the dynamics of innovation within specific sectors. In a broad sense, the SSI framework, as an industrial policy, has been widely used by countries aiming to promote the development or competitiveness of their industries (Robinson, 2010). The SSI framework is rooted in several intellectual traditions, including evolutionary economics, the innovation systems approach, and industrial organization. Evolutionary economics emphasizes the role of learning, knowledge accumulation, and the dynamic processes of change within industries (Nelson & Winter, 1982). The innovation systems approach focuses on the interactive nature of innovation, involving a wide range of actors such as firms, universities, and government agencies (Lundvall, 1992; Edquist, 1997). Industrial organization literature contributes by examining the structure, conduct, and performance of firms within sectors (Scherer, 1990).

In latecomer countries, industrial policy plays a particularly important role in its emerging and strategic industrial sectors (Chen, Rong, Xue, & Luo, 2014; Guo, Zhang, Dodgson, & Gann, 2019; Zhang, 2016). In particular, China's industrial policy has been built upon the concept of a national innovation system (NIS), which focuses on the country-level analysis of innovation processes and emphasizes the role of national institutions, policies, and cultural factors in shaping the innovation capabilities of a country (Freeman, 1987; Lundvall, 1992; Nelson, 1993). Existing research suggests that China's policy interventions facilitate multiple stakeholders, including institutes for research and funding, enterprises, and government bodies, to work together to achieve a top-down goal, such as its 'two bombs and one satellite' projects. These frameworks typically emphasize top-down policy interventions and the role of government and institutional actors in driving innovation, and it worked well when the technological trajectory of which was certain and defined (Gao, Liu, & Zhang, 2011). They often view innovation processes as linear and sequential, focusing on the interactions between policy, research institutions, and industry (Lundvall, 1992; Malerba, 2002). However, this framework is less effective in the process of overcoming the liability of newness during the rise of a strategic technology/industry where technological complexity is high.

Indeed, China uses the NIS not just to make up for market failures, but also to actively intervene in economic structural reforms, increase industrial competitiveness, and support strategic sociotechnical transitions (Savaget, Geissdoerfer, Kharrazi, & Evans, 2019). This is because the large state presence dominates in China's economy, which influences the balance between industrial sectors and regions, and between state-owned and private businesses (Lin & Boris, 2010). For example, government support in R&D in the Chinese wind turbine industry (Awate, Larsen, & Mudambi, 2012; Chen et al., 2014), and policies that promote the capacities of the core components on the supply chain of China's offshore oil and gas equipment-manufacturing industry (Li, Li, & Tan, 2022), play critical roles in its catch-up and the transformation to a global leader in these industries.

However, in emerging technologies/industries where technological trajectories are uncertain and existing knowledge and capabilities are inadequate, top-down policy frameworks are less effective. For example, China's policy to support its homegrown 3G standards, TDSCDMA, proves to be a failure (Zhang, 2016). As argued by Loorbach and Rotmans (2010), catch up in an industry of technological complexity involves factors in society and its subsystems. Technological complexity is related to technological uncertainty, which can be measured with the number of elemental units involved in a technology and the degree of interdependence/interconnections among these components (Mewes & Broekel, 2022; Singh, 1997; Xu & Xu, 2023).

Different from the NIS framework, the SSI framework considers the unique characteristics of each sector, especially its knowledge base, technologies, demand conditions, and institutional settings (Malerba, 2002). Knowledge plays a central role in SSI, with different sectors characterized by distinct knowledge bases and learning processes. For instance, the machine tools industry relies heavily on tacit knowledge accumulated through long-term interactions between producers and users (Kim & Lee, 2008). In contrast, sectors like biotechnology are driven by scientific knowledge and formal R&D activities (Malerba, 2004). The degree of knowledge accessibility, cumulativeness, and appropriability varies across sectors, influencing the patterns of innovation and industrial dynamics (Cohen & Levinthal, 1989).

Thus, in technologically complex industries or sectors like automobile, when facing technological regime shifts, the mechanisms that drive structural changes are complex, caused by dynamic interactions and feedback loops between elements across different levels or organizational boundaries in a non-linear fashion (Geels & Schot, 2007). In such industries, mass-collaboration of entrepreneurial activities, including changes in manufacturing mode, business models in organizing supply chains, even consumers' behaviours, drive latecomer's rise or transformation.

An Innovation Ecosystem (IE) Framework

While SSI offers a sector-specific view that is useful for industry-specific strategies and interventions, its focus is on the interactions among firms and non-firm actors within certain system boundaries, emphasizing institutions, public policies, and the surrounding environments (Malerba, 2022). However, it does not sufficiently address the complex technologies, which relies on the construction and coordination of collective actions and the interdependence among multiple stakeholders, especially in the face of an uncertain and fast-changing technological environment (Adner, 2017; Adner & Kapoor, 2010; Autio & Thomas, 2014).

Innovation ecosystem (IE) frameworks, characterized by value co-creation, knowledge sharing, and the recombination of diverse resources and capabilities across organizational boundaries, offer an explanation of how collective actions are organized to drive innovation (Dattée et al., 2018; Jacobides et al., 2018). The IE frameworks focus on the structure and relationships among business firms, including complementary and substitute relations, that drive self-organizing, co-adaptation, and co-specialization in innovation (Adner & Kapoor, 2010; Teece, 2007). Adner (2017) argues that entrepreneurship is the driving force that breaks traditional boundaries and reaches a wider domain set by intended interdependencies.

The concept of IE frameworks is rooted in the idea of business ecosystems (Moore, 1993), which describe the network of organizations—including suppliers, distributors, customers, competitors, and other stakeholders—involved in the delivery of a specific product or service offered by a focal firm. In this view, the focal firm acts as a central hub or 'keystone' that orchestrates the activities of the various ecosystem members (Baldwin & Clark, 2000). As innovation has become increasingly distributed and open, with firms relying more on external sources of knowledge and technologies, the concept of IE has gained prominence in both academia and business.

Innovation ecosystems extend the business ecosystem perspective by recognizing the importance of diverse actors in driving innovation (Nambisan & Sawhney, 2011; Adner & Kapoor, 2010). They represent "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution" (Adner, 2006, p. 2). Unlike the business ecosystem perspective, which is centered around a single firm, innovation ecosystems are more decentralized and involve a wider array of participants, including research institutions, universities, entrepreneurs, investors, and even users or competitors (Nambisan & Baron, 2013; Zahra & Nambisan, 2011). Hence, the focus shifts from optimizing a firm's value chain to fostering an environment conducive to innovation and new value creation (Autio & Thomas, 2014).

Central to the IE framework are platforms that mediate multi-stakeholder collaboration in value co-creation (Jacobides, Cennamo, & Gawer, 2018). Mediated by platforms, an innovation ecosystem strategy enables interactions among a set of upstream suppliers and downstream users in value co-creation along an industrial supply chain (Adner, 2006; Adner & Kapoor, 2010; Kapoor & Furr, 2015). Recent studies suggest that platforms are not only intermediaries linking multiple actors but also provide ‘standards’ that enable various modules/components with complementarities to collaborate, thus extending the functionality of the system (Baldwin & Clark, 2000).

In such ecosystems, standards define an overall technical architecture and specify interfaces among components and subsystems for a technological system (David & Greenstein, 1990). They have emerged as platforms that enable inter-organizational interactions and facilitate innovation at the supply chain level (Zhang, Dodgson, & Gann, 2022). Enterprises and entrepreneurial firms that specialize in certain components or parts can work together by adhering to industrial standards and aligning their offerings with the evolving needs of the ecosystem, generating higher value at a systemic level than the sum of all components. This co-specialization and co-adaptation in feedback loops enable firms in the supply chain to focus on their core competencies and collaborate with other ecosystem actors who provide complementary value. This can lead to the creation of value networks, where the interdependencies between different components on a supply chain drive innovation across organizational boundaries (Hullova, Trott, & Simms, 2016).

In supply chain-driven innovation ecosystems, complementarity arises when the presence or performance of one component enhances the value or functionality of another or the system as a whole (Hullova et al., 2016). Collaboration within such an innovation ecosystem is essential for the co-creation of value in a technologically complex sector (Amit, Snihur, & Zott, 2020; Nambisan, Zahra, & Luo, 2019; Zhang & Williamson, 2021). While the IE framework elucidates the mechanisms by which diverse stakeholders collaborate, it does not explain how the system as a whole aligns its goals, responds to the environment, shares risks, and engages in joint problem-solving at a sectoral level.

A Theoretical Map

From the perspective of catch-up, an endogenous ability in product development and production innovation, especially in an industry as complex as automaking, requires the long-term accumulation of technological innovation capability and engineering know-how to achieve expected levels of quality and competitiveness on an established technological trajectory, i.e., ICEV (Zhang et al., 2022). The SSI framework focuses on the role of institutions, policies, and interactions among firms and non-firm actors in promoting sectoral-level innovation (Malerba, 2002). In contrast, the IE framework emphasizes relationships and networks among firms, highlighting the importance of platforms and entrepreneurial ventures in fostering innovation (Adner, 2006). While both these frameworks offer certain explanations for the complex processes involved in China's NEV rise, there is room for synthesizing them. In Figure 1, we map the theoretical frameworks that are used to answer the research questions in this study.

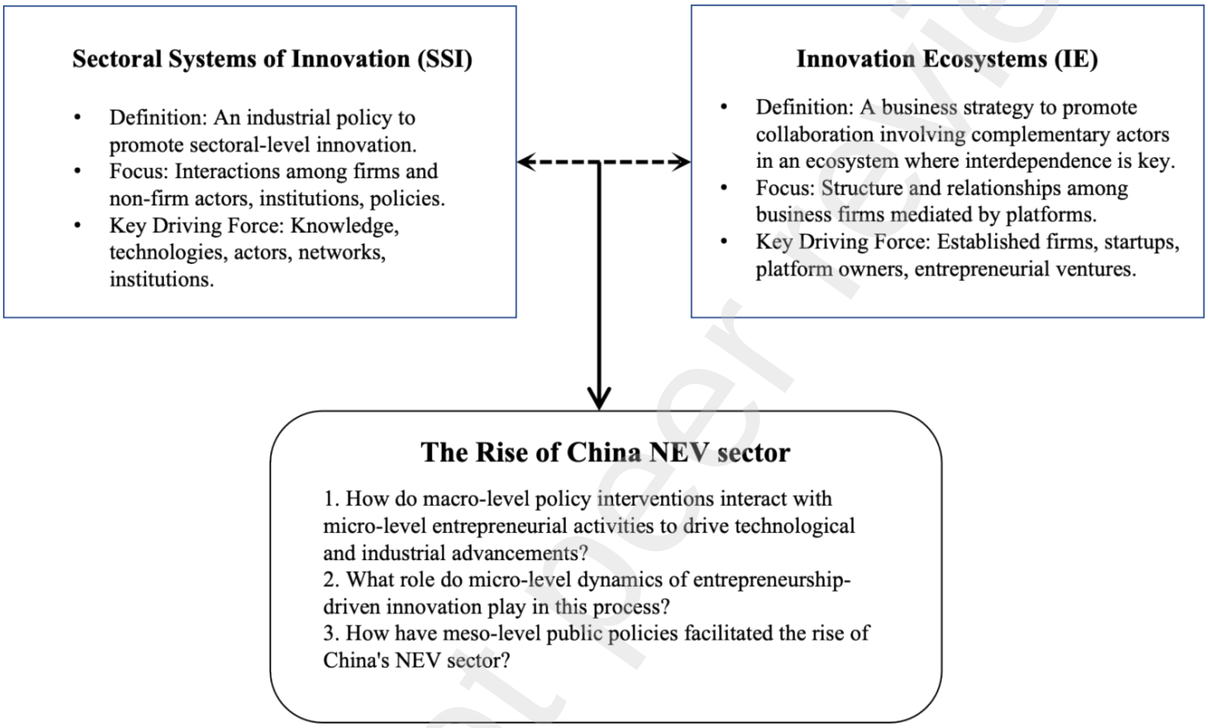


Figure 1. A theoretical map

METHODS

Research Design and Setting

This study adopts a qualitative case study approach, which is particularly suitable for addressing the research questions this research aims to answer, due to its exploratory nature and ability to provide a deep understanding of complex phenomena within their real-life context (Eisenhardt, 1989; Yin, 2014). Given the rapid and multifaceted development of China's NEV industry, this method enables a comprehensive understanding of how various factors interact over time to drive technological and industrial advancements.

In this study, we treat the rise of China's NEV sector as the focal case. China is the world's largest and fastest-growing car market (Accenture, 2021). As of the end of 2023, China had emerged as the world leader in the NEV industry by sales volume, representing over 60% of the global total. In that year, Chinese automotive enterprises exported 5.171 million units, with 25% being NEVs, thereby becoming the world's largest car exporting country, surpassing Japan.2 The year 2023 saw continued robust growth in NEV sales, both within China's domestic market and in its exports.

The auto industry, as a pillar industry, has been the focus of much policy attention in China. Industrial policy aimed at developing China's auto industry began in 1986. Starting from a very weak technological and industrial foundation, the policy focused on an approach of 'market for technology'—mandating foreign car manufacturers to form joint ventures with local partners in order to gain entry to the Chinese market, under the condition of transferring technologies for car manufacturing and component production (Zhang et al., 2022). This policy hoped that through such a scheme, China would build its indigenous technology in the automotive industry by 'importing, absorbing, and re-innovating' foreign technologies (Zhang et al., 2022). After decades of development, however, China's car market became large but had little indigenous innovation in critical components of the ICEV sector, such as engines and gearboxes (Economist, 2020). How China's NEV industry overcame latecomer disadvantages and capitalized on the opportunities presented by technological regime shifts offers a real-life experiment in understanding latecomers' catch-up.

To answer the research questions, we collected and analyzed the following data guided by our theoretical map as depicted in Figure 1.

[2] https://www.whaleautos.com/2023-Global-Automotive-Export-Countries-Ranking-id46076097.html, accessed on April 30, 2024.

Data Collection

We followed the data collection method used in conducting a 'revelatory' case (Eisenhardt & Graebner, 2007). The primary data sources include:

- Government policies: We collected industrial policies directly related to China's NEV sector between 2006 and 2023 at the national level (The list of the policy documents is in Appendix I). We also extracted work reports at the provincial level for the 25 cities which are located in those provinces and included in the 'Ten Cities, Thousand Vehicles' program, as pilots, to promote NEV adoption. We used the keywords related to NEV manufacturing, NEV supply chain, environmental protection, sustainability, and carbon emission reduction (altogether 32 keywords as shown in Appendix II) to choose the work reports.
- Market data: Secondary data on NEV manufacturers and key component suppliers were collected from industry reports, company documents, and academic publications. This included data on market shares, production capacities, and technological capabilities.
- Interviews: We conducted 12 semi-structured interviews with key stakeholders, including policymakers, founders and investors in EV start-ups, executives of established NEV firms, and industry experts. These interviews were used to verify our preliminary findings and provide insights into the practical challenges and strategies employed in the NEV sector.

Data Analysis

The data analysis followed an iterative process, combining qualitative and quantitative techniques:

- Policy analysis: Our data analysis comprised three stages. Initially, open coding was employed to discern key contexts and activities, as suggested by Gioia, Corley, and Hamilton (2013). We then engaged in comparative iterations to identify primary codes, as per Miles and Huberman (1994). This was followed by the generation of axial codes, highlighting patterns and potential relationships among primary codes, in line with Braun, Clarke, and Weate (2016). We also adopted a mapping strategy (Langley, 1999) to sorted and synthesized policy documents at the national level into categories.

- Market data analysis: We employed time series analysis to map the dynamics of the NEV ecosystem. This included tracking the top global EV makers and leading component suppliers over time to understand the global NEV supply chain. This comparative data analysis allowed us to examine the dynamics of Chinese manufacturers in this market. Our method differs from panel data analysis. Instead of concentrating on outcomes associated with specific times and objectives, our approach involves comparing manufacturers which emerged in the market at various times, as well as those which left the market.
- Correlation analysis: To explore the relationship between policy support and NEV sales, we conducted a correlation analysis using data from 25 pilot cities of the 'Ten Cities, Thousand Vehicles' program. This involved mapping keyword frequencies from provincial work reports where the pilot cities belong to against NEV sales revenues of those cities. On the X-axis, we display the frequencies of keywords appearing in the provincial work reports, year by year. On the Y-axis, we matched the sales revenue of NEVs (we take the natural logarithm of these values) in those cities, year by year. We conducted further panel data regression analysis of these two variables.

Justification of Research Design and Methods

By employing an inductive case research design, this study is well-equipped to answer the research questions regarding the rise of China's NEV sector.

<u>Understanding macro-level interventions (RQ 1)</u>

The case study approach allows for a detailed examination of how policies are enacted and adjusted over time, capturing the iterative nature of policy-making and its impact on entrepreneurial activities.

Role of micro-level dynamics of entrepreneurship-driven innovation (RQ2)

Policy and market data analyses provide a comprehensive view of the interactions between government interventions and market responses. The thematic analysis of these interviews helps to elucidate the entrepreneurial activities that contribute to the sector's growth.

Meso-level policy facilitation (RQ 3)

By synthesizing data from policy documents, market data, and interviews, we can trace the evolution of public policies and their role in shaping the NEV ecosystem. The correlation analysis between policy support and NEV sales further quantifies the impact of public policies on sectoral development.

The design facilitates a deep understanding of the macro-level policy interventions, the role of entrepreneurship-driven innovation, and the meso-level policy mechanisms that have enabled this sectoral transformation. The multiple sources of data helped accomplish triangulation (Jick, 1979), increasing the reliability of the data and the validity of the findings.

FINDINGS

Macro-level Policy Interventions

In 2010, new energy vehicles were designated as one of China's seven strategic emerging industries.[3] Subsequently, a decade-long national subsidy program for NEV was initiated. Using data analysis of policy at the national level, we find that there are three major incentives behind China's NEV policies.

First, increasing energy security. Automobile fuel has been the fastest growing area of

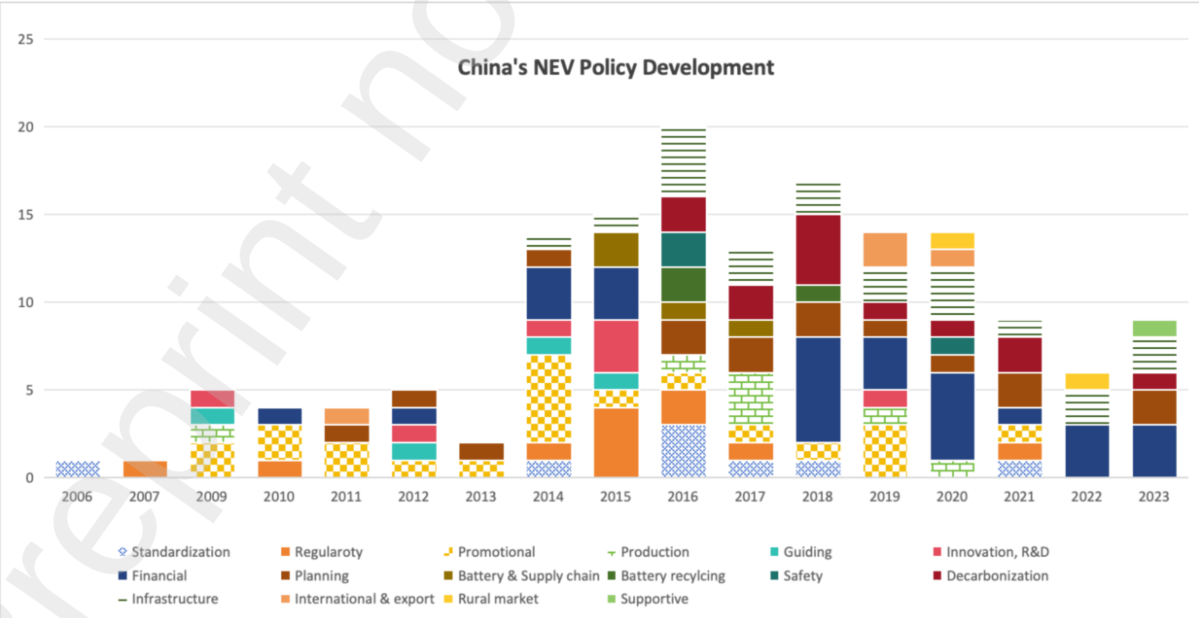
[3] https://www.uschina.org/sites/default/files/sei-report.pdf, accessed on April 30, 2024.

China's oil consumption, due to the rapid increase in car ownership in recent decades. The external dependency of China's crude oil industry increased from 55% in 2010 to 71% in the first half of 2022, far exceeding the international safety threshold. To preserve China's strategic oil reserves, the government needed to promote a transition to new energy or alternative energy vehicles.

Second, reducing pollution. In recent years, more than 80% of carbon monoxide (CO) and more than 40% of nitrogen oxides (NO_2) in China's large cities have been from ICEV emissions, which contributed to pollution in these cities.

Third, developing an autonomous automobile industry. The lessons from unsuccessful catch-up in ICEV sector suggest that developing an autonomous NEV industry provided an alternative route for China to catch up with the industrial forerunners in automobile industry.

For these reasons, the NEV sector has received a range of policy support. Since 2006 until the end of 2023 there have been 153 policies at the national level on NEV development (see Appendix I). We categorized these policies by the year they were launched as shown in Figure 2.



Source: Compiled by the authors from secondary sources, including relevant government websites.

Figure 2. China's NEV Policy Development (2006-2023)

Our analysis of keywords in the NEV-related policies suggests that, although many policies were enacted by multiple policymaking bodies, they have shown patterns corresponding to distinct developmental stages. These policies addressed different aspects of the NEV ecosystem, from standardization and regulatory frameworks to financial incentives and infrastructure development.

Phase I: Early Development and Demonstration (2006-2012)

In the initial phase from 2006 to 2012, the focus was primarily on standardization, regulatory frameworks, and promotional activities to lay the groundwork for NEV development. The Ministry of Science and Technology (MoST) issued the "Guidance for Implementation of the National '863' Plan" in 2006, emphasizing the R&D of technology standards and key components. In 2007, the National Development and Reform Commission (NDRC) introduced the "Administrative Rules for Production License of New Energy Vehicles," defining NEVs and establishing production standards.

This period also saw significant promotional efforts such as the "Ten Cities and Thousand Vehicles" project in 2009, which aimed to showcase NEV technology in urban settings. Financial incentives began to play a crucial role, with pilot subsidies for private NEV purchases and tax incentives to encourage adoption.

Phase II: Infrastructure and Supply Chain Development (2013-2016)

From 2013 to 2016, the focus expanded to include infrastructure development and supply chain integration. 2014 marked a milestone for China's NEV industry when pure battery and hybrid battery vehicles were confirmed as the main technological trajectories for NEVs in the country, as outlined in the "Interim Provision on Investment Projects and Production License

Management of Newly Built Pure Electric Passenger Vehicle Manufacturers (Draft for Comments)" by the NDRC. This period emphasized the construction of charging infrastructure, essential for supporting the growing number of NEVs. Policies were introduced to ensure the availability of charging facilities and to promote the sustainable recycling of used power batteries.

Additionally, the supply chain for key components, particularly automotive power batteries, received attention. The State Council and various ministries issued guidelines to build a robust supply chain, addressing both production capabilities and recycling processes.

Phase III: Comprehensive Strategic Planning and Decarbonization (2017-2020)

The years 2017 to 2020 were characterized by a more holistic approach, incorporating comprehensive strategic planning and a strong focus on decarbonization. The 13th Five-Year Plan (2016-2020) outlined detailed strategies for NEV development, emphasizing technological innovation, environmental sustainability, and energy efficiency.

The government introduced a basket of financial support and fiscal subsidy programs to encourage R&D and production innovation in NEV manufacturing and battery technologies. As a result, the industry experienced substantial growth, especially in the construction of the supply chain. At least 450 NEV makers, and 1500 power battery-related enterprises entered the competition.

Policies aimed at reducing carbon emissions and improving energy efficiency were introduced, aligning with broader environmental goals. This period also saw an increased emphasis on safety standards, ensuring that NEVs met high safety requirements to protect consumers and promote public confidence.

Phase IV: High-Quality Development and Intelligent Vehicle Technologies (2021-2023)

The most recent phase from 2021 to 2023 reflects a mature and multifaceted approach to NEV development, focusing on high-quality development and the advancement of intelligent vehicle technologies. From 2020 to 2022, the annual subsidies gradually reduced by 10%, 20% and 30%, respectively, and came to a halt in 2023, but the NEV adoption accelerated. The penetration rate of NEV (the percentage of buyers who purchase an NEV of the total number of car buyers in a year) in China took a decade - from 2010 to 2020 - to reach 5%, but less than one year to double the rate, and reached 35%.

Policies during this period have sought to refine existing frameworks, optimize financial subsidies, and enhance the charging and battery swapping infrastructure. By the end of 2023, there were 70 NEV makers and 450 power battery enterprises that survived internal competition -- competitive NEV makers gained market share, forcing those that relied on subsidies to withdraw from the market.

Meanwhile, China's NEV makers started to expand in the global market. There has also been a significant push towards the electrification of public transport and promoting NEVs in rural areas. Additionally, the development of intelligent and connected vehicles has become a key priority.

Micro-level Dynamics of Entrepreneurship-driven Innovation

Since 2014 when China confirmed battery EVs as a main technological trajectory for NEV sector, the government has issued policies to guide and subsidize component manufacturers, to strengthen the supply chain for NEVs. The government mandated that all NEVs sold in China from 2019 should be made with Chinese parts and components. Power batteries, electric motors, and electronic control systems are the critical components on NEV supply chains.

NEV manufacturers

Our analysis of key phrases in secondary data shows that there have emerged three types of

NEV makers in China since 2009:

- NEV start-ups: Start-up NEV automakers, with little automaking experience, are supported by venture capital funds based on their accumulated experience in related industries, such as IT, internet and AI, and innovative business models and design, but relying on external supply chains and manufacturing contractors for production. Examples include Nio, Xpeng and Li Auto, which entered the industry with the view of running the automaking business in an internet type of business model. Though strong in design and software, this group of NEV start-ups lacked experience in physical car manufacturing and therefore faced challenges in mass production and meeting profitability targets.
- Domestic ICEV automakers transforming into NEV makers: Domestic automakers, such as SAIC, BAIC, Geely, Great Wall and BYD, became leading NEV makers, transforming from their ICEV businesses. This group of automakers had experience in whole car manufacturing, and supply chain management; some of them (i.e., BYD and Great Wall) had also built capability in power battery production and other supply chain manufacturing.
- Foreign funded or Sino-foreign joint venture (JV) NEV makers: Tesla is the only foreign-owned pure battery EV maker in China. The JV group were those which had built strong business in China's automobile market with Chinese partners in the ICEV era and engaged in transformation into the NEV business. They introduced their NEV models from their home markets to compete with the other two groups.

Spillover effects of Tesla

Our research suggest that Tesla's entry to China's market has helped the country develop a supply chain in the EV market (Murmann & Perkins, 2018; Teece, 2018). The Shanghai government provided discounted loan and subsidized land for Tesla's Gigafactory and granted the factory the status of a wholly owned foreign enterprise, the first in the auto industry in the country.[4] In less than three years, Tesla fulfilled the condition for the government subsidies of building a localized supply chain in China. Its ratio of locally produced parts increased from 50% at the end of 2019 to 70% in October 2020, and, over 95% in 2022.

The EV supply chains have spillover effects, benefiting the local EV makers (Zhang, 2023). In its supply chain, Tesla partnered with 360 Chinese tier-one suppliers, 60 of which also became global suppliers for Tesla, according to various news reports.[5]

One interviewee commented that Tesla has played a critical role in stimulating the amassing of such a supply chain ecosystem in China.

> *Tesla's advancement in supply chain technologies is also facilitating Chinese companies in improving their parts and components technologies. Spurred by Tesla's influence, integrated die-casting technology is now widely adopted by local EV makers. This approach is reminiscent of Apple's supply chain model, in which China has built its supply chain in consumer electrics and electronic products, and recently in smart phones, based on its accumulation of hardware manufacturing.*

One investor in the EV sector we interviewed commented:

> *Innovation across industries should be enterprise-oriented, market-oriented, but the government guided platforms, especially in commonly used technologies, are critical for the co-evolution in the supply-chain ecosystem. Actors from different industries have come to form an interdependent innovation ecosystem.*

CATL, the leading lithium battery maker, provided its battery solutions and services for the global makers. Its customers included Tesla, BMW, Mercedes-Benz, and China's NEV

[4] In October 2018, Tesla bid $140 million for a pocket of land (866,000 square metres) designated for industrial use near Shanghai Harbour. A building permit was granted in December 2018, and the land was prepared for construction, with electricity installed onsite short afterwards. On 11 November 2019 the first China-made Tesla Model 3 EV emerged from Tesla's Gigafactory in Shanghai.

[5] https://english.news.cn/20230905/ce9d9c797d2747a693e23fd393fcfa58/c.html (accessed on April 30, 2024) and https://asia.nikkei.com/Business/Automobiles/Tesla-rides-high-on-cost-savings-from-China-s-Gigafactory (accessed on April 30, 2024).

start-ups, like Nio and Xpeng.

BYD, China's leading NEV maker, started its business as a battery manufacturer for mobile phones. Since entering the automaking industry in 2003, BYD has invested in R&D in both NEV manufacturing and power battery technologies. One interviewee commented:

> *BYD took a 'dual technological route' strategy in its business, starting with dual-mode PHEVs when the battery technology was insufficient to cover long mileages, but maintaining its R&D in BEVs and batteries. The company is betting on solid-state lithium batteries which promise to provide higher power density, and travel over 1000 kilometres per charge. To back its battery ambition, the company also invested in upstream lithium mines. BYD partners with the Chinese Academy of Sciences, Electronics Research Institute, Automotive Engineering Research Institute and Electric Power Research Institute, in developing cutting-edge lithium battery technology.*

According to Zhang (2023), the geographic distribution of China's EV supply chains is notably concentrated in two key regions, each offering unique advantages to the industry. The Yangtze River Delta region, encompassing Shanghai, Jiangsu, Zhejiang, and extending to Anhui, is renowned for its robust traditional automotive supply chain. Meanwhile, the Pearl River Delta, centered around Shenzhen and Guangzhou, has leveraged its strong electronics supply chain and manufacturing prowess, providing a wealth of electronic components and batteries for EVs.

In 2023, Shenzhen led in EV production with 1.786 million units, closely followed by Shanghai with 1.287 million units.[6] Conversely, cities such as Changchun, Wuhan, and Beijing, previously celebrated in traditional automobile manufacturing, now find themselves outside the top ranks in EV production. For example, automobile production in Beijing significantly dropped from a peak of 2.74 million units in 2016 to just over 1 million in 2023.[7] One of our interviewees commented that a lack of regional supply chain hub was a

[6] https://finance.sina.com.cn/money/future/roll/2024-01-19/doc-inaczvhe8564496.shtml, accessed on April 30, 2024.

[7] http://lwzb.stats.gov.cn/pub/lwzb/gzdt/201707/t20170728_4250.html and https://finance.sina.com.cn/money/future/roll/2024-01-19/doc-inaczvhe8564496.shtml, accessed on April, 30, 2024.

key reason for the decline of EV production in these cities. The ranking decline of BAIC, Beijing flagship automaker, was an example.

The market data of the top 20 global NEV makers is shown in Table 1.

Table 1. Top 20 NEV Makers

Ranking	2019	2020	2021	2022
TOP 1	Tesla	Tesla	Tesla	BYD
TOP 2	BYD	Volkswagen	BYD	Tesla
TOP 3	BAIC	BYD	SGMW	SGMW
TOP 4	SAIC	SGMW	Volkswagen	Volkswagen
TOP 5	BMW	BMW	BMW	BMW
TOP 6	Volkswagen	Mercedes-Benz	Mercedes-Benz	Mercedes-Benz
TOP 7	Nissan	Renault	SAIC	GAC
TOP 8	Geely	Volvo	Volvo	SAIC
TOP 9	Hyundai	Audi	Audi	Changan
TOP 10	Toyota	SAIC	Hyundai	Chery
TOP 11	KIA	Hyundai	KIA	KIA
TOP 12	Mitsubishi	KIA	GWM	Geely
TOP 13	Renault	Peugeot	Renault	Hyundai
TOP 14	Chery	Nissan	GAC	DongFeng
TOP 15	GAC	GAC	Peugeot	Volvo
TOP 16	Volvo	SGMW	Toyota	Audi
TOP 17	SGMW	Toyota	Ford	Hozon
TOP 18	DongFeng	Chery	Chery	Ford
TOP 19	Changan	Porsche	Xpeng	Li Auto
TOP 20	JAC	NIO	Changan	Peugeot
Share of top 20 in global sales	**83.5%**	**78.4%**	**74.1%**	**74.9%**

Source: CleanTechnica database

From Table 1, we can observe several critical trends:

- From 2019 to 2022, the global market share held by the top 20 EV manufacturers changed from 83.5% to 74.5%, indicating that new entrants carved out significant share. Nearly half of these top 20 EV makers were from China or owned by Chinese companies.

- Tesla and BYD remained at the top of the rankings, highlighting their sustained dominance in the NEV market. In 2022, BYD surpassed Tesla to claim the market leadership, a position Tesla had maintained since 2019.
- In 2020, China's SGMW (SAIC-GM-Wuling) overtook the German manufacturer Volkswagen to secure the third spot.
- Chinese NEV start-ups have shown an upward trend of catching up in market share. NIO moved up from the 18th position in 2021 to 11th in 2022, and XPeng reached 14th in 2022. Li Auto and Hozon also appeared in the rankings, showcasing the dynamic nature of the NEV market and the increasing presence of new players.
- Traditional automotive giants such as Ford and Toyota maintained lower but stable rankings. Renault and Mitsubishi experienced notable declines.
- Chinese brand BAIC, ranked 3rd in 2019, dropped out of the top 20 by 2022.

In Figure 3, we also mapped the trajectories of the top 20 NEV makers in the global market between 2019 and 2022, which illustrates fluctuations in rankings.

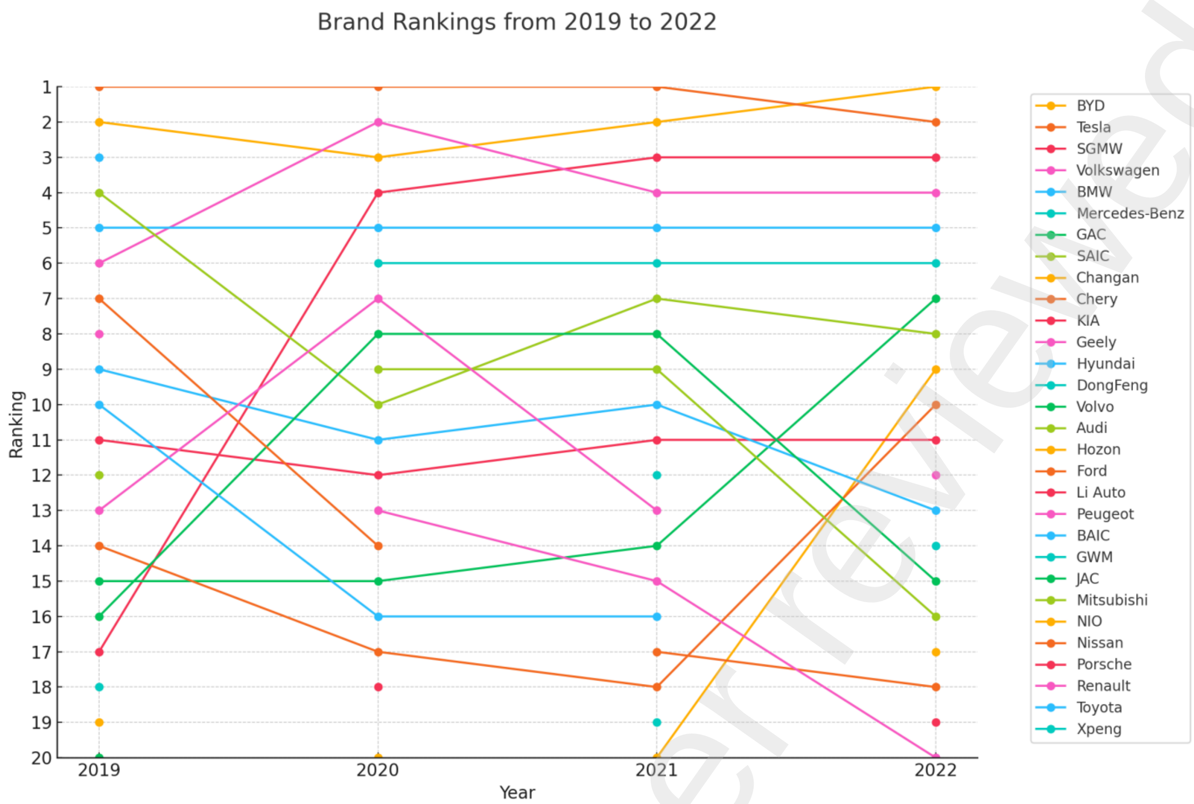
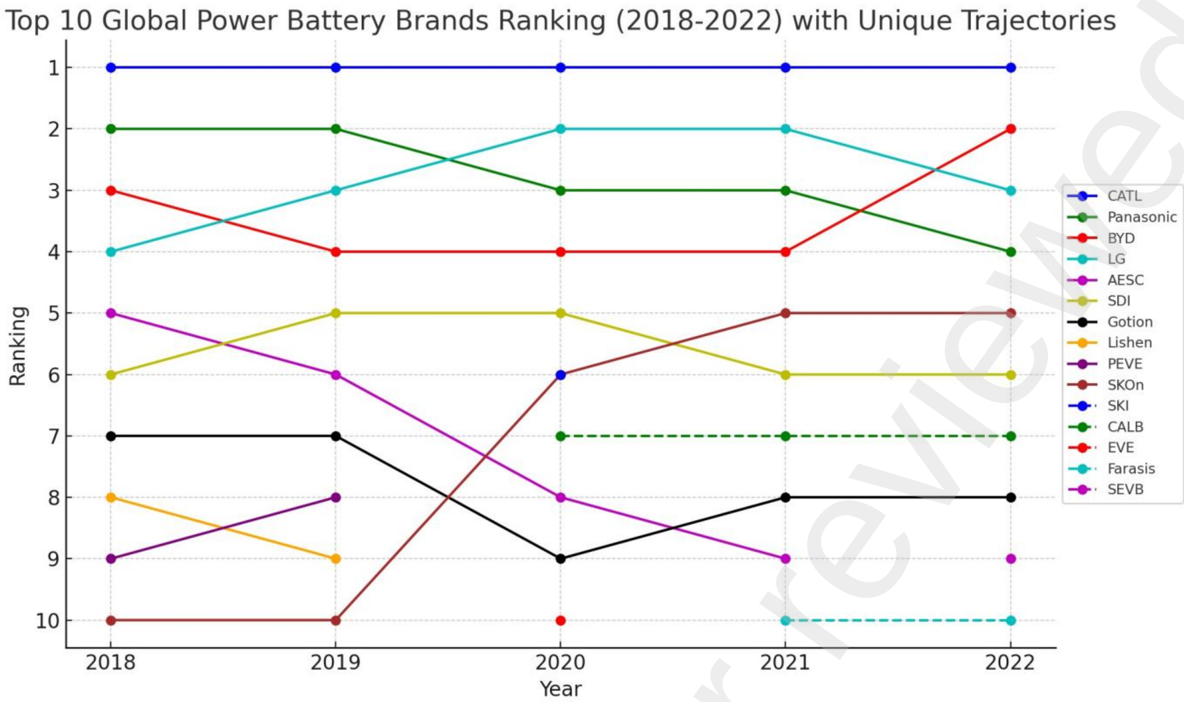


Figure 3. Top 20 NEV Brands in the Global Market (2019-2022)

<u>*Power battery*</u>

In Figure 4a, we illustrate the trajectories of the top 10 global power battery brands from 2018 to 2022. Each line represents a brand's ranking over the five-year span.

Thirteen firms appeared in this list, with the top 10 commanding a monopolistic market share. In 2022, the top four manufacturers are CATL, BYD, LG, and Panasonic, two are Chinese brands (CATL and BYD), one Japanese (Panasonic) and one South Korea. CATL consistently led the pack, while Panasonic had been experiencing a gradual decline. LG and BYD were actively competing for a second place. The competition intensified further down the rankings, especially among the lower-tier manufacturers, where new entrants frequently emerged but often struggled to sustain their positions. Notably, SK On had made rapid progress in recent years, particularly since 2020. Both Samsung SDI and Gotion High-Tech maintained a stable market presence.



Source: GTII data and SNEResearch

Figure 4a. The Rise of China's Power Battery Manufacturers in the Global Market[8]

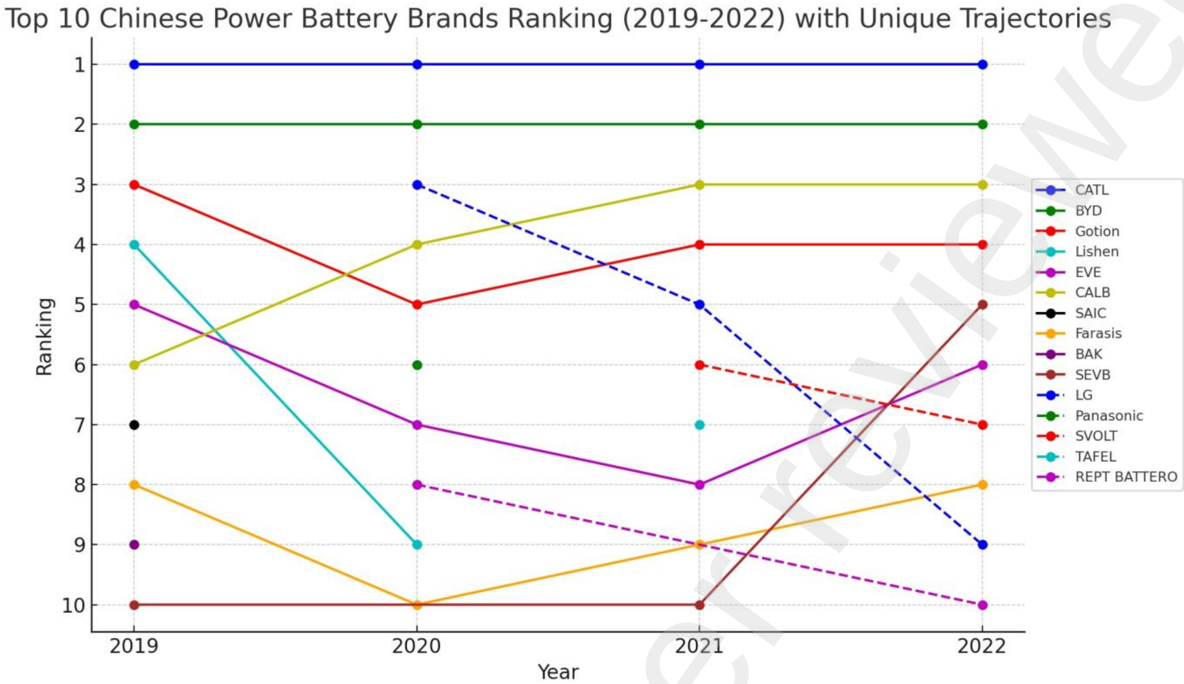
In Figure 4b, we illustrated the trajectories of the top 10 Chinese power battery brands from 2019 to 2022. Each line represents a brand's ranking over the four-year span.

Similar to the global market, CATL and BYD dominated China's domestic power battery market. LG and Panasonic were experiencing a declining market share in China, which directly impacted their global performance, as China maintained the largest NEV market share globally.

For Chinese power battery manufacturers, the competition in the domestic market is more intense than in the global market, with new manufacturers continually emerging. In the entire list, SAIC, BAK Battery, and TAFEL Battery each appeared only once. Notably, Farasis and SEVB, two manufacturers after achieving significant scale in China, began to capture a certain share of the global market. Battery manufacturers that performed well in the

[8] Note: The rankings are determined by the market share of each brand each year. This method is applied to all market-related analysis.

Chinese market seemed to have a higher ranking in the global market.

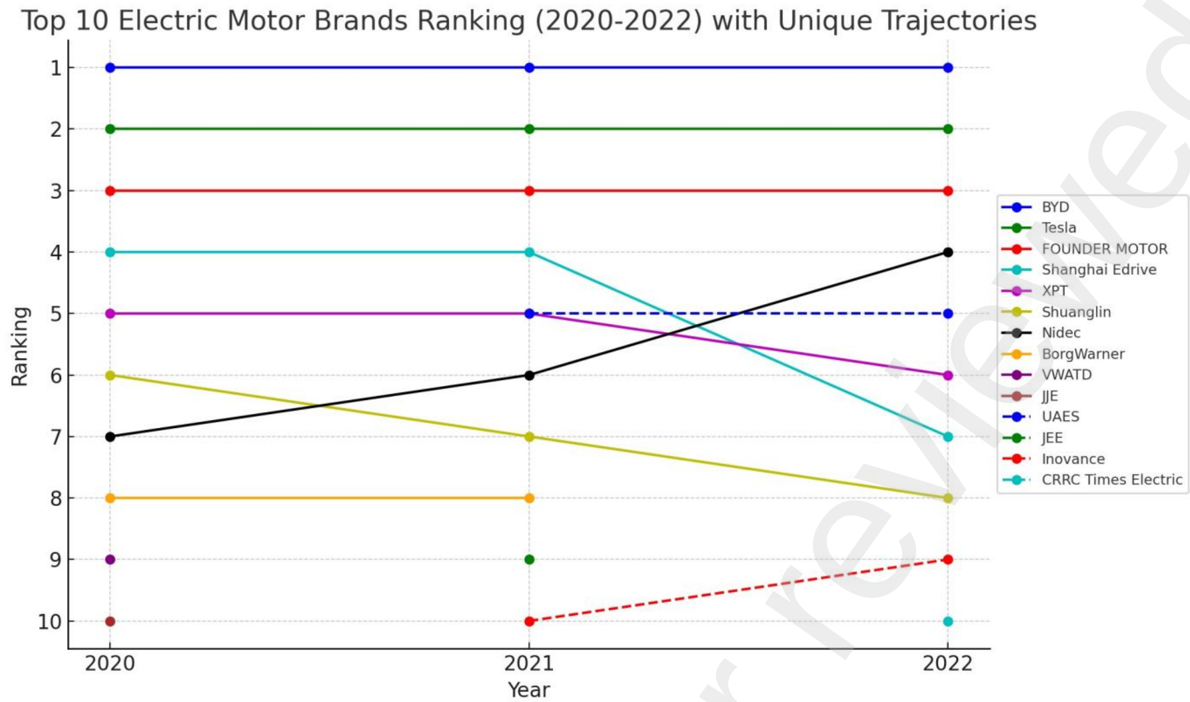


Source: China Automotive Battery Research Institute Co., Ltd.

Figure 4b. The Domestic Dynamics of China's Power Battery Manufacturers

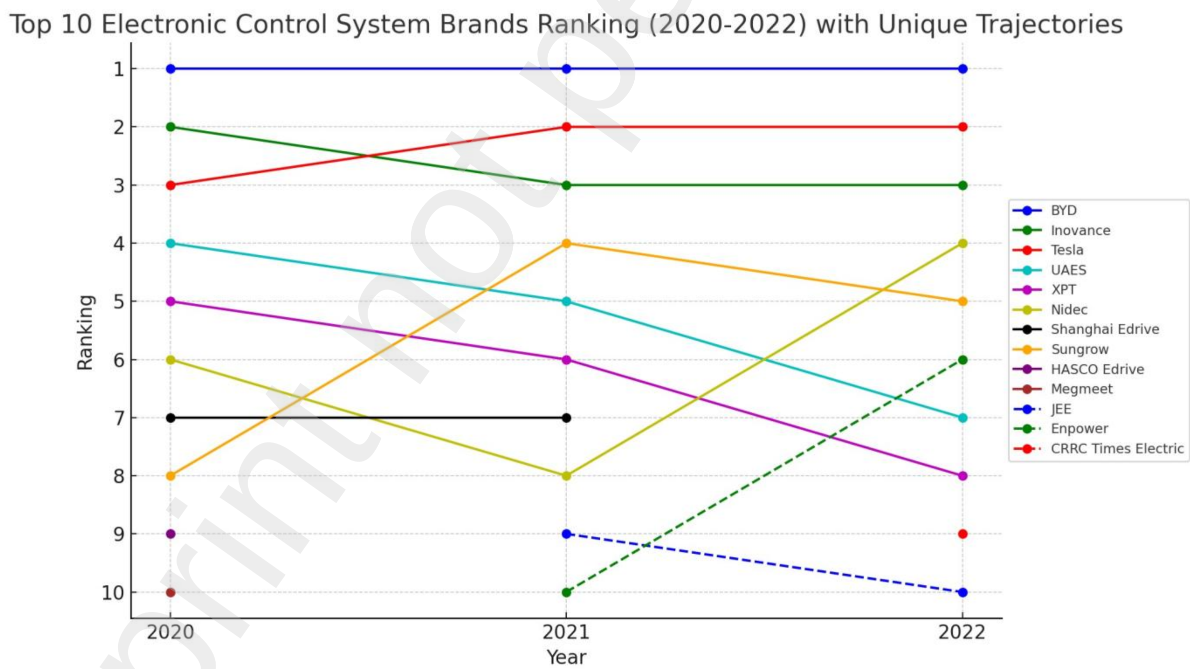
Electric motors, electric control systems, and electric drives

In addition to power battery, which contributes to nearly 50% of the entire cost of an battery EV, electric motor, electric control system and electric drive are major components in EV manufacturing. In Figure 5a-5c, we mapped the trajectories of the top 10 brands of these component manufacturers from 2020 to 2022 by market share in the global market.



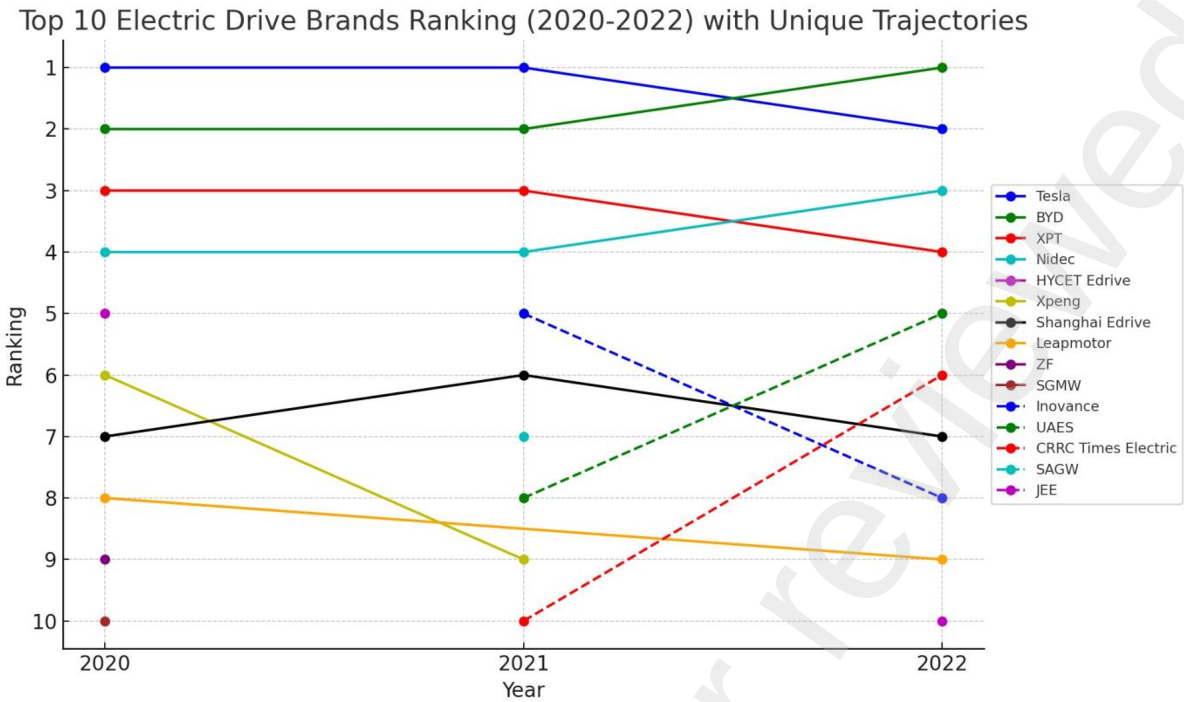
Source: NE-times database

Figure 5a. The Rise of Chinese Electric Motor Manufacturers in the Global Market



Source: NE-times database

Figure 5b. The Rise of Chinese Electric Control System Manufacturers in the Global Market



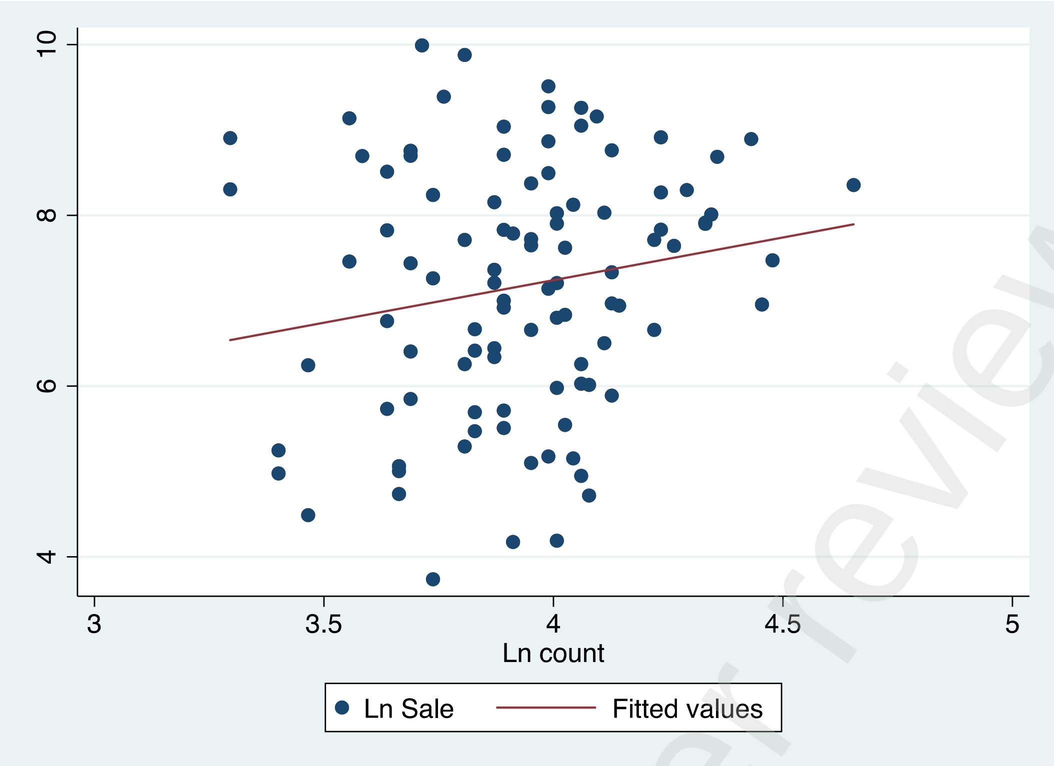
Source: NE-times database *(no data of imported manufacturers included)*

Figure 5c. The Rise of Chinese Electric Drive Manufacturers in the Global Market

There is considerable overlap between EV makers and component manufacturers. For example, Tesla, BYD, XPeng and Li Auto are also the component manufacturers in electric motors, electronic control systems and electric drives. There are also special suppliers, such as Founder Motors, BorgWarner, VWATD, and Shuanglin. Unlike in the power battery sector, foreign enterprises or foreign capital invested enterprises have a higher market share.

Meso-level Policy Facilitation

The correlation analysis between policy support for and the NEV sales, using data from 25 NEV pilot cities under the 'Ten Cities, Thousand Vehicles' program, is shown in in Figure 6.



Note: On the X-axis are the counts of EV related keywords in government reports and on the Y-Axis the sales revenue (natural logarithm) of EVs at the city level (2019-2022)

Figure 6. Correlation between Policy Incentives and the Rise of the NEV Sector

A positive correlation can be observed between the counts of NEV related keywords in government reports and the sales revenue (natural logarithm) of NEVs at the city level . Further fixed effect panel data regression analysis also confirms such a positive correlation (as shown in Table 2), which is statistically significant at the 1% level.

Table 2. Descriptive Statistics of Variables

Variables	Obs	Mean	Std.Dev.	Min	Max
Sale	100	3046.86	3942.753	42	21795
LnSale	100	7.171	1.464	3.738	9.989
Count	100	52.64	13.83	27	105
LnCount	100	3.931	0.258	3.296	4.654

DISCUSSION

The NEV sector's growth, influenced by multiple sources of causality and independent developments, involved complex competition between emerging and incumbent regimes (e.g., fuel vs. new energy sources) and different technological trajectories for new energy alternatives (e.g., battery, plug-in hybrid, fuel-cell, or hydrogen).This development was marked by a technological 'war' and the consequent evolution of an innovation ecosystem comprising supply chains, complementary technologies (e.g., batteries), and infrastructures (e.g., charging networks) within a sectoral innovation system framework. Our case study suggests that public policy played an instrumental role in facilitating co-adaptation and co-specialization among stakeholders, coordinating the production of ecosystem-level goods (e.g., technical standards, supply chains and charging infrastructure), and connecting macro- and micro-level factors in a feedback loop, allowing policy adjustments in response to technological and market developments.

An Integrated Analytical Framework

Recognizing the limitations of both SSI and IE frameworks in explaining the development of latecomers in technologically complex sectors, such as China's NEV rise, we propose an integrative framework of a sectoral innovation ecosystem.This approach parallels techno-social transition theory (Geels & Schot, 2007). This framework, at the meso level, synergizes macro-level policy approaches with micro-level entrepreneurship-driven innovation ecosystem approaches, as depicted in Figure 7.

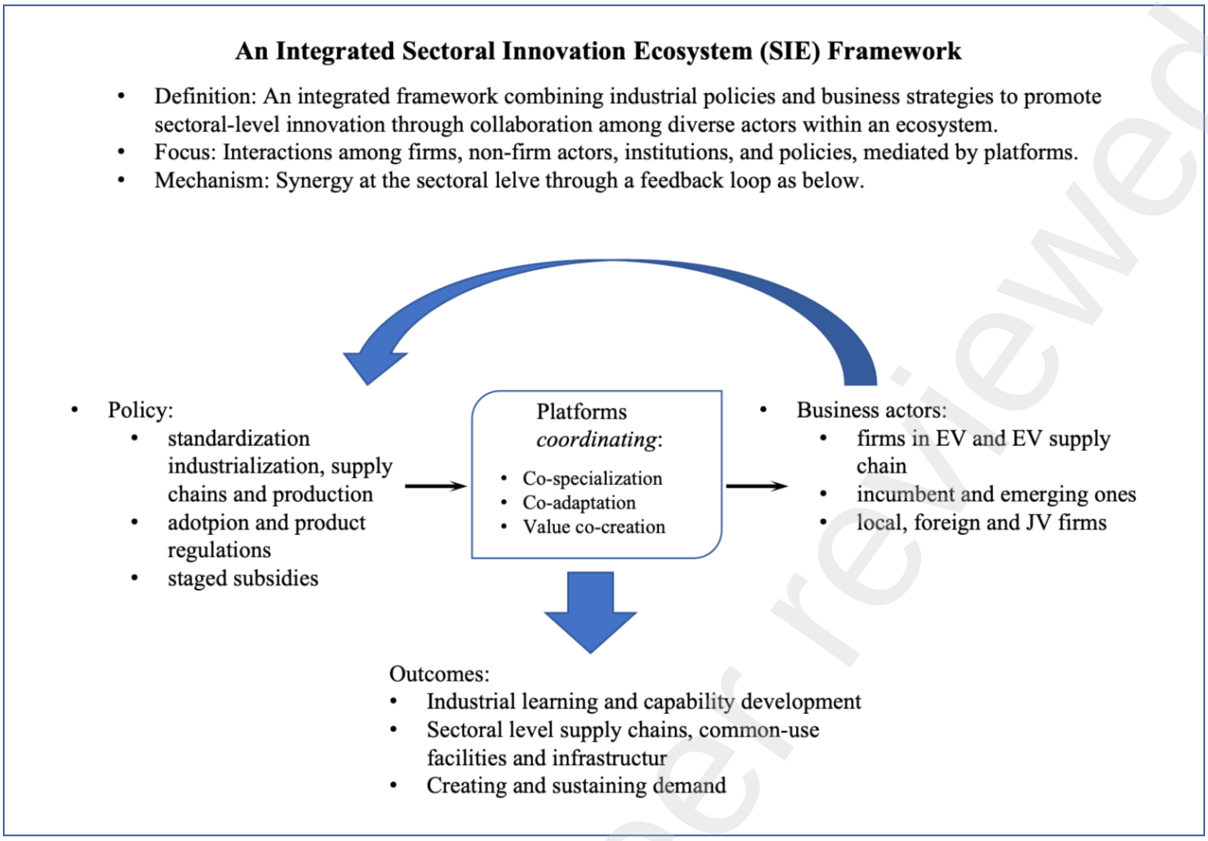


Figure 7. An Integrated Framework

As shown in our case study, a sectoral innovation ecosystem is complex, characterized by diverse motivations of participating entities. We extend the SSI framework by incorporating networks of interdependent firms and ventures collaborating to create and scale value-creating knowledge and resources, characteristics of the IE framework. This integrated framework emphasizes the reciprocity between the institutional settings and entrepreneurship-driven innovation community within these ecosystems.

The SIE framework synthesizes these perspectives, positing that the interplay between policy-driven macro-level factors and micro-level entrepreneurial dynamics is crucial for sectoral-level innovation, particularly in latecomer contexts like China. This approach allows for an examination of micro-level interactions within ecosystems and how these are influenced by macro-level institutional contexts.

Mechanisms of the SIE Framework

In Table 3, we summarize the commonalities and differences of these three frameworks.

Table 3: Comparison of SSI, IE, and SIE Frameworks

	Sectoral Systems of Innovation (SSI)	Innovation Ecosystems (IE)	Sectoral Innovation Ecosystem (SIE)
Definition	An industrial policy to promote sectoral-level innovation.	A business strategy to promote collaboration involving complementary actors.	An integrated framework combining industrial policies and business strategies to promote sectoral-level innovation.
Focus	Interactions among firms, non-firm actors, institutions, and policies.	Structure and relationships among business firms mediated by platforms.	Interactions among firms, non-firm actors, institutions, and policies, mediated by platforms.
Key Driving Force	Knowledge, technologies, actors, networks, institutions.	Established firms, startups, platform owners, entrepreneurial ventures.	Synergy between knowledge, technologies, actors, networks, institutions, established firms, startups, platform owners, ventures.
Orientation	Policy-oriented.	Business-oriented.	Balances both policy-oriented and business-oriented perspectives.
Approach	Reductionist, evolutionary economics.	Complementarity, self-organizing, co-adaptation, co-creation.	Integrates reductionist, evolutionary economics with complementarity, self-organizing principles, co-adaptation, co-creation.
Actors	Government agencies, universities, research institutions, firms.	Established firms, startups, platform owners, entrepreneurial ventures.	Government agencies, universities, research institutions, firms, startups, platform owners, entrepreneurial ventures.
Boundaries	Clearly defined.	Clearly defined.	Clearly defined by sectoral activities, yet flexible to dynamic interactions and co-evolution among stakeholders.
Interactions	Market and non-market relations; dynamic interactions facilitate knowledge exchange, collaboration, and diffusion of innovations.	Formation of entrepreneurial networks is crucial for knowledge spillovers and collaborative innovation.	Both market and non-market relations; dynamic interactions facilitate knowledge exchange, collaboration, and innovation diffusion.
Scope and Focus	Broader focus on sectoral-level policies and institutions influencing innovation.	Focus on micro-level interactions within specific networks of firms and ventures.	Broad focus on sectoral policies and institutions influencing innovation, with micro-level interactions in specific networks.
Institutional Influence	Emphasizes both formal and informal institutions at the national level.	Focuses on specific institutional settings influencing actor behaviors within the ecosystem.	Emphasizes formal and informal institutions at the national level and specific institutional settings influencing actor behaviors.

A Pragmatic Policy Approach

Government policies provide the foundation for sectoral development by offering incentives, setting standards, and creating an enabling environment for innovation (Freeman & Soete, 1997). As seen in China's rise in the NEV sector, contrary to traditional literature, macro-level policy interventions exert indirect influence on micro-level actors rather than acting as direct driving forces (Malerba, 2002; Meuer et al., 2015; Jung & Lee, 2010; Lundvall, 1992). China's NEV sector has evolved through distinct phases, reflecting an adaptive approach to policy development. Initially focusing on standardization and regulatory frameworks, recent policies emphasize high quality, safety, and intelligence in NEV technologies. This adaptive policy regime has transitioned from a top-down method to one that recognizes market and entrepreneurship-driven innovation (Gao et al., 2011; Gu & Lundvall, 2006; Zhang, 2016; Zhang et al., 2022). This pragmatic and adaptive policy framework contrasts sharply with misconceptions about China's industrial policy as a master plan for picking technological and market winners (Zhang, 2016).

Government's Role in the Sectoral Innovation Ecosystem

Unlike business-driven innovation ecosystems, the sectoral innovation ecosystem involves interactions and resource exchanges between actors and the environment, encompassing technologies, knowledge, demand, market conditions, policies, institutions, and external shocks. The government acts as a guide, cheerleader, and catalyst, facilitating discussions, testing technological trajectories, and supporting both supply- and demand-side actors. They also function as platforms, in both physical (e.g., location-based supply chain hubs) and virtual (e.g., technical standards) format, facilitate collaboration among diverse actors through co-adaptive feedback loops, thus, enabling knowledge spillovers and resource sharing (Jacobides et al., 2018). Effective sectoral innovation ecosystems create social value beyond business value, with government policies signaling lead firms to develop supply chains that diffuse throughout the sector.

Entrepreneurship-Driven Innovation through Value Co-specialization Co-creation

In an innovation ecosystem, entrepreneurial enterprises, often starting with limited production capabilities, engage in self-organizing, co-adaptation, and co-specialization to bring innovations to market and grow across the sector. This bottom-up approach, akin to biological ecosystems, enables startups to leverage established supply chains and reach wider markets (Adner, 2017; Nambisan et al., 2019). Reflecting the literature on resource reallocation and reconfiguration, assets like intellectual property and know-how are reabsorbed and reshaped within such ecosystem, akin to atoms forming new chemical compounds amidst industrial consolidation (Jacobides et al., 2018).

Dynamic Interactions

As shown in the case of China's NEV rise, the interplay between firms, research institutions, and government bodies leads to the rise of a sector, involving the development of complementary technologies, shared infrastructure, and coordinated market strategies (Autio, Nambisan, Thomas, & Wright, 2018). Continuous feedback between policy implementation and market responses allows for adaptive policy frameworks that evolve with technological and market developments, ensuring policies remain relevant and effective in promoting sectoral growth (Geels & Schot, 2007).

Theoretical Contributions

The SIE framework builds on and extends existing literature on SSI and IE. While SSI provides a broad perspective on the role of institutions and policies in sectoral innovation, it often overlooks micro-level firm interactions and entrepreneurial activities (Malerba, 2002). Conversely, IE emphasizes networks and platforms but may neglect formal institutions and policies, and the interactions between the ecosystem actors and the institutional environment (Adner, 2006). The SIE framework integrates insights from both approaches, offering a holistic view of innovation that considers macro- and micro-level factors, as well as their interdependence.

The SIE framework provides a comprehensive understanding of how policy and market forces interact to drive industrial transformation. It highlights the significance of value co-creation at sectoral levels and resource reallocation and knowledge exchanges among ecosystem actors. This framework enriches the innovation literature by incorporating both policy-driven and entrepreneurial dynamics, highlighting the importance of platforms and adaptive policies in fostering sectoral innovation.

For managers and entrepreneurs, the SIE framework emphasizes the need to engage with platforms and leverage policy incentives to drive innovation. It highlights the importance of collaboration and value co-creation within the ecosystem. Managers should consider the broader sectoral environment when planning strategies, as understanding market technological, and institutional conditions can better inform their decisions. Policymakers need to recognize the impact of micro-level interactions within innovation ecosystems on overall sectoral performance. The SIE framework can guide the design of adaptive and pragmatic policies that support sectoral innovation and promote sustainable growth.

Future research should explore insights from firm-level actors and the role of the capital market in the NEV sector to enhance understanding of this transition and identify challenges faced by China's NEV players in global competition. As more cases of sectoral innovation ecosystems emerge, quantitative studies can provide empirical validation for this integrated framework.

CONCLUSIONS

Our detailed case study of China's rise in the NEV sector demonstrates that a sectoral innovation ecosystem (SIE), facilitated by meso-level public policy, has been crucial in enabling value co-creation and the production of ecosystem-level goods/infrastructure shared by all actors. A pragmatic policy regime connected macro- and micro-level factors in a feedback loop, allowing policymakers to adjust policies in response to external developments. This integrated framework broadens the scope of innovation literature by highlighting the significance of value co-creation at sectoral levels and has important implications for policy and practice, particularly for other latecomer countries seeking similar industrial development paths.

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Appendix I: Policy documents related to NEV[9]

Year	Title/Theme	Policy Making body	Policy Type
2006	The guidance for implementation of the National '863' plan for energy-saving and new energy vehicles, focusing on the R&D of technology standards and key components of power systems	MoST	Standardization
2007	Administrative Rules for Production License of New Energy Vehicles, which defined the concept and scope of new energy vehicles for the first time and customized unified standards for the production of various new energy vehicles	NDRC	Regulatory
2009	Notice on Pilot Work of Demonstration and Promotion of Energy Saving and New Energy Vehicles	MoF, MoST	Promotional
	'Ten Cities and Thousand Vehicles' energy-saving and NEV demonstration and application project	MoST	Promotional
	Regulations on the Administration of Access to New Energy Vehicle Manufacturers and Products	MIIT	Production
	Adjustment and Revitalization Plan of Automobile Industry	SC	Guiding
	Investment Direction for Technological Progress and Technological Transformation of Automobile Industry	MIIT	Innovation
2010	Notice on Pilot Subsidies for Private Purchase of New Energy Vehicles	MoF, NDRC, MoST, MIIT	Financial
	Notice on Expanding the Demonstration and Promotion of Energy-saving and New Energy Vehicles Public Services	MoF, NDRC, MoST, MIIT	Promotional
	Letters on Strengthening Safety Management of Demonstration and Promotion of Energy-saving and New Energy Vehicles	MoF, NDRC, MoST, MIIT	Regulatory
2011	Guiding Opinion on Promoting the Internationalization of Strategic Emerging Industries	MoC, NDRC	Internationalization
	Notice on Further Pilot Work of Demonstration and Promotion of Energy-saving and New Energy Vehicles	MoF, NDRC, MoST, MIIT,	Promotional
2012	Notice on Organizing the Development of New Energy Vehicle Industrial Technology Innovation Project	MoF, MIIT, MoST	Innovation
	Twelfth Five-Year Plan' for the Development of Electric Vehicle Science and Technology	MoST	Guiding
	Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020)	SC	Planning
	Notice on Expanding the Scope of Hybrid Urban Bus Demonstration and Promotion	NDRC	Promotional
	Notice on the Policy of Vehicle and Vessel tax on Saving Energy and Using New Energy	MoF, SAT, MIIT	Financial
2013	The 12th Five-Year Plan for Energy Development	SC	Planning
	Notice on Continuing the Promotion and Application of New Energy Vehicles	MoF, NDRC, MoST, MIIT	Promotional

[9] Provincial level polices are not included.

2014	Guiding Opinions on Accelerating the Promotion and Application of New Energy Vehicles	SC	Promotional
	Interim Provision on Investment Projects and Production License Management of Newly Built Pure Electric Passenger Vehicle Manufacturers (Draft for Comments)	NDRC	Regulatory
	Notice on Issues Related to the Electric Vehicle Electricity Price Policy	NDRC	Guiding
	Implementation Plan for Government and Public Institutions to Purchase New Energy Vehicles	Stat Affairs Office, MoF, NDRC, MoST, MIIT	Financial
	Announcement on Exemption of New Energy Vehicle Purchase Tax	MoF, SAT, MIIT	Financial
	Work Plan for Promotion of New Energy Vehicles in Public Transports in Beijing, Tianjin and Hebei (2014-2015)	MIIT, NDRC, MoST, MoF, MoEP, MoHURD, NEA	Promotional
	Implementation Opinion on Accelerating the Promotion and Application of New Energy Vehicles (Draft for Comments)	MoT	Promotional
	Strengthen the overall planning of vehicle, oil and road and accelerate the comprehensive prevention and control plan of motor vehicle pollution	MoHURD, MoT, MoC, GAQSIQ, NEA	Planning
	Notice on Rewards for New Energy Vehicle Charging Facility Construction	MoF	Infrastructure
	National Key R&D Plan New Energy Vehicle Key Specialty	MoST	R&D
2015	Specification Conditions for the Automotive Power Battery Industry	MIIT	Supply chain
	Implementation Plan for Key New Energy Vehicles of National Key R&D Plan (Draft for Comments)	MoST	R&D
	Implementation Opinion on Accelerating the Promotion and Application of New Energy Vehicles in the Transportation Industry	MoT	Promotional
	Specifications and Conditions for Automotive Traction Battery Industry	MIIT	Supply chain
	Notice on Financial Support Policies for the Promotion and Application of New Energy Vehicles in 2016-2020	MoF, MIIT, MoST, NDRC	Financial
	Notice on Preferential Policies for Vehicle and Vessel Tax on Energy Conservation and Use of New Energy	MoF, MIIT, SAT	Financial
	Notice on Improving the Price Subsidy Policy for Oil for Urban Public Transports and Accelerating the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoT	Financial
	Regulations on the Management of Battery Electric Passenger Vehicle Enterprises	NDRC, MIIT	Regulatory
	Guiding Opinion on Accelerating the Construction of Electric Vehicle Charging Infrastructure	SC	Infrastructure

	'Made in China 2025': Energy-saving and New Energy Vehicles included in China's High-End Equipment Innovation Projects.	SC	Innovation
	Interim Measures for the Administration of Regulatory Announcement of Lithium-ion Battery Industry (Draft for Comments)	MIIT	Regulatory
	Assessment Methods for Promotion and Application of New Energy Commercial Vehicles for Public Transports (Trial)	MoT, MoF, MIIT	Promotional
	Interim Regulations on Investment Projects and Production Access Management of Battery Electric Passenger Vehicle Manufacturers (Draft for Comments)	NDRC	Regulatory
2016	Technical Policy for Recycling Electric Vehicle Traction Battery	NDRC, MIIT, MoEP, MoC, GAQSIQ	Battery recycling
	On the '13th Five-Year Plan' Incentive Policy for Charging Infrastructure of New Energy Vehicles and Strengthening the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC, NEA	Infrastructure
	Notice on Carrying out the Verification of the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC	Regulatory
	Standards and Conditions for the Industry of Comprehensive Utilization of Used Power Batteries of New Energy Vehicles	MIIT	Standardization
	Interim Measures for the Administration of Announcement of Industrial Standards for Comprehensive Utilization of Waste Power Batteries of New Energy Vehicles	MIIT	Standardization
	Notice on Carrying out Special Safety Inspection on Electric Vehicle Infrastructure	NEA	Safety
	Notice on Replacement of Electric Vehicle Charging Infrastructure in Residential Areas	NDRC, MIIT, MHURD NEA	Infrastructure
	Measures for the Administration of Carbon Credits of New Energy Vehicles	NDRC	Decarbonization
	Regulations on the Management of New Energy Vehicle Manufacturer and Product Licenses (Revised Draft for Comments)	MIIT	Production
	Interim Measures for the Concurrent Management of Average Fuel Consumption of Enterprises and New Energy Vehicle Credits (Draft for Comments)	MIIT	Decarbonization
	The Administrative Regulations on Battery Electric Passenger Vehicle Enterprises	NDRC, MIIT	Regulatory
	Notice on Further Improving the Safety Supervision of the Promotion and Application of New Energy Vehicles	MIIT	Safety
	Specifications and Conditions for the Automotive Power Battery Industry (Draft for Comments)	MIIT	Standardization
	Interim Measures for the Administration of the Recycling and Utilization of Electric Vehicle Power Batteries (Draft for Comments)	MIIT	Battery recycling
	The 13th Five-Year Plan for the Development of National Strategic Emerging Industries	SC	Planning

	General Notice on matters related to the responsibilities for Approving the promotion and application of new energy vehicles	MoF, MIIT, MoST, NDRC	Promotional
	Notice on Accelerating the Integrated Construction of Parking Lots and Charging Infrastructures	NDRC, MHURD, MoT, NEA	Infrastructure
	Notice on Adjusting the Financial Subsidy Program for the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC	Financial
2017	Notice on Further Promoting the Application of New Energy Vehicles	MoF, NDRC, MoST, MIIT	Promotional
	Administrative Rules for New Energy Vehicle Manufacturers and Product License	MIIT	Production
	Construction Scheme of Energy Saving Standard System	NDRC	Standardization
	The 13th Five-Year Plan for Energy Conservation and Emission Reduction	SC	Decarbonization
	Implementation Plan of Extended Manufacturers' Responsibility System	SC	Production
	Guiding Opinion on Accelerating the Construction of Electric Vehicle Charging Infrastructure	MoF, NDRC, MoST, MIIT	Infrastructure
	The 13th Five-Year Plan for the Development of Modern Comprehensive Transportation System	NDRC	Planning
	Action Plan for Promoting the Development of Automotive Power Battery Industry	MoF, NDRC, MoST, MIIT	Supply chain
	Guiding Opinion on Accelerating the Development of Renewable Resources Industry	MoF MoST, MIIT	Decarbonization
2018	Notice on Administrative Measures for the Cascade Utilization of New Energy Vehicle Power Battery	MIIT, MoST, MoEP	Battery
	Notice on Improving Green and Low Energy Consumption	NDRC, NEA	Decarbonization
	Opinions on Carbon Transformation System	NDRC, MIIT	Decarbonization
	Mechanisms and Policy Measures on Carbon Reduction	MoF, MIIT, MoST, NDRC	Decarbonization
	Notice on the Financial Subsidy Program for the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC	Financial
	Notice on the Financial Subsidy Program	MoF, MIIT, MoST, NDRC	Financial
	Notice on Developing Smart City Infrastructures for Ne Energy Vehicles	MHURD, MIIT	Infrastructure
	Outline of National Standardization Development	SC	Standardization
	The Complete, Accurate and Comprehensive Implementation Plan of the New Development Concept	SC	Planning
	Notice on Further Improving the Financial Subsidy Programs for the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC	Financial
	Notice on Further Improving the Financial Subsidy Program for the Promotion and Application of the New Energy Vehicles	MoF, MIIT, MoST, NDRC	Financial
	Notice on the Demonstration and Application of Fuel-Cell Vehicles	MoF, MIIT, MoST, NDRC	Promotional

	Notice on the Establishment and Implementation of Vehicle Emission Inspection and Maintenance System	MoEP, MoT, SAMS	Standardization
	Notice on Several Measures to Stabilize and Expand Automobile Consumption	NDRC, MoST, MITT, MPS, MoF, MoEP, MoC, PBC, SAT, BIRC	Promotional
2019	Notice on Improving the Financial Subsidy Program for the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoST, NDRC	Financial
	Announcement on the Relevant Policies of Exemption of Vehicle Purchase Tax for New Energy Vehicles	MoF, SAT, MIIT	Financial
	Notice on Intelligent Vehicle Innovation and Development	NDRC, MoT, MoC,	Innovation
	Notice on Restoring the 10% Tax Rates of Automobile Purchase Tax of 1.6 Liters and Below	MoF	Financial
	Notice on the Pilot Implementation Plan for the Extension of Responsibilities of Automobile Manufacturers	MIIT, MoST, MoF, NDRC	Production
	Notice on Developing Smart City Infrastructures for Smart Vehicles in Pilot Cities	MHRUD	Infrastructure
	Notice on Several Policies to Promote the Steady Growth of Industrial Economy	NDRC, MIIT, MoF, PBC, SAT, BIRC	Promotional
	Notice on Supporting the Promotion and Application of New Energy Buses	MoF, MIIT, MoT, NDRC	Infrastructure
	Announcement on the Release of the National Standard for Automobile Gas and Charging Stations	MHRUD	Infrastructure
	Notice on Measures of Declaration of Export Licenses for New Energy Vehicles	MoC	Export
2020	The 14th Five-Year Plan for the Development of Modern Comprehensive Transportation System	SC	Planning
	Several Provisions on Vehicle Data Security Management (Trial)	CAO, NDRC, MIIT, MPS, MoT	Data security
	Opinions on Further Improving the Service Guarantee Capacity of Electric Vehicle Charging Infrastructure	EVCIDA	Infrastructure
	Opinion on Strengthening the Access Management of Intelligent Connected Vehicle Manufacturing and Product Licenses	MIIT, CAO	Intelligent vehicle
	Notice on Further Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles	MoF, MIIT, MoT, NDRC, NEA	Financial
	Notice on Extending the Purchase Tax Exemption for New Energy Vehicles	MoF, SAT, MIIT	Financial
	Management Specification for Road Test and Demonstration Application of Intelligent Vehicles (trail)	MIIT, MoT, MPS	Intelligent vehicle
	Announcement on Adjusting the Technical Requirements for New Energy Vehicles Exempted from Vehicle Purchase Tax	MIIT, MoF, SAT	Financial
	Guidance on High-Quality Implementation of the Regional Comprehensive Economic Partnership (RCEP)	MoC	International

	Notice on Promoting New Energy Vehicles to the Rural Market	MIIT, MoC, NEA	Rural market
	Notice on Strengthening the Supervision of New Energy Vehicle Safety	SAMS	Safety
2021	The New Energy Vehicle Industry Development Plan (2021-2035)	SC	Planning
	Guidelines for Promoting Automobile Consumption in the Commercial Field and Some Local Experiences and Practices	MoC	Promotional
	Announcement on the Management of Automotive Industry Standard Provisions (Batch 43)	MIIT, SAMS	Standardization
	Opinions on Accelerating the Establishment of Green Production and Consumption Regulations and Policy Systems	SC	Decarbonization
	Work Plan for Expanding Public Charging and Battery Swapping Infrastructure during the 14th Five-Year Plan	SC	Infrastructure
	Notice on the Adjustment of Financial Subsidy Policies for New Energy Vehicles in 2022	MoF, MIIT, MoT, NDRC	Financial
	Work Plan for the Optimization of the Transportation Structure (2021-2025)	SC	Public transport
	Action Plan for Carbon Dioxide Peaking Before 2030	SC	Decarbonization
	Measures for the Administration of Automobile Loans	BIRC	Financial
2022	Opinions on Further Improving the Charging Infrastructure to Support the Development of New Energy Vehicles	NDRC	Infrastructure
	Notice on Extending the Tax Exemption Policy for the Purchase of New Energy Vehicles	MoF, SAT, MIIT	Financial
	Notice on Carrying Out the 2022 New Energy Vehicle Promotion Activities in Rural Areas	MIIT, MoRA, MoC, SEA	Rural market
	Opinions on Further Improving the Fiscal Subsidy Policy for New Energy Vehicles	Ministry of Finance	Financial
2023	Opinions on Supporting the High-Quality Development of New Energy Vehicle Industry	MIIT, NDRC, SRG, CNCC	Supportive
	Notice on Carrying Out Pilot Projects for Comprehensive Electrification in Public Service Fields in Urban and Rural Areas	MIIT, MoHURD	Public transport
	Notice on Extending and Optimizing the Fiscal Subsidy Policy for the Purchase of New Energy Vehicles	MoF, SAT, MIIT	Financial
	Guiding Opinions on Further Improving the Charging and Swapping Infrastructure System	SC	Infrastructure
	Decision on Revising the Measures for the Parallel Administration of Average Fuel Consumption and New Energy Vehicle Credits for Passenger Car Enterprises	MIIT	Decarbonization
	Work Plan for Enhancing the NEV Industry (2023-2024)	MoF, MoT	Planning
	2023 Third Quarter New Energy Vehicle Industry and Information Technology Development Situation Report	SGCC	Infrastructure

Source: The authors compiled from publicly available government websites

Notes:
BIRC: Banking and Insurance Regulatory Commission
CAO: Cyberspace Administration Office of the State Council

CNCC: China National Chemical Corporation
EVCIDA: Electric Vehicle Charging Infrastructure Delivery Authority
GAQSIQ: General Administration of Quality Supervision, Inspection and Quarantine
MHURD: Ministry of Housing and Urban-Rural Development
MIIT: Ministry of Industry and Information Technology
MoRA: Ministry of Agriculture and Rural Affairs,
MoC: Ministry of Commerce
MoEP: Ministry of Environmental Protection
MoF: Ministry of Finance
MoHURD: Ministry of Housing and Urban-Rural Development
MoST: Ministry of Science and Technology
MoT: Ministry of Transport
MPS: Ministry of Public Security
NEA: National Energy Administration
NDRC: National Development and Reform Commission
NSA: National Standardization Administration
PBC: People's Bank of China
SAIC: State Administration for Industry and Commerce
SAMS: State Administration of Market Supervision
SAT: State Administration of Taxation
SC: The State Council (General Office)
SGCC: State Grid Corporation of China
SRG: State Railway Group

Appendix II: keywords related to EV appearing in provincial work reports

Environmental Protection; Environmental Conservation; Environment; Low Carbon; Emission Reduction; Ecology; Environmental Quality; Air Quality; SO2; CO2; Particulate Matter; PM2.5; Air Pollution; Air; PM10; Smog; Greenhouse Gases; Energy Consumption; Conservation; Energy; New Energy; Clean Energy; Coal-to-Electricity Conversion; Renewable; Sustainable; Blue Sky; Blue Sky with White Clouds; Low-Carbon Economy; Green Economy; Eco-City; Green Commuting