Leapfrogging attempt by creating Institutional Windows of Opportunity in the Chinese Electric Vehicles sector

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Abstract

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The techno-economic paradigm shift in the automobile industry gave a promising opportunity for developing countries to enter Electric Vehicles sector at its initial stage, and consequently leapfrog towards leadership. In comparison with old successful attempts?e.g., LCD screens?, EV sector is more complexed. It requires specific infrastructure, and it is highly dependent on vertically integrated sectors, such as battery production and development. In 2009, China introduced a set of policies to leapfrog with rather optimistic production goals, which were not achieved. The policy was modified in 2012 and two years later, the production trajectories went up.

The main analytical framework used is Lee & Malerba (2017) special issue on the catching-up, where three types of Windows of Opportunities were presented. However, most academic articles deal with technological and supply, and less with the institutional windows. Thus, this paper investigates whether endogenous institutional windows can stimulate the market to catch-up and overtake the leading
position, with the following research question: How did change of the policy regime in 2012 affect the catching-up process in the Chinese Electric vehicle sector.

The data used consists of almost 300 different national and local policies regarding electric vehicles in China for the above mentioned periods. The data was first translated from Chinese into English, coded and later analyzed. Additionally, different academic articles and reports were used.

The results showed critical shortcomings in the first period. Additionally, the insufficient policy could not dictate the market, contrary, the market created its own path to cover demand. In China, instead of catching-up in EV, the market for Low-speed EV developed. The intensive subsidies gave different results for EV passenger cars and EV buses, which indicates that the policy unsuccessfully addressed various types of demand.
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Abstract—The techno-economic paradigm shift in the automobile industry gave a promising opportunity for developing countries to enter Electric Vehicles sector at its initial stage, and consequently leapfrog towards leadership. In comparison with old successful attempts—e.g., LCD screens—, EV sector is more complex. It requires specific infrastructure, and it is highly dependent on vertically integrated sectors, such as battery production and development. In 2009, China introduced a set of policies to leapfrog with rather optimistic production goals, which were not achieved. The policy was modified in 2012 and two years later, the production trajectories went up. This paper analyzed the policy, technological development, and realized production in two periods, and the results showed critical shortcomings in the first period. In the new regime, market for electric buses developed relatively better than for the passenger cars, as they have different demand characteristics. Moreover, the insufficient policy could not dictated the market for passenger cars, contrary, it created its own path to cover demand. Instead of catching-up in electric passenger cars, the market for Low-speed EV developed.

I. INTRODUCTION

Electrical vehicles (EV) probably is among the most innovative and dynamic industrial fields worldwide at the moment, and one with significant technological ramifications throughout many different branches of industry. The EV industrial field advances on a global scale, as producers of vehicles, suppliers of components and services, and a wide range of potential entrants survey opportunities in such disparate areas. China promotes an ambitious electric mobility program with two primary objectives: to reduce urban air pollution and to enhance the competitiveness of its national automotive industry [1]. A range of industrial policies is being applied, and several pathways to electric mobility are being explored in parallel. This paper analyzed two policy regimes, first between 2009-11 and the second 2012-14. The goals set in the first EV policy in 2009 were not achieved [2] and the government introduced a new plan in 2012 for the period of next eight years. Two years later the sector awoke and continued to develop according to new policy’s goals, see Figure I. An obvious explanation would give credit to improved and better policies, however, looking at the electric vehicles as just a new cycle in the automobile industry, different stages demands different strategy [3].

Following the global evolution of this field attracts a lot of interest from academics as well as from decision-makers in industry, finance, and politics. A key theoretical framing for understanding the global adaptation and innovative dynamics of electrical vehicles has been the so-called catching-up hypothesis. It primarily depicts innovation as a process of technological adaptation, where in the socio-economic terms most advanced and mature societies provides the spring bed for the development of technologies, and where other economies follow suit, as the technology advances and these countries build sufficient capacity to absorb technological progress [4], [5].

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The aim of the paper was to investigate the differences between both regimes and provide an answer to How the change in the policy regimes influenced the Chinese catching-up process in the EV sector. Both EV passenger cars and EV buses were addressed with the same policies, however the characteristics of each demand are different. Hence, the second focus is to explore How each sub-sector reacted to the proposed policies.

Chinese EV policy regimes were studied by analyzing all policies and regulations involving term “new electric
vehicle”, on both national and local level. Policies are technology sensitive [7]; thus its replication from other industries does not result in the same manner. Collected policies were inspected with the adopted framework from Binz et al. [7], which divides policies’ target to Knowledge, Market Access, Financial Investments, and Technology Legitimacy. The original framework contained the policy-mix for catching-up in three different industry types: design-intensive, complex product systems and process-intensive. Automobile industry is process-intensive, therefore, the latter was used in the adopted framework (Table [8]).

This paper is structured as follows. Section two reviews the catching-up literature, focusing on sectoral catching-up, windows of opportunities and catch-up cycles. After the Data and Methods are presented, the fourth section introduces the automobile industry, followed by in-depth analysis of the Chinese domestic EV regulations and policies. Section six compares the state of technology development of EV passenger cars and EV buses. Finally, the conclusion summaries and discusses the policy issues raised.

II. THEORY: SECTORAL CATCHING UP AND WINDOWS OF OPPORTUNITIES

At its origin, the catching-up hypothesis suggested that countries dealing with backwardness towards leading nations have an opportunity for faster growth and consequently, to catch-up with the frontier. With the focus on the country level, “…if advanced technology at any time is heavily scale-dependent and if obstacles to trade across national frontiers, political or otherwise, are important, large countries will have a stronger potential for growth than smaller ones” [8, p.393]. In spite of this potential, the catching up process is complicated and hard to replicate. Consequently, there are only a few developing countries—e.g., Japan, Korea, China—that managed to get developed in last few decades. Moving the level of analysis from macro to mezzo level shows that due to the differences in sectors, a country that catches up in some sectors could fail in others [9], [10].

The catching-up on the industry (sector) level often results in the leadership change or at least in market share changes [11], [12]. The industries with a stable and incremental technology change are controlled by leaders, and therefore it is hard for latecomers to enter the markets successfully. However, due to the industry cycles and different opportunities, the market can be disrupted [13]. The sectors’ economic developments vary due to different characteristics, hence they need customized policies, access to knowledge, possibilities to learn, intellectual property, workforce, etc. [14].

A. Sectoral Catching-up

The catching-up on the sectoral level is highly studied in the high-tech with frequent technological changes, e.g. mobile phones [14], [15]. Nevertheless, there are examples of old or long-term evolution industry analysis, like wine industry [13], steel and iron [11]. The shift from the macro level to mezzo perspective required the use of sectoral innovation system framework, which identifies three main elements—actors, knowledge base, institutions. Yet, despite significant differences between sectors, the successful catching-up requires a dynamic interplay between both, national and sectoral innovation system [14].

Following Schumpeterian hypothesis, different sectors’ characteristics give advantages to firms of different sizes. In capital-intensive, concentrated and advertising-intensive, larger firms are in better position to innovate. Contrary, in sectors at the early stage of its life-cycle, less-production intensive with a higher share of R&D employees, smaller firms tend to be more innovative [16]. Therefore, in the long-evolutionary sectors big and concentrated firms played an important role in country’ s catching up. Korean catching-up in iron and steel sector based on the success of a state-owned company POSCO and few “chaebols” (conglomerates), which were given state support and guarantees for bank loans [11]. Similarly, many big automobile producers in China are state-owned and some the result of joint-ventures with foreign multinationals [17]. On the other hand, medium-sized firms in Korea have to adapt their R&D to the sector’ s specifics and rely on open innovation [18].

Big firms in catching-up need skilled labor and good supply chains to maintain growth, improve efficiency and innovate, thus it is important to have good regional support—clusters [19]. Especially vertical links between suppliers and producers, which often operates in different sectors. Although sectors have different characteristics, they influence each other, yet one’s catching-up does not guaranty success for others, for instance, China successfully catch-up in telecommunication equipment but not in semiconductors [10]. Similarly, Korean automobile sector and machine tools sector [20].

The benefits of a local cluster may present a threat of locking-in, thus pipelines for knowledge transfer are essential [21]. Likewise, focusing only on domestic markets tempers the view on foreign knowledge and the variety of demand needs [22]. Characteristics of sectors and the state of local demand may influence the development of the sectors, as it was the case in Wind power and solar PV sector in China [23], [24]. The first one in the early stage focused on the domestic market and later more actively went internationally, as on the other hand solar PV first develop in a foreign market and then on domestic.

A major role in sectoral catching up plays government and its policies, which can promote interactions between actors, stimulate production and support internationalization [14], [25]. In time of technical change and potential market disruption, government should move from “linear model”, where it is mostly limited to supporting
basic R&D, towards “sequential linear model” that allows it to intervene in all sequential development phases with financial support, market introduction, creating standards etc., and finally government can move towards “interactive model”, that intervene in all segments at any time [26]. Additionally, sectors’ specificities and countries’ unique macro position defines the catching-up strategy [27]. Thus, it’s role is to build infrastructure and enables education, support local firms and creates a friendly environment for international venture capital, give subsidies for firms and customers and if needed tax stimulations [22]. Sectors’ specifics dictate governments to use different policies to achieve catching-up [7], moreover, as the country lowers the gap towards front-runners in specific sectors, the policy has to adopt as well [28]. For example, Korean catching up in the electronics industry stopped in the middle of 1990s after two decades of very fast development, as they failed to use technology diversification strategies and built-up on the existing technological learnings [28].

Finally, an important role for sectoral catching-up through knowledge creation and skilled labor lays on education, research at universities and public laboratories [29]. Especially in the early stages, the channel for developing countries to acquire new technologies and organizational forms goes through students and researchers with advanced training abroad. Local institutions are crucial in sectors, which products demand local specifics, such as agriculture and medicine, where practices and knowledge cannot be directly copied. In manufacture intense sectors, local institutions need to provide trained engineers and applied scientists [29].

B. Windows of Opportunities

The change in sector’s leadership can occur due to “techno-economic paradigm shift” [30] in the maturity phase in the product life-cycle. The higher costs for technological and structural adjustments put forerunners in a disadvantaged position, and contrary latecomers can skip this and go lighter and faster in a new technological system. This convenient moment—Windows of Opportunities—for latecomers, does not automatically lead towards catching up [31]. Nevertheless, the opportunity to catch-up can emerge even without technological change but with endogenizing windows through the policy, as it happened in India’s pharmaceutical catching-up [32]. Additionally, latecomer may catch-up or even forge ahead due to the windows opened by others—exogenous—e.g., the Korean firms using foreign knowledge to leapfrog in display industry [33]. Moreover, windows can emerge due to the increased or changed demand [15], so three different types of windows were identified: technological; demand; institutional [3]. Technological windows open with new technical developments, and actors with the latest technology can take over the market over those that cannot easily adapt. On the other hand, the institutional window could be open by a new public policy that creates different conditions for actors. In many successful catching-up cases the institutions played an important role in creating a better environment for business to develop [3]. As stated, it is not crucial to use technological Windows of opportunity to catch-up, yet it is important to have sufficient technology transfer from the forerunner countries. In the last period, it is not enough to use conventional approach—e.g. FDI, licences—but rather unconventional, mainly the local and global R&D, and outward knowledge-seeking FDI [34].

EV sector’s development relies on the development of battery sector. Therefore, vertical integration between both sectors plays an essential role [17]. One’s slower progress hinders the development of other. On the other hand, becoming a frontrunner in the battery sector and covering most of the world’s demand might endogenize demand window of opportunity in the battery sector. Consequently, this might present an advantage in the EV catching-up.

The Chinese government placed EV sector as one where they will become world leader and in such a way proposed sets of policies. The newly created environment should enable industry’s development by addressing manufacturing and demand. To explore proposed policies, Binz et al.’s framework is used and it facilitate connecting it to the catching-up doctrine, more precisely to Institutional Windows of opportunity.

C. Catching-up cycles

Literature provides various models that studied different economic and production stages and cycles. In the second part of the twentieth century, scholars researched the patterns for developing countries’ catching-up. Wild-geese-flying pattern model [35], analyzed Japanese process from entering international markets as less developed till becoming a highly industrialized country. Venron’s Product Lifecycle theory, Rowstow’s theory of the stages of economic growth and others were the foundation for [30] techno-economic paradigm shift and consequently, the opportunity to catch-up. The catching-up cycle framework builds upon Venron’s theory, by adding the latecomer’s opportunity to take over R&D and innovation, and not only production [3]. It consists of four stages—entry, gradual catch-up, forging ahead, falling behind. As actors in sectoral systems are interconnected, the sector changes in each stage, therefore latecomers need to adapt their strategy to the stage. In “entry stage”, latecomer can use its macro advantages—e.g., natural resources, low labor costs, a low value of local currencies—yet in the “gradual catch-up stage” this has to be supplemented with learning and building of capabilities. In the “forging ahead stage”, latecomer has to take over the leadership, whether by using the existing Windows or by creating one and is often caused by a stage-skipping or path-creating [14].
III. DATA AND METHODS

The main data used in this paper consists of national and local policies regarding electric vehicles in China between years 2009 and the end of 2014. The policies were collected from “China Association of Automobile Manufacturers” website [6] and captures all policies, regulations, and news that include term “新能源汽车”–new energy vehicles. This term is used by the Chinese government to designate electric vehicles in policies, and it only consists of battery electric vehicles and plug-in hybrid electric vehicles. In total, 294 entries were found, among them, 113 were dated in the period between 2009 and the end of 2011, the remaining 181 entries fall in the period 2012 and the end of 2014. The data was first translated from Chinese into English, coded and later reviewed. To evaluate policies’ results and measure industry development, production and sale statistics were collected from different databases and market reports.

IV. AUTOMOBILE INDUSTRY

Automobile industry plays an essential role in many countries’ economy, and due to its scale-intensity, governments support its development [25, 26]. The mass production started in the U.S. and was later spread across traditional European countries, followed by another triumphant entrance by Japan [36]. Through the decades, the global oligopolistic structure was created with many latecomers that managed to catch up [14], e.g., South Korea. In last period, automobile sector industry started a technological paradigm shift, as decarbonization of the world economy demands cleaner ways of transportation [17].

A. Chinese catching-up in automobile sector

Chinese automobile sector for passenger cars started to develop after the reform in 1978, and since then its production gradually increases. In 1990, China produced 42 thousand cars, ten years later 607 thousand and in 2006 3.8 million and the share of passenger cars compared to total vehicles first time went above 50 percent with less than hundred thousand cars in export [37]. In 2017, China was the biggest car manufacturer in the world with 34% share with the production of 24.8 million and with 891 thousand passenger cars exported. Among them, more than 10% are electric vehicles. However, among exporters, China only takes 20th place with one percent in global export, which indicates that Chinese automobile sector relies solely on the domestic market [38]. In 2016, Iran (19.3%), India (9.5%) and Vietnam (6.8%) were leading destination countries for Chinese vehicle exports. [6]. From the catching-up cycle perspective, the automobile sector has “coexistence of the old and the new leaders” situation, where latecomer became a leader but shares leadership with old traditional leaders. China did not take any market share from traditional leaders—e.g., USA, Germany, Japan—, nevertheless, they managed to fill the new demands from growing domestic market.

The unregulated sector of Micro EV allowed the Chinese manufacturers to create their path towards electrification by producing Low-speed Electric Vehicles. Only in 2014, more than 2 million units were produced [39], which are not included in the official NEV statistics.

V. DOMESTIC EV REGULATION IN CHINA

The Chinese government introduced a series of different regulations to spur electric vehicle sector with four primary goals: technological upgrading, energy security, local pollution reduction and solving carbon emission. The alternative to fuel vehicles policy in China was first introduced in 1991 and was updated in every coming five-year plan since the transportation was recognized as a crucial factor to meet nation’s energy and air quality goals. During the tenth five-year plan—starting in 2001—an R&D strategy for EV was introduced for fuel-cells, hybrid, and pure electric vehicles. High financial investment in R&D continued in the eleventh five-year plan, supplemented with the first commercial market development [40].

In 2006, the State Council introduced “The National Medium and Long-Term Program for Science and Technology Development (2006-2020)”, which included electric vehicle sector. Chinese development plan for these 15 years period relied on indigenous innovation, leapfrogging, promoting development and leading the future. Indigenous innovation was described as “…enhancing original innovation, integrated innovation, and re-innovation based on assimilation and absorption of imported technology, in order to improve our national innovation capability.” [41, p.9]. This policy was supported with the restricted EV import and demand for better technology transfer from foreign firms, yet it resulted in lower technology import [2].

A. Period 2009-2011

In the years of global economic crises, the Chinese government introduced a policy package to spur the economy and its primary element was the “Plan on Shaping and Revitalizing the Auto Industry”. In addition to the environmental goals, the government saw an opportunity to leapfrog and consequently catch-up in the automobile sector by taking a leading position in electric vehicles. At that time policymakers acknowledged three main bottlenecks—market, technology, supporting facilities. This policy from 2009 aimed at a production of 500 thousand EVs and an increase of share for “non-fuel” vehicles to a 5% of total passenger cars sold till the end of 2011. The stimulation was also directed to the whole automobile sector and planned to expand own-brand vehicles on a domestic market to 30% and the export increase to 10% of the production [1].

The supporting policy by Ministry of Finance & Ministry of Science and Technology proposed “The Ten Cities, Thousand Vehicles Program” with fiscal instruments to encourage the development of EV sector, start-
with tracking systems had to be established by both EV manufacturers to speed up the development and production, improve existing local policies that are discriminatory to establish fair competition on the market and to clean improvements launched at the end of 2011 directed to system, to increase EV legitimacy [46]. As a result, on all tasks and establish accident warning information to conduct comprehensive and systematic investigations

The manufacturers had to provide necessary production capacities and consistency, additionally, products had to meet regulations for safety, environmental protection, theft prevention, and were not allowed to infringe the intellectual property rights of others [43].

In 2010, four ministries introduced an extension [45] to subsidy regulations from 2009 and it covered the private purchase of EV and battery leasing. Subsidies could go up to 50,000 yuan/hybrid EV and 60,000 yuan/pure EV and the regulation were limited to first 50 thousand EVs.

In 2011, regulation for strengthening EV pilot projects was launched to get understanding of why EV is still in the initial stage of large-scale production. Pilot cities had to conduct comprehensive and systematic investigations on all tasks and establish accident warning information system, to increase EV legitimacy [46]. As a result, improvements launched at the end of 2011 directed to establish fair competition on the market and to clean up existing local policies that are discriminatory to foreign products. Furthermore, EV manufacturers had to speed up the development and production, improve sale and after-sale services. A battery recycling system with tracking systems had to be established by both EV and battery manufacturers [47]. In December 2011, the National Development and Reform Commission revised a “Foreign Investment Catalog” that characterizes FDIs into three groups: encouraged, permitted, and restricted. In the revised catalog, the conventional automobile investments were removed and investments in EV were placed in the “encouraged” group [48].

According to Howell et al. [2], the results were far short of the goals with less than 12 thousand EVs on the roads—6% global share—at the end of 2012 and approximately 40 thousand—8 thousand privately owned vehicles—at the end of 2013. Besides the global problems, e.g., battery costs and low mileage range. China had four additional problems that slowed down the progress. China lacked the capacity to create or transfer state of the art EV technology and the trade barriers hindered foreign companies to properly enter the market. Moreover, China’s trade barriers between its province blocked the creation of sufficient supply value chains, and finally, the government’s focus towards high end EVs, resulting in overlooking fast developing low-speed EVs. Contrary to government’s plan to leapfrog and overtook leading position, China had fallen behind in EV readiness. Krieger et al. [49] measured it by considering both countries’ supply and demand side, and China who was only behind United States and France in 2010 had been overtaken by Japan and Germany in 2012.

The 5 billion-Yuan subsidy fund could cover more than 83 thousands vehicles, but the results were disappointing. By estimates only 500 vehicles were privately owned, e.g., Shanghai had only 10 electric vehicles. The main reasons were a higher price than conventional vehicles and inconvenience in the daily use [50]. In addition to the state policies, municipal governments introduced their own stimulus. In Beijing, the buyers of electric cars were excluded from the license plate lottery, which goal was to cut new car sales in the congested city [51].

<table>
<thead>
<tr>
<th>System Resource</th>
<th>Policies for Process-intensive products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge</td>
<td>Supporting the quick translation of new technologies to the manufacturing process</td>
</tr>
<tr>
<td></td>
<td>Support for entrepreneurial experimentation in private start-ups</td>
</tr>
<tr>
<td></td>
<td>Support imports of capital equipment, turn-key plants, and/or knockdown kits</td>
</tr>
<tr>
<td>Market Access</td>
<td>Promotion of domestic markets:</td>
</tr>
<tr>
<td></td>
<td>Policies aimed at creating domestic mass markets to facilitate economies of scale in production</td>
</tr>
<tr>
<td></td>
<td>Promotion of export market:</td>
</tr>
<tr>
<td></td>
<td>Establishment of export processing zones with state-of-the-art trade infrastructure</td>
</tr>
<tr>
<td></td>
<td>Intervention to decrease factor costs (raw materials, capital costs, labor costs, energy costs)</td>
</tr>
<tr>
<td>Financial investments</td>
<td>Providing low-cost loans for plant expansion, equipment purchase</td>
</tr>
<tr>
<td></td>
<td>Creating a supportive private equity and venture capital system</td>
</tr>
<tr>
<td>Technology Legitimacy</td>
<td>Adopting international quality certification&amp;standards systems</td>
</tr>
<tr>
<td></td>
<td>Mobilizing policy/public support based on success stories in export markets</td>
</tr>
</tbody>
</table>

Source: [7]
TABLE II
EV policies in researched periods

<table>
<thead>
<tr>
<th>Time period</th>
<th>Type of policies</th>
<th>Specific Policy and rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009-11</td>
<td>Knowledge</td>
<td>State Council 2009 - IPR - Manufacturers must have patents for their products</td>
</tr>
<tr>
<td></td>
<td>Market access</td>
<td>MIIT 2009 - EV solutions classified by technical stage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MSTk&amp;MF&amp;MII&amp;RC 2011a - improve competition and speed up manufacturing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>NDRC 2011 - EV placed in FDIs catalogue in the “encouraged” group</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MF&amp;MII&amp;RC 2009/10 - 1/1000 pilot cities program</td>
</tr>
<tr>
<td></td>
<td>Financial investments</td>
<td>MF&amp;MII&amp;RC 2009 - subsidies for EV purchase and EV manufacturers</td>
</tr>
<tr>
<td></td>
<td>Technology legitimacy</td>
<td>MF&amp;MII&amp;RC 2010 - subsidies extension</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shanghai EV zone 2011 - international demonstration zone</td>
</tr>
<tr>
<td>2012-14</td>
<td>Knowledge</td>
<td>State Council 2012 - Scientific planning of industrial layouts</td>
</tr>
<tr>
<td></td>
<td>Market access</td>
<td>State Council 2012 - New production plan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>State Council 2012 - building charging facilities; improving standards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>State Council 2012 - supporting internationalisation (trademark registration &amp; acquisitions)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CAAC 2013 - encouragement for private purchase - granting car licenses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MF&amp;MII&amp;RC 2013 - increase in number of pilot cities</td>
</tr>
<tr>
<td></td>
<td>Financial investments</td>
<td>State Council 2014 - elimination of local protectionism, improving quality, business model innovation</td>
</tr>
<tr>
<td></td>
<td>Technology legitimacy</td>
<td>MF&amp;MII&amp;RC 2014a - new grant for cities with outstanding performance</td>
</tr>
</tbody>
</table>

B. Period 2012-2014

The unsuccessful policy from 2009 showed weaknesses, which were addressed in “Energy Saving and New Energy Auto Industry Development Plan 2012-2020”. Its premises were that technological and transformational upgrading in the automobile sector is an important task for economic growth and international competitive advantage [2]. The goal was to reach production of 500 thousand EVs in 2015 and 2 million in 2020. The policy also addressed the pollution of vehicles with internal combustion and its fuel per 100 kilometers should decrease to the international advanced level in 2020 [52]. The policy proposed five groups of tasks:

1) Energy-saving and EV technology innovation project

Raise the support for developing core technologies for enhancing industrial competitiveness by linking national science and technology programs with technological innovation system. Especially the technical innovation of power battery, as they were the cutting-edge technology. The government guided enterprises to invest more in R&D and promote cross-industry collaboration. To ensure that, shared test platforms, development databases and common collection of relevant patents should be established.

2) Scientific planning of industrial layouts

The industry needed to have conditions to implement R&D into production; therefore the task was to develop new EVs’ production capacities according to the actual needs of the industry and market. The principal goal was to establish battery cluster with large-scale production companies (10 billion watt-hours) with continuous innovation capabilities.

3) Improvement of pilot demonstrations

To meet new production goals, the scope of pilot cities had to increase to large and medium-sized cities, supported with new subsidy policy. As there was still missing the dominant model for battery handling, new business model innovation was encouraged for battery leasing, charging and replacement services. Additional to current types of EVs, new alternatives to fuel had to be still researched (e.g., fuel cell EV).

4) Charging facilities construction

A new overall development plan for charging facilities had to be included in any modern urban transportation system planning, and pilot cities had to use government’s offers and actively attract other social funds.
5) Improvement of standards and support policies

With aim of accelerating EV sector, the government allocated funds to technological development, standard setting, and market application by building technological innovation system that integrates production, study and research. This was supported by improved “punishment” policies for vehicles powered by fuel. The plan also included support (e.g., risk compensation) for financial institutions to actively participate in EV projects. A multi-level talent training system included talents from different disciplines (e.g., product development, business management, IPR, electrochemistry, vehicle engineering) and encourage companies, universities and scientific research institutions to recruit talents from abroad. Accompanied with stimulated international collaboration between manufacturers, universities and research centers, the inflow of missing knowledge could be generated. Additionally, the government supported enterprises in internationalization processes such us trademark registrations and acquisitions.

Ministry of Finance and Ministry of Industry and Information Technology introduced supporting policy [53] with additional funds. The first supported technological innovation in the EV sector and the second newly designed and developed EV models. Funds could be assigned to different technological teams, that combines industry, academia and research industry. To ensure projects’ continuity, funds had been disbursing in batches, 40% after plan implementation, 50% after mid-evaluation of the project is passed, and last 10% at the end. The same ministries supplemented this policy with additional application conditions [54]. Companies should have strong R&D capabilities, which input in the last two years accounted for at least 3% of the main business income. They should also have key-parts supply systems and after-sale service systems and their production should pass ISO9001 and ISO/TS 16949 quality system certification.

In the frame of above-described policies, additional subsidies for pilot cities to accelerate the development of EV sector were proposed in 2013 [55]. To be subsidized, pilot cities had to have a cumulative number of EV not less than 10 thousand vehicles in megacities and 5 thousand in other cities in the period between 2013-15. The number of foreign brands shall not be less than 30% and the obstacles for foreign brands had to be removed. The purchase of new vehicles by public institutions should not contain less then 30% electric vehicles and EV manufacturers could also gain subsidies for each EV sold.

In September 2013, the State Council issued the “Air Pollution Prevention Action Plan”, which included the promotion of EV in public sector and encouragement for private purchase with financial subsidies and granting car licenses. Additionally, more than 60% of all public buses in Beijing, Shanghai, and Guangzhou had to be electric or “clean fuel” [56]. At the end of 2013, the government decided to increase the number of pilot cities and in the first batch of 30 mega-cities or regions [57] and half a year later introduced new policies for public EV purchase [58]. The share of new EV vehicles purchased gradually increased from 30% set in 2013. The charging facility ratio towards EV had to come closer to 1:1 and every new parking areas had to consist EV charging facilities. Finally, both public and educational activities had to increase awareness of the importance of promotion of the EV for the environment.

Five years after the first major plan and two years after the second plan, the State Council announced the third plan [59], consisting of 25 specific points divided in six chapters: construction of charging facilities; guide manufacturers to innovate their business models; public services promotion; policy improvement; elimination of local protections; strengthening of technological innovation and product quality. The novelty was proposed tax exemption for EV [60], that were introduced at the end of the year and it covered the period between 2014-17. The plan was accompanied with two additional policies at the end of 2014, the first was 2nd batch of pilot groups [61] and it increased the number to 39. The second one was related to constructing new charging facilities [62] and it worked as a reward to pilot cities with outstanding results and without local protectionism. The grant had to be used in further charging facilities development.

The comparison of both policy regimes (Figure II) shows, that government gave more attention to Knowledge and Financial investments in the second period, compared to the first one. The policies tried to increase collaboration between different actors, e.g., universities, firms, and opened market for foreign firms—Knowledge. In the first period, national and local governments contributed most of the capital. With policies in the second period, different actors in the financial markets were stimulated to participate in the sector’s development—Financial investments.

![Policy regimes comparison](image-url)
C. Local policies

The EV policy in China followed their development formula with the experimental strategy on localized pilots to initiate systematic reforms. Based on the central metaphor of Chinese gradualism “crossing the river by feeling for the stones”, the strategy allows to test different models of development, and are later refocused back into the national policy [63], [64]. Thus, the policy comes from the national government—Top-down—and from the local government—Bottom-up—approach, where each pilot city could choose their strategy, as seen from the table [11].

The pilot cities used their characteristics and designed specific models with different business models. Beijing—State Leadership model—used strong public and private collaboration experiences to build EV industrial base. [63] Shanghai—Platform-Led Business Innovation model—created international demonstration zone to attract private investments and established EV rental business. This was the only internationally orientated program and included testing zones, data collection, and a network of science, EV manufacturers and energy suppliers [65]. In Shenzhen, the local government actively promoted EV industry development and introduced financial leasing model to reduce the purchase costs. Hangzhou decided to start renting both, vehicles or only batteries. Additionally, they implemented battery switching. And finally, Changqing invested in fast-charging batteries [63].

In August 2011, two years after the project started, all pilot cities were far from the plan. In average, the progress of pilot cities was 26% [66] and the national government intervened with a policy to strengthen pilot projects [46]. The city with the highest progress (55% of the plan) was city Hefei, whose local policy from 2010 gave additional 10 thousand yuan per EV on top of the national subsidy. The strategic alliance for technological innovation was formed with 24 manufacturers, key universities, research institutes and financial institutions. The aim was to increase collaboration and to build their brands [67]. In 2012, the “The Ten Cities, Thousand Vehicles program” came to an end and the national government should transfer them into a nationwide policy. Due to the diversity of the pilot projects, the standardization was hindered. Therefore, the city pilot strategy did not manage to jump-start a national EV industry and consequently to leapfrog [63].

VI. STATE OF TECHNOLOGY

In 2009, policymakers were aware of bottlenecks—market, technology, supporting facilities—in EV sector and the policy should address them. Despite the subsidies, in the following years, customers did not demand electric vehicles, mostly due to their shortages compared to the vehicles on internal combustion. In 2010, the batteries’ state of technology was not satisfactory. The manufacturing cost per kWh was between 3.4 and 5 thousand Yuan and it presented high part of the EV costs. The batteries’ life was between 3-5 years or circa 160 thousand kilometers, which was less than conventional vehicles [68]. By the February 2014, the battery production cost decreased to around 3.15 thousand Yuan per kWh, which was still much higher than 2 thousand planned for 2015 [2].

The average Chinese EV in 2011 had an average range of around 160 kilometers [68] and this had not improved much in next two years. The best selling EV in 2013 (JAC iEV) had a range around 120 kilometers, and the second (BYD e6) around 160, with an option to used bigger batteries—62 kWh—and thus reached up to 300 kilometers [69].

The supporting infrastructure presented a crucial obstacle in sector’s development. In 2010, pilot cities used different tactics to tackle it and at that time, charging stations were mainly developed for electric buses. Slow charging speed lowered bus’s potential operating time and thus battery swapping model emerged. For normal operation, charging station had to had 60 percent more batteries than buses, for example charging station that covered 50 buses needed 80 additional batteries with 240 9kWh charging slots [68]. Due to high battery prices, the investment for charging facilities were high. Slow charging speed effected passenger EV as well, as charging took up to eight hours and many charging facilities could not entirely charge the batteries. Some pilot cities developed their own battery swapping systems, which decreased the EV purchase cost, yet customers had to pay monthly fees. If not subsidized, the fee were relatively expensive for users [2].

VII. Sub-sector analysis

Both studied policy regimes addressed EV passenger cars and buses with the same regulations and subsidies, thus, their global market development was different. In the former, many countries started with production and in the later, there were mostly pilot programs—not considering trams. Connecting this with the Catching-up cycles, EV bus sub-sector was in different cycle stage, compared to EV passenger cars. They were not latecomer and had to invest more in domestic R&D. In spite of aforementioned problems with charging stations, EV bus industry developed relatively faster than industry of bus with internal combustion. Between the years 2010 and 2016, the average share of EV buses in total EV was 27%. In 2014, the share was 32.2%, which is more than twelve times higher than the share of buses with internal combustion in the all vehicles produced in China in the same year—2.55% [70]. The regulation from 2013 forced big cities to rapidly replace existing buses with electric ones, which increased the demand. As the result, in 2017 many cities became highly electrificated—Shenzen 100% [71], and Chinese purchase of EV buses present more than 99% of whole global purchase [72]
### TABLE III
Five pilot cities’ strategies

<table>
<thead>
<tr>
<th>Pilot</th>
<th>Model</th>
<th>Plan / Realisation 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>State Leadership</td>
<td>Creation of strong EV industrial base</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public and Private collaboration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EV exemption from car license plate lottery system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>International demonstration zone</td>
</tr>
<tr>
<td>Shanghai</td>
<td>Platform-Led Business Innovation</td>
<td>EV rental business</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Financial leasing model for purchasing cost reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Promotion of its own plug standard</td>
</tr>
<tr>
<td>Shenzhen</td>
<td>Cooperative Commercialization</td>
<td>EV battery rental to reduce purchase cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battery switching</td>
</tr>
<tr>
<td>Hangzhou</td>
<td>Flexible Rental</td>
<td>Battery switching</td>
</tr>
<tr>
<td>Chongqing</td>
<td>Fast Charging</td>
<td>Fast-charging batteries</td>
</tr>
</tbody>
</table>

Source: [63]

Another view on the industry development could be to look at the manufacturing development and to the willingness of car manufacturers to produce EV. The policy addressed both public institutions and private purchase, first with direct orders and subsidies [56], and later mostly with subsidies. As seen from the Figure III, the number of projects with electric or hybrid buses increased faster than passenger EV. The demand from pilot cities was mostly for electrification of public transport and not as much from private citizens. The new manufacturing projects were the result of demand and as there was no real demand for passenger cars, the car manufacturers did not see an opportunity in faster transition. The data were obtained from “Catalogue of Recommended Models for Energy Saving and New Energy Vehicles, Demonstration, Extension and Application Projects”, published monthly since June 2009 by the Ministry of Industry and Information Technology. The catalog contains all products and projects that are approved by the central government and consequently are allowed to be supported by local governments [6]. The graph shows the effect of the policy from 2013, which speed up electrification of public transport, preferably with pure electric buses.

**Fig. 3. Catalogue of Recommended EV Models [6]**

VIII. CONCLUSION

The Chinese leapfrog attempt in 2009 counted on “indigenous innovation” and domestic market, contrary to Korea in LCD sector, who endogenize exogenous innovations, and by using foreign market became a leader [33]. Electric vehicles need supplemented infrastructure and the development of vertically integrated sectors—batteries—, which is more complex than TV sector that only demanded customers’ behavior change—legitimation. Due to the lack of domestic infrastructure, the EV manufacturing was not able to develop; therefore they should focus on foreign markets with a higher degree of EV readiness to faster achieve economy of scale that lowers costs. Contrary, in the first observed period, there was no policy support to export EV in foreign markets, see Table II. Due to the import restrictions [41], the knowledge transfer from foreign markets was insufficient, which hindered R&D capabilities. The government addressed this in the 2012 plan, which supported internationalization processes with trademark registrations abroad and international acquisitions’ support [52]. Moreover, in the supporting policy, the obstacles for foreign brands had to be removed [55].

The leapfrog strategy and its goals were promising, however, looking in-depth into policies arises many doubts. Correlating to different routes for latecomers to catch-up, the Chinese route could be seen as “Product Technology Pioneering Strategy”, which try to use radical product technology innovation to find the dominant design [27]. The theory suggests latecomer country should reach the lead-market users and gather technological knowledge. In 2009, the government introduced a regulation which defined maturity stage of different EV solutions and assigned them different management strategy [43]. Considerably conservative regulations did not promote manufacturing state of the art technology, but to stay with older types. Additionally, focusing only on the domestic market left them far from the lead-market users, whose demand was for more efficient EV vehicles. Filling the local—less demanding—market did not pressure manufacturers to innovate and consequently
define the dominant design. Last but not the least, 2009 plan had relatively high production goals, which resulted in starting manufacturing before the R&D would come with suitable solutions that would be better for the market.

Another problem in searching for the dominant design was in the pilot strategy, which allowed local governments to find their way of development. The lack of national standardization resulted in different charging solutions that are not compatible. Consequently, the products were localized and this hindered inner-country trade and knowledge transfer. At the end of pilot projects, the variety of solutions could not be transformed into the national policy, or even match international standards. The standardization problem was first addressed in 2012 plan and encourage institutions to come with a unified system that is aligned with international standards.

All the EV policies addressed both EV sector and battery manufacturing sector at the same time. According to Yu et al. [10], vertically integrated sectors should be seen as two separate sectoral systems, which influence each other’s development. Despite good lithium-ion battery production for mobile phones and similar products, the policy [43] placed all the EV with lithium-ion battery in the development stage and older Nickel-metal hydride batteries in the production stage. As different management methods supported both stages, this regulation affected the battery sector and its development.

The analysis of both periods showed that 2012 policy tried to solve the problems that appeared during the first period. It also changed the original leapfrog strategy to more slower catching-up approach, based on national innovation system—connecting institutions, industry, and science [52]. The new regime gave more attention to knowledge creation&transfer, and private investments. The comparison of the EV’s state of technology in China did not show significant improvement between both periods. Therefore, it is hard to evaluate, what stimulated the consumption and changed the direction of production in years 2013-14, see Figure 2.

The results show different dynamic in EV passenger cars and bus sub-sector. The policies were effectively addressing public demand than private purchase. Part of the explanation could come from different infrastructure need, as public transport can have big charging facilities where buses charge before departure. Contrary, private customers need more convenient solutions closer to their daily routine. The other part of explanation comes from the higher prices of electric vehicles compared to vehicles with the internal combustion. Despite the subsidies for EV and obstacles on purchasing vehicles on fuel, the insufficient policy in 2009, could not force the market to adopt, contrary, the market responded and created its path by producing LSEV for increasing local demand for private vehicles.

China has the biggest automobile market in the world, and only by filling the domestic demand, it is the biggest manufacturer. Yet, its export is considerably low, which is not common for the Chinese successful catching-up examples—e.g. Solar PV, Wind, mobile phone sector. Despite national-owned manufacturers with strong government support, none of the automakers became globally important multinational giant. Therefore, the studied EV sector arise some questions to the catching-up literature. First, most of the policy recommendation are divided among different types of the manufacturing—design and intensity—, and as is the case of EV sector, demand characteristics play an important role. The government can effectively stimulate sectors where buyers are public entities, and less where buyers are private customers. Second, what is the criteria of successful catching-up. Technology-wise, Chinese EV perform worse and cannot reach highest international standards, nevertheless market-wise their global market share is becoming the highest, though with a trivial export.

**References**


