Innovating Up, Down, and Sideways: The (Unlikely) Institutional Origins of Experimentation in China's Plug-in Electric Vehicle Industry

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Abstract

A vast literature has attempted to understand the factors that accelerate experimentation and innovation in technologically-sophisticated emerging industries—but less is known about these processes in the context of industrializing nations. We apply inductive, grounded theory-building techniques to characterize and explore the origins of divergent innovation trajectories in once such context: the plug-in electric vehicle (PEV) industry in China. Triangulating annual vehicle make and model sales data for 2003-2014 (plus monthly data for the most recent five years); 112 English and Mandarin archival documents from industry, academic, and news outlets; and 51 semi-structured interviews across industry, government, and academic stakeholders, we develop four in-depth case studies. We find that in contrast to the innovation trajectories of the multinational and Chinese arms of joint venture (JV) firms, independent domestic Chinese firms (those with no historic JV partnerships) are undertaking significant innovation and experimentation in China's PEV industry. Our results suggest that national institutions—specifically the formal JV and local content requirements—which discouraged PEV innovation in multinational firms and inhibited the capabilities of Chinese JV partners to independently develop their own PEVs resulted in a protected PEV market for independent domestic firms. The influence of these national institutions has combined with local institutional support in the form of additional market protection and subsidies to turn regional markets into protected laboratories for independent domestic firms to experiment with a variety of innovations. That said, for these domestic firms to grow beyond their early, protected regional markets, China will need to develop paths to national market integration.

Keywords: Innovation; Plug-in Electric Vehicles; China; National Policy; Local Institutions

Highlights

- China's JV regulations have led to a protected, JV-free market for electric vehicles.
- Local institutional support has incubated new sources of PEV innovation.
- Independent domestic automakers are leading these diverse forms of PEV innovation.
- Future PEV market growth will require greater national market integration.

1. Introduction

A vast literature has attempted to understand the factors necessary to enable and encourage innovation in technologically sophisticated emerging industries. While much of this literature is focused on developed nations, less is known about how these processes unfold in industrializing nations. For example, while there is clear evidence that China is contributing to critical innovations in the global ecosystem (Breznitz & Murphree, 2011; Nahm & Steinfeld, 2014), scholarly literature and expert studies suggest China still struggles to contribute to innovation at the technological frontier (Branstetter et al., 2015; Glennon et al., 2017; National Research Council, 2013). In this study, we advance this line of inquiry by probing the antecedents of diverse forms of innovation by independent domestic Chinese firms in one technologically sophisticated emerging industry: the plug-in electric vehicle (PEV) industry in China.

The origin of this inquiry is a puzzle: independent domestic firms—those with no historic joint venture (JV) partnerships—are engaging in a variety of innovative activities in the PEV industry while domestic firms with JV partners as well as foreign firms are virtually absent, focusing instead on selling mature incumbent technologies. Any explanation for emerging PEV innovation in China will need to address not only the drivers of innovation among independent domestic firms, but also the virtual absence of PEV innovation among incumbent firms.

We advance the argument that a national institution—specifically, the JV requirement—aimed at facilitating technology transfer from foreign to domestic firms in a mature industry has unintentionally fostered the emergence of diverse local "laboratories" for domestic innovation in an emerging alternative competitor: the plug-in electric vehicle. Applying inductive, grounded theory-building techniques (Eisenhardt, 1989; Glaser & Strauss, 1967), we show how local institutions, in particular grants for technology development and subsides to foster local market entry, enable very diverse activity in these laboratories. Triangulating annual vehicle make and model sales data for 2003-2014 (plus monthly data for the most recent five years); 112 English and Mandarin archival documents from industry, academic, and news outlets; and 51 semi-structured interviews across industry, government, and academic stakeholders, we develop four in-depth case studies of independent domestic Chinese firms: Chery New Energy Vehicles, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies.

All four of our independent domestic case study firms are innovating in different subsectors of the PEV industry: Chery is a traditional automaker designing, manufacturing, and selling both conventional gasoline and plug-in electric vehicles; Haike is an automotive transmission startup company developing a low-cost flywheel hybrid transmission for PEVs; Jiayuan is developing low-cost, low-speed electric vehicles; and Kandi is developing PEVs for its car sharing service. The firms face different regulatory constraints and target different market segments. Each firm has a unique history that has led to its individual capabilities and innovation directions. We use evidence from the divergent development paths of these case studies to demonstrate how the configuration of national and local institutions can channel not just the direction of innovation, but also who engages in it, with implications for the direction and pace of clean energy transitions that may originate from the developing world.

Our results are surprising. In contrast to work by Nam (2011) and Howell (2016), which find that the national JV regulations are hindering domestic innovation, our results suggest that national JV regulations are creating a protected and underserved PEV market in China upon which independent domestic firms are able to capitalize. In addition, local institutional support such as providing market protection and subsidizing localized production are extending incubation periods for independent domestic firms to experiment in different directions. The details of our case study firms provide insights into how at the local and national level both market and institutional factors have created local laboratories for experimentation involving significant innovation in China's PEV industry by independent domestic firms and, consistent with Nam (2011) and Howell (2016), the lack thereof in the overseas and domestic Chinese arms of JV firms.

Our findings illustrate how overlapping national and local institutions can unexpectedly lead to positive outcomes in terms of diverse experimentation in emerging technologies. However, the same diversity of localized conditions that leads to innovative variety may impede the emergence of strong regional or national market players in the domestic and global PEV industry. Greater national integration of PEV regulations, technology standards, and R&D support will be needed to support the industry's development at scale.

2. Background

2.1 Innovation in China

Despite a dramatic rise in patenting and other innovative activities in China over the past decade, scholarly literature (Branstetter et al., 2015; Glennon et al., 2017) and expert studies (National Research Council, 2013) suggest that China continues to struggle to contribute to invention at the technological frontier. At the same time, China has contributed critical innovations to the global ecosystem, such as commoditizing existing products (e.g. crystalline solar technologies), recombining existing technologies to better meet market needs at lower costs (e.g. Huawei, cf. Ernst & Naughton, 2008, 2012), and conducting the product development and process engineering necessary to scale up and commercialize new products (Breznitz & Murphree, 2011; Herrigel, 2010; Nahm, 2012; Nahm & Steinfeld, 2014; Steinfeld, 2015).

By re-engineering focal models of foreign competitors, indigenous Chinese firms in the automobile, construction equipment, machine tool (Brandt & Thun, 2010), motorcycle (Ge & Fujimoto, 2004), telecommunications (Ernst & Naughton, 2008), solar photovoltaics, wind turbine (Nahm & Steinfeld, 2014; Steinfeld, 2015), and nuclear power (Metzler & Steinfeld, 2013) industries have been able to deepen their levels of technological upgrading and gain domestic market share by developing “good enough” products at substantially lower cost. Firms have also engaged in organizational innovations, such as the micro-divisionalization that Haier adopted when it reorganized over 60,000 employees into more than 2,000 teams (Meyer et al., 2016). Throughout the process of commercializing emergent technologies, both Chinese and multinational firms have experienced “multidirectional, simultaneous learning” (Nahm & Steinfeld, 2014). However, despite this important collaboration in production engineering in both wind (Lam et al., 2014) and solar (National Research Council, 2013) innovation, other developed nations continue to lead the technological frontier.

With impressive progress in innovation behind it, Chinese policy in recent years has been focused on overcoming this last hurdle of domestic firms leading the innovation frontier (Lewin et al., 2016; McGregor, 2010; State Council, 2006)—a holy grail sought over the decades by many industrializing nations (Acemoglu et al., 2005; Acemoglu & Robinson, 2013; Amsden, 2001; Breznitz, 2007; Taylor, 2016), with debated success (Nakamura & Branstetter, 2003). While existing literature has focused on nations that have made progress shifting from imitation to innovation and successful engagement in the global economy, less is known about how industrializing nations may engage in and encourage experimentation during early stages of technology and industrial evolution in technologically-sophisticated industries (e.g. not assembly of high-technology products) that do not yet have established markets.

2.2 Innovation Trajectories

Economic theory suggests that firms surviving in the same industry should, in general equilibrium, have similar organizational and technological practices, as only the most economically competitive practices will survive (Tirole, 1988). More recently, given the empirical reality that firms in seemingly the same market can have vastly different sizes, economic research has brought in the concept that differentiated product markets can lead to firm heterogeneity (Melitz & Redding, 2014). Firms also respond to non-economic (e.g. institutional isomorphic) pressures, including mimetic (mimicry of lead organizations' actions), normative (professionalization leading to common actions), and coercive (social and political pressures), causing organizations and practice to resemble each other's dominant patterns over time (DiMaggio & Powell, 1983).

These economic and sociological theories assume general equilibrium or isomorphic tendencies over time. As such, they say less about firm behavior in the early stages of an emerging industry. The literature on technology change and industrial evolution are clear that convergence should not be expected in the early stages of an industry's lifecycle. Theories on the product life cycle predict a large number of diverse firms should enter the market in early stages of new industries and only after a "shake out" occurs will the rate and diversity of product innovations decline (e.g. Agarwal & Gort, 1996; Gort & Klepper, 1982; Klepper, 1996; Suarez & Utterback, 1995; Utterback & Abernathy, 1975). The strategy literature then seeks to understand how firms within this emerging technology and market context can develop competitive advantages (e.g. Cockburn et al., 2000; Helfat, 1997; Teece et al., 1997). The thrust of this literature suggests that to successfully engage, nations must support (and perhaps actively so) experimentation in these early stages.

Past research makes compelling arguments for national funding needing to supporting parallel experimentation in early phases of R&D efforts (Nelson, 1961; Scherer, 2011). Historical examples suggest that parallel experimentation across different firms may be equally central to achieving industry-wide breakthroughs (Holbrook et al., 2000; Mowery & Nelson, 1999).

Holbrook et al., (2000) find that diverse specialization in the four major leaders of the early U.S. semiconductor industry was largely driven by customer needs and events that constrained their ability to depart too far from existing capabilities. In this case, this diversity was fostered by antitrust and IP policies that reduced licensing costs and "enabled high levels of cross-licensing and entry by new firms, which contributed to rapid growth and innovation" (Mowery & Nelson, 1999). Recent research on subsidiary firm capability accumulation in Taiwan's semiconductor industry has shown non-linear and often discontinuous innovation processes where firms developed diverse, specialized capabilities due to subsidiary autonomy, changing customer needs, and changing opportunities to access new capabilities from multinational enterprise internal and host country networks (Collinson & Wang, 2012).

2.3 Tensions Between National and Local Institutions in China

Research has noted differences in and conflicting mandates of the institutions shaping China's national and regional innovation systems (Breznitz & Murphree, 2011; Nahm, 2014). Li (2009) suggests that institutional variation across different regions in China is underlying the increasing gap in regional innovation performance. Because local governments are dependent on local businesses for revenues, they have been found to intervene with policy decisions that benefit the local economy, even if the outcomes conflict with central government goals of industrial or technology upgrading. For example, local governments have repurposed high-technology zones established by the central government into capital-intensive, export-oriented manufacturing facilities that attract large amounts of foreign investment and promise faster investment returns but don't necessarily support emerging technologies (Heilmann et al., 2013).

Other research has argued that such tensions between local and national innovation systems have played an important role in shaping the emerging innovative capabilities of firms in China. In China's renewable energy industry, Nahm (2014) illustrates how Chinese wind turbine and solar panel manufacturers repurposed central government resources, such as high-technology zones, and utilized local policies and institutions that supported manufacturing to develop new specialized, knowledge-intensive capabilities in technology scale-up and commercialization, or "innovative manufacturing" (Nahm & Steinfeld, 2014). These rapid, cost-effective manufacturing techniques grew out of a combination of China's national innovation system, which provided entrepreneurial firms access to global production networks through licensing and collaborations with foreign partners, and local innovation systems, which provided support for more traditional manufacturing activities through incentives such as tax breaks, low-cost land, and preferential loans (Nahm, 2014). Breznitz & Murphree (2011) suggest that it is precisely these innovative capabilities in product commercialization that may be the key to sustainable economic growth for China's future.

Prior literature on China's automotive industry has been particularly focused on how national and local institutions can shape patterns of technology development. At the local level, governments have resisted central government pressures for industry consolidation (Huang, 2002; Thun, 2006). At the national level, the JV institution opened China's automobile industry to extraordinary levels of foreign direct investment by requiring non-Chinese automobile manufacturers to form JV firms with domestic Chinese partner firms in order to manufacture and sell vehicles in China. Despite being rooted in the industrial policy strategy of 以市场换技术 (*yǐ shìchǎng huàn jìshù*), or "trading the market for technology," prior research suggests that the policy did not have its intended effect; rather than absorbing foreign technology and know-how, Chinese partner firms in JVs became dependent on their foreign partners' technology and brands and failed to develop their own independent R&D capabilities (Brandt & Thun, 2010; Feng, 2010; Howell, 2016; Huang, 2003; Lazonick & Li, 2012; Nam, 2011). Nam (2011) uses a case study to illustrate how Chinese JV partner firms have become engaged in a "passive" learning mode with their multinational partners, leaving their innovation capabilities less developed. Other research shows empirically that the JV institution has discouraged Chinese JV partner firms from investing in products that might compete with their JV partner's products to avoid cannibalization (Howell, 2016). Referring to JV firms' dependence on multinational partners for technology and brands, former Minister of Machinery and Industry He Guangyuan said, "*It's like opium—once you've had it, you will get addicted forever*" (Reuters, 2012).

We label domestic Chinese firms that have *not* historically developed with JV partnerships as "independent" domestic firms. This distinction goes well beyond mere legal associations of firm ownership and indeed has had large, path-dependent impacts on the technical and R&D capabilities of firms in the traditional automobile and PEV industries. It is important to note that distinguishing some firms as "independent" with respect to the JV system does not imply that their *innovations* are also independent of all outside input or influence.

2.4 China's Policy Push for Plug-in Electric Vehicles

The development of a domestic PEV industry has increasingly become a cornerstone of Chinese automotive policy, starting with the inclusion of PEVs in China's 863 national R&D program in the 1980s. In many respects, PEV technology originated far from China and its (re-)emergence was essentially external to developments on the mainland, given that even in the early to mid-2000s private vehicle ownership was still considered a luxury. Since then, vehicle production and demand in China has rapidly grown and been associated with increasing oil demand and air pollution. Vehicles consume approximately half of all crude oil used in China (Ma et al., 2012) and contribute to over half of all volatile organic compound, carbon monoxide, and nitrogen dioxide emissions (Lang et al., 2013).

While PEVs have become attractive to reduce oil consumption and pollution from passenger cars, they are also seen as a strategic opportunity for Chinese automakers to obtain a position of leadership in an emerging technology in the global automotive industry. In its 2006 medium- and long-term plan for science and technology development, the State Council emphasized 自主创新 (*zìzhǔ chuàngxīn*), or "indigenous innovation," as the central development strategy for science and technology industries. With the global PEV industry still in its infancy, some Chinese policy makers hope that innovative Chinese firms can "leapfrog" to PEVs without having to develop frontier innovation capabilities in internal combustion engine technology (Howell et al., 2014).

To support these efforts, the Chinese government has aggressively promoted the domestic development of 新能源车 (*xīn néngyuán chē*), or "new energy vehicles," which includes plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs). Of these technologies, China has prioritized BEVs and PHEVs. PHEVs couple a gasoline engine with a small battery pack and electric motor that improves fuel efficiency and provides a short driving range (usually less than 40 miles) of electric-only driving before switching to gasoline. BEVs run purely on electricity and can reach driving ranges of 100 to 250 miles with large battery packs and large electric motors. An important subset of BEVs known as "low-speed EVs" (LSEVs) use more mature technologies, such as lead acid batteries, and typically have maximum speeds of less than 80 km/h and driving ranges of around 50 to 80 km. With prices as low as RMB 30,000 (~$5,000), these LSEVs are being adopted far more rapidly than PHEVs and BEVs despite failing to qualify for any government incentives.

Both local and central governments have provided incentives to support a transition to PEVs. Local governments frequently offer free or subsidized land and office space, local infrastructure support, and local subsidies for PEV sales. The central government offers subsidies to private consumers that scale with battery capacity (RMB 3,000 per kWh) and reach a maximum value of RMB 50,000 (U.S. $8,200) for PHEVs and RMB 60,000 (U.S. $9,800) for BEVs. Importantly, these subsidies are restricted to vehicles that adhere to the "Three Transverses" and "Three Longitudes" R&D strategy implemented by the Ministry of Science and Technology (MOST, 2006).[1] To qualify for subsidies, the vehicle drivetrain must be one of the "transverse" vehicle types and at least one of the "longitude" technologies must be manufactured in China. Given these types of local content requirements, many foreign automakers have been unwilling to bring their most advanced vehicle technologies to China (Feng, 2010; Nam, 2011). For example, despite being the top-selling PHEV in the U.S., the Chevrolet *Volt* has not been sold in China; with LG Chem batteries from South Korea and a motor and control system developed and manufactured in-house, the *Volt* does not qualify for any central government incentives.

3. Methods and Data

We derive new theoretical insights on innovation in China's PEV industry through inductive grounded theory-building, iterating between theory, quantitative data, and qualitative data (Eisenhardt, 1989; Glaser & Strauss, 1967). Our unit of analysis is firms in China's PEV industry, and our analysis rests on three data sources: vehicle sales data, semi-structured interviews, and archival data.

Sales Data: We collected firm-level vehicle sales data from 2003 to 2014, including fields on the original equipment manufacturer (OEM), brand, vehicle model, vehicle trim, and the local and foreign partners for JV firms. Over the 11-year time span, our data set includes 78 OEMs, 95 brands, and 652 vehicle models sold in China. Two of our case studies, Haike Technologies and Jiayuan EVs, do not show up in these sales data as both had not begun sales by 2014. Since vehicle sales figures are reported by the firms themselves, we collected data from two different sources for comparison: 1) Automotive Industry Yearbooks published by the Chinese Association of Automotive Manufacturers (CAAM, 2014), and 2) the automotive website gasgoo.com

[1] The "Three Transverses" are the new energy vehicle types (BEVs, PHEVs, and FCVs), and the "Three Longitudes" are the core PEV technologies (batteries, motors, and battery management systems).

(Gasgoo.com, 2015) which publishes monthly vehicle sales in China by make, model, and trim. Since the automotive yearbooks are only published in print, the data were hand-copied to spreadsheets. We used a custom-built web scraper in Python to collect sales data from gasgoo.com to verify the automotive yearbook sales. These data largely agree over their overlapping years (2010-2014) with only small variation between a few firms, none of which differ on order of magnitude at the annual level. Aggregated sales totals by manufacturer and brand also match those reported by the China Passenger Car Association.

Table 1: Summary of Sales Data Collected

	CAAM Automotive Industry Yearbooks	Gasgoo.com
Years	2003 - 2014	2010 – 2014
Data type	Annual sales by make and model	Monthly sales by make, model, & trim
Collection Method	Hand-curated from paper archives at Tsinghua University	Scraped using Python

Interviews: We conducted 51 semi-structured interviews totaling nearly 70 hours between May 2014 and October 2016. Interviewees were contacted through a combination of a snowball technique (previous interviewees introduced future interviewees) and cold-calling different sources. Approximately half of the interviews (27/51) were with managers and engineers at our four focal case study firms; 10 of the interviews were with managers and engineers at JV firms; and 14 were with a variety of stakeholders in China's PEV industry, including university researchers, non-profits, government experts, consultants, and reporters. Interviewees outside the four case study firms provided important perspectives (in particular from more senior managers at JV firms) who have multiple decades of experience working in multiple automotive firms in China and abroad. Gaining insights from these interviewees provided comparisons from which to better understand statements from the case study firm interviewees. These interviews also clarified the historical context of how China's automotive market has evolved over time and the role policies have played in shaping the market today, in particular with respect to strategies of multinational firms operating within the JV system. Finally, interviews with JV firm managers and outside industry experts were used to cross-check the information from our interviews with the independent domestic case study firms.

Archival Data: We collected additional archival materials (not including the sales data) on each case study firm. These documents included scholarly reports on the firms, such as previous case studies from English and Chinese sources, press briefings about events in a firm's history, investment reports, company presentation materials, magazine articles, and news reports. As the only publically-traded firm among our cases, Kandi Technologies had many more available archival materials, including quarterly SEC filings from 2008 through 2016 and online investor reports. Table 2 below summarizes the full set of interviews and archival documents obtained, and Table 4 in the Appendix provides a detailed list of the interviewees by organization and position.

Table 2: Summary of Interviews and Archival Data

Category	Organization	Interviews			Archival Documents	
		Number of Unique Interviewees	Total Number of Interviews	Total Length of Interviews (min)	Total Number of Pages	Number of Unique Documents
Case Study Firms	Chery NEV	14	15	1,150	178	6
	Jiayuan EVs	3	6	550	120	8
	Haike Technologies	3	4	490	72	8
	Kandi Technologies	2	2	180	2,845	90
JV Firms	JV Firm 1	4	5	375	Triangulation with existing literature: (Nam, 2011; Nam & Li, 2012)	
	JV Firm 2	1	1	120		
	JV Firm 3	2	2	180		
	JV Firm 4	1	1	120		
	JV Firm 5	1	1	80		
Other (secondary sources)	Universities	4	4	215	NA	
	Non-profits	3	3	180		
	Government	2	2	120		
	Consultants	4	4	340		
	Newspaper	1	1	35		
Total:		45	51	4,135	3215	112

4. Sales Data Results: Independent Domestic Firms Are Leading China's PEV Industry

Figure 1 compares the relative market shares by vehicle manufacturer, brand, and firm type between all conventional vehicles and all PEVs in 2014. Of the approximately 19.7 million conventional vehicles sold in 2014, the vast majority were sold by JV firms—which collectively sold 13.9 million vehicles (70.6% of the market)—and Chinese JV partner firms—which collectively sold 3.2 million (16.2%). Independent domestic firms captured the smallest share with only 2.6 million in sales (13.2%). In contrast, independent domestic firms dominated sales within the PEV market, selling 46,843 (87%) of the 53,827 PEVs sold. JV firms sold just 582 (1%) while Chinese JV partner firms sold 6,402 (12%).

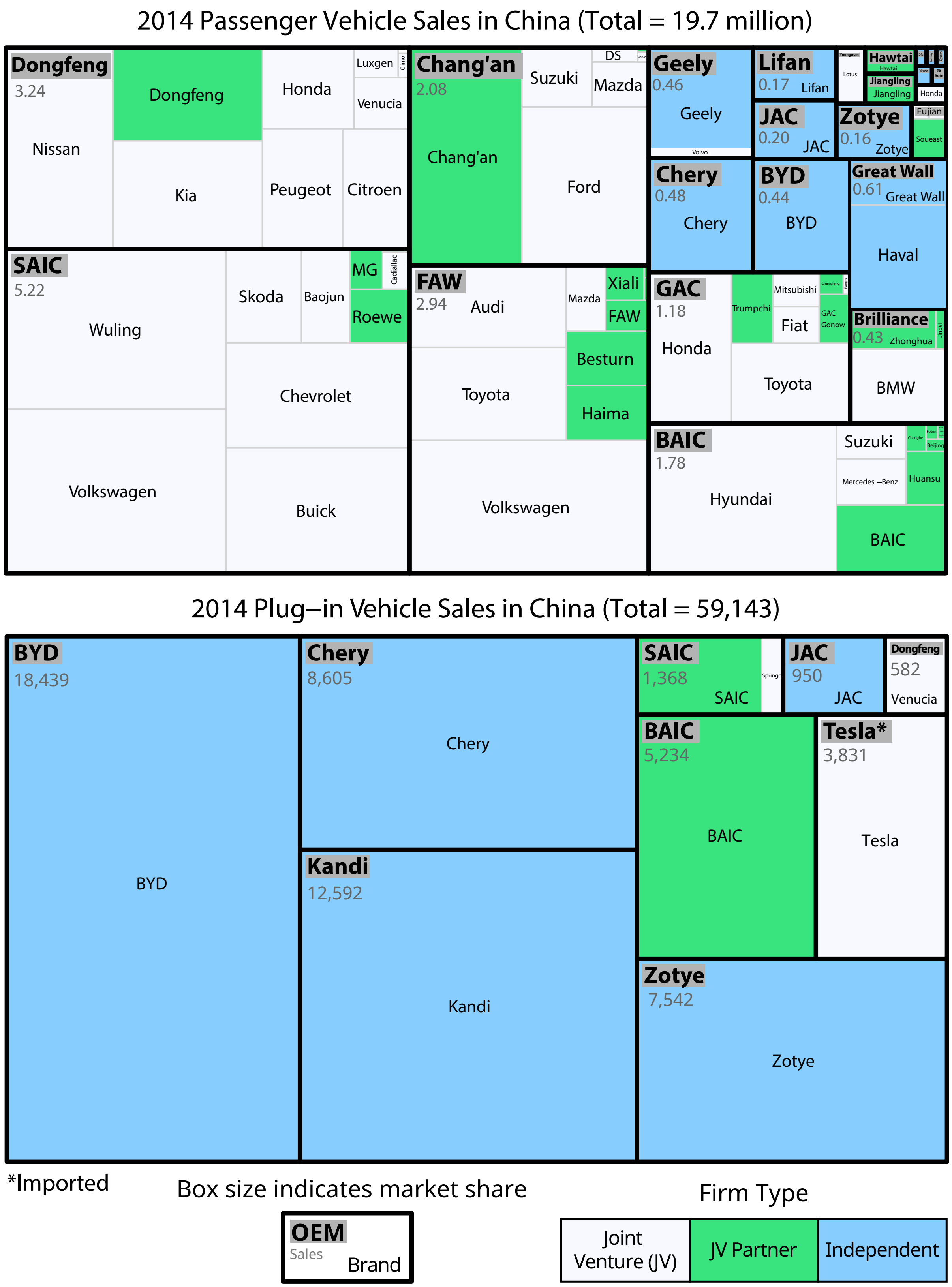

Figure 1: 2014 all passenger vehicle sales (top) and plug-in vehicle sales (bottom) in China by manufacturer and brand (sales in top figure given in millions).

As the sales data in Figure 1 shows, despite capturing the majority of the conventional vehicle market, JV firms have a remarkably small presence in China's PEV market where independent domestic firms have captured the vast majority of market share. This is the central puzzle that we probe in the remainder of this paper. Our interview data revealed several factors that have led to disincentives for multinational firms to enter China's PEV industry.

First, JV firms have followed the technology and development strategies of their multinational partners. By licensing and selling relatively older traditional vehicle technologies from their home markets, these foreign firms have been able to maintain high prices and make record profits through their JV firms, even after splitting profits with their JV counterparts. As one former JV firm manager said, "*Selling gas cars makes money! The business case [for PEVs] is weak. Margins [for conventional vehicles] in the west are only 3-5%, but in China they're around 10%!*"[2] Foreign firms perceived bringing their most advanced conventional and PEV technologies to China (along with necessary global suppliers) at large scale as exposing themselves to unnecessary risk. Participation in a JV requires that foreign firms share intellectual property with their JV partner firms that could later become competitors. To receive subsidies, they would have to source one of the "three longitude" technologies (batteries, motors, or battery management systems) in China. Focusing instead on established product lines with established supply chains in conventional vehicles is a more conservative strategy that has resulted in high profitability and lower uncertainty.[3]

Of the few PEVs produced by JV firms in China, many have been low volume demonstrations to meet a government requirement. For example, some local governments have suspended land rights to expand conventional vehicle manufacturing facilities unless the JV produces a PEV. To meet these requirements, the JVs often retrofit a few hundred existing conventional vehicles with an electric drive train. Since these PEVs are manufactured in low volume (and often by hand), they are extremely costly and are often sold at a loss (even after subsidies) as taxi fleets rather than to private consumers. Such maneuvering has enabled the global automakers to, as one former JV

[2] Interview 7.
[3] Interviews 1, 2, 7, 9, 10, & 13.

manager put it, "*check the box*"[4] on making PEVs while continuing to expand their businesses in conventional gasoline-powered vehicles.[5]

Evidence also suggests that the JV institution may have limited the R&D and innovation capabilities of Chinese JV partner firms in the PEV industry. The former Chief Engineer at Beijing Auto (a large, state-owned partner of multiple JV firms) said their PEVs were mostly direct conversions from their conventional vehicles and were "*not in the same league*"[6] compared to those developed by some of the independent domestic firms, referring to the relative levels of technology integration. With the limited JV involvement in China's PEV industry, independent domestic firms have been left with market opportunities that the Chinese partners of JV firms have failed to capture. These independent domestic firms have undertaken a wide diversity of innovations within the PEV industry. To examine the origins of this diversity in more detail, we explore the innovations of four case study independent domestic firms.

5. Four In-Depth Firm Case Study Results

Our in-depth interviews revealed four examples of independent Chinese firms within China's PEV industry with extraordinarily different forms of innovation: Chery New Energy Vehicles, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies. In focusing on these four firms, our intent is not to identify a representative set of all independent domestic firms but rather to illustrate the range of innovative activities in China's PEV industry. These firms also do not exhaustively represent a full set of innovations but rather represent an illustrative set of some of the types of diverse innovations by independent domestic firms. These firms span multiple business strategies, including manufacturing and selling whole vehicles (Chery and Jiayuan), manufacturing and selling vehicle components (Haike), and manufacturing and renting vehicles (Kandi). Two of these firms (Chery and Kandi) each have sizable portions of China's PEV market share (see Figure 1). While Haike and Jiayuan are still in start-up phases, we include these cases to illustrate the diverse forms of PEV innovation. Comparing the histories and innovations of each firm, we find a combination of national and local institutions may be supporting these independent domestic firms in experimenting in diverse innovation trajectories.

[4] Interview 13.
[5] Interviews 2, 7, 9, 13, & 14.
[6] Interview 34.

5.1 Chery New Energy Vehicles[7]: 脚踏实地 (Stepping on Solid Ground)

Chery New Energy Vehicles (hereto referred to as Chery NEV) is a subsidiary of the larger automaker Chery Automobile, an independent domestic automaker owned by the local government of the city of Wuhu in Anhui province. Founded in 1997 as an automotive parts supplier, Chery has gradually expanded and become one of China's largest independent domestic automakers with six domestic production plants and 15 complete knock down plants[8] in developing nations around the world. From 2003 to 2011 annual sales grew from approximately 90,000 to 630,000 conventional vehicles, including exports.

Over the company's 15-year history, Chery has transformed from a technology *imitator* to a technology *integrator*. Chery accumulated much of its technology as well as vehicle design and production capabilities by conducting joint R&D projects with multinational automotive suppliers and consultants and aggressively hiring experienced engineers and managers from multinational automakers. Rather than simply outsourcing design work to automotive suppliers, Chery used its relationships with global auto suppliers as conduits for absorbing technical skills and know-how. Describing a past joint R&D project, the assistant manager to the president said, "*The most important thing is doing it…learning by doing is the path to doing it on your own.*"[9]

For example, Chery jointly developed its ACTECO engine line (its first engine brand with self-owned intellectual property rights) by working with the Austrian engine firm AVL. From 2002 to 2008, their collaboration evolved from one where AVL served as "master," managing product development timelines and conducting R&D primarily in Austria, to "consultant," where AVL supplied technical assistance while nearly all R&D was managed and conducted within Chery's automotive R&D center in Wuhu (Feng, 2010). The collaboration produced 3 engine designs developed for 18 vehicle models. During that same period, Chery's R&D force grew from approximately 500 engineers to nearly 3,000 (Luo, 2005).

Not all collaborations led to successes. Chery's first hybrid vehicle was developed with British automotive consulting firm Ricardo from 2006 to 2008. Chery originally sent a small team of 20 engineers to train with Ricardo on a hybrid electric powertrain, but their lack of experience left the

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[7] Official Name: 奇瑞新能源汽车技术有限公司 (Chery New Energy Automotive Technology Co., Ltd).

[8] Complete knock down plants assemble vehicles using kits that contain every component needed for assembly.

[9] Interview 16.

team dependent on foreign support, especially with integrating the battery management system.[10] The former project director at Chery reflected on the collaboration using an analogy of a racing team where Chery was the "driver" and Ricardo was the "coach," but the four "wheels" were four international suppliers providing the technology to make the system run. "*Without these suppliers*," he said, "*the 'car' wouldn't have any 'wheels'*!"[11] The project resulted in two hybrid technologies: an integrated starter generator and a belt-driven starter generator, which are reported to reduce fuel consumption by 32% and 7-10% compared to Chery's conventional vehicles.[12] Although the hybrid was showcased in the 2008 Beijing Olympics as the first (and only, at the time) produced by a Chinese automaker, it's drive train was not as advanced as other fully integrated hybrid systems such as that in the Toyota *Prius*. In addition, payment to Ricardo and other international suppliers was expensive, and Chery's engineers were unable to fully control the vehicle design without foreign support. While the project was ultimately abandoned after the Olympics, the original founder of Chery NEV described the experience as an important "*stepping stone*"[13] towards developing their next project (the *S18* BEV) on their own.

Chery has also acquired skills and know-how by hiring experienced technical experts and managers from multinational automakers. Many of Chery's early engineers came from the R&D centers of large state-owned automakers with JV partnerships. Since the multinational half of JV firms conducted the majority of technical R&D, underutilized engineers at the Chinese partner half were eager to join Chery. Even Chery's president and CEO, Tongyao Yin, was a 12 year veteran and star engineer at FAW as manager of the FAW-Volkswagen *Jetta* plant (Luo, 2005). Over 100 FAW workers left to join Chery to develop the *A11* "*Fengyun*," Chery's first vehicle, a variant of the SEAT *Toledo* based on the VW *Jetta*. Much of the R&D work for the following three models released in 2003 was done by engineers from Dongfeng Motors, another large state-owned automaker that share a JV with Volkswagen.

Chery has also filled many management positions with "sea turtles",[14] a term used to describe experienced Chinese technical experts who left China in their youth to work abroad before

[10] Interview 17.
[11] Interview 52.
[12] Interview 18.
[13] Interview 24.
[14] The name refers to the fact that sea turtles return the beach where they were born to reproduce after living a long life away at sea.

returning to China later in life, bringing deep technical and managerial know how and often 20 or more years of experience. For example, Ming Xu, who worked for Visteon in Detroit, was hired in the early 2000s as director of Chery's R&D center (Luo, 2005). Past research has suggested that these returnees have played an important role in the growth phase of Chinese firms (Kenney et al., 2013). Some of these sea turtles, known as "*qianren*,"[15] received RMB 1 million ($140,000) from the central government through a national program to incentivize returning to China to aid domestic Chinese firms in developing technical knowhow. A former senior engineer at Chery referred to these *qianren* as "*secret weapons*"[16] as they are perceived as having been critical in deciding where to focus technical efforts and prioritizing which problems to solve in order to shorten timelines to the start of production.

Over time, Chery has applied its conventional vehicle design and production capabilities towards developing its PEV business, Chery NEV. In 2001, Chery NEV began its first PEV project after receiving a RMB 100,000 ($14,000) research grant from China's 863 national R&D program.[17] While integrating PEV components was the largest early technical challenge, a more fundamental challenge at the time was sourcing them given how few PEV component suppliers existed in China in the early 2000s. As a result, much of Chery NEV's early R&D efforts were on developing components such as motors, controls, and batteries with emerging suppliers such as Tianjin Gateway, Wanxiang, and Shanghai Electric Drive—now all major suppliers in the industry. Reflecting on the PEV industry in the early 2000s, one of Chery NEV's founders said, "*There were no shortcuts—we worked with partners, suppliers, and dealers to establish an entire ecosystem for making EVs.*"[18] The early PEVs of that time were seen mostly as engineering prototypes and the first products of a series of innovation design stages.

Chery NEV's business grew along with China's national policies. In the mid 2000s, China entered a demonstration stage where special standards for PEVs, such as a maximum speed, crash safety, horse power, and range, were introduced nation-wide to improve production consistency even though they were lower than those for conventional vehicles. As products matured, tighter

[15] 千人: Literally "thousand person," the term means people who have a "thousand" capabilities—a very experienced or senior-level engineer or manager often with a technical background.
[16] Interview 34.
[17] Interview 24.
[18] Interview 47.

sets of standards were released and pilot programs such as "Ten Cities, Thousand Vehicles" which provided PEV subsidies to private buyers were implemented to increase domestic sales. Chery NEV designed its *S15* BEV to meet these standards, which required the use of lithium ion batteries.

The *S15* was the predecessor to their most recent BEV, the *eQ*. A major breakthrough and cost-saving measure for the design of the *eQ* was developing a common platform with the *QQ5*, one of Chery's more popular conventional vehicles. Since the original BEV *S15* was built on the same chassis as the conventional *QQ*, the floorboard had to be raised to fit in batteries, which significantly reduced passenger leg room. Battery pack development took almost 3 years and required 8 different battery modules to fit into the chassis. After realizing these design flaws, Chery NEV co-developed a new platform with the larger Chery Auto platform division that uses a common chassis between the conventional *QQ5* and BEV *eQ*, which today share over 90 different component modules and are both assembled on a single production line.[19] The common platform helped reduce battery pack development time to 18 months and also enabled a more flexible battery module system allowing customized driving ranges. While high battery costs from two different Chinese suppliers still make the *eQ* more expensive than similarly sized conventional vehicles, current subsidies bring the price down to under RMB 100,000 (~$15,000) and even lower in some cities with the addition of local subsidies. For comparison, Chery's conventional *QQ5* sells for RMB 40,000 – 55,000 (~$6,000 - $8,300).[20] Since going on the market in 2014, Chery NEV has sold 30,000 *eQ* BEVs.

Chery NEV has developed PEVs by building on Chery Auto's accumulated vehicle design and production capabilities from years of conducting R&D projects with multinational and local suppliers and hiring experienced veterans of the automobile industry. We summarize their story with the Chinese idiom "脚踏实地" (*jiǎotàshídì*), which literally means "to step on solid ground"; figuratively, the phrase means achieving incremental improvement by building on past experience.

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[19] Interview 19.

[20] Interview 24.

5.2 Haike Technologies[21]: 大巧若拙, 大道至简 (Dumbing Down is the Way Up)

Haike Technologies is a hybrid transmission startup firm founded in 2012 based in Changzhou, Jiangsu Province. Haike is commercializing a hybrid transmission that uses a mechanical flywheel and electric motor to recover energy losses during vehicle braking. Unlike traditional electric hybrid systems that recover energy from braking by charging a battery, the flywheel system stores kinetic energy by spinning a disc to very high speeds. The primary advantages of flywheels over electric hybrids is that they avoid efficiency losses from converting between kinetic and electrical energy, and they can reduce BEV costs by reducing the power and capacity requirements of the battery pack and motor.

Early applications of the flywheel hybrid technology were originally developed for large stationary energy storage used in accelerating and decelerating light rail systems. One of the earliest vehicle applications of was the 1991 Chrysler *Patriot*, an early prototype hybrid race car. During the 1990s, concerns over safety ultimately led to the U.S. and British governments refusing to grant research funding on the technology in favor of battery technology for energy storage.[22] The primary concern was the ability to safely control the energy stored in the spinning flywheel that, as one of Haike's engineers put it, is like "*taming a wild animal.*"[23] The inability to secure R&D funding in England and the U.S. in the late 1990s and early 2000s was one of the motivations to consider commercializing the technology in China.[24]

Nearly all development for vehicle applications of the technology has occurred by two firms in England and Haike in China. The two British firms have focused on the niche market of formula racing where flywheels have been strategically used for improving energy recovery and rapid acceleration. These systems typically use advanced carbon fiber flywheels that can spin up to 60,000 rotations per minute to maximize energy storage. Because of the complex manufacturing processes associated with these systems, they are produced in low volumes. In contrast, Haike is developing their technology for mainstream commercial and industrial PEVs using a solid metal flywheel with a maximum speed of only 20,000 rotations per minute. Coupled with an electric

[21] Official name: 常州海科新能源技术有限公司 (Changzhou Haike New Energy Tech Co., Ltd.).
[22] Interviews 27 & 35.
[23] Interview 27.
[24] Interview 35.

motor for control, Haike's system stores an adequate amount of energy but can be mass produced at lower cost using established manufacturing processes.

Haike Technologies was co-founded by Dr. Frank Liao, a *qianren* sea turtle with over 20 years of experience in automotive engineering in the U.S., and the technology's patent holder from the U.K. As a consultant at Magna in 2005, Dr. Liao became interested in the technology through academic papers on the topic, and in 2006 he was awarded a patent on the system in the U.S. In 2009, he became the Chief Technology Officer at Beijing Automotive New Energy Vehicle with hopes of implementing the technology, but company leadership rejected his proposal. In 2012, Dr. Liao left Beijing to found Haike Technologies with the goal of commercializing the technology and becoming a Tier 1 supplier. Haike has 15 employees, most of whom have Ph.D. degrees and came from senior level engineering positions at other automotive firms. Including Dr. Liao, four of their employees are *qianren* sea turtles.

Dr. Liao chose to headquarter Haike in Changzhou due to its favorable environment for technology startups, including free office space and reduced rent on pilot production facilities. One of Haike's senior managers said, "*When I first went to Changzhou, I noted the strange level of support at the full levels [of government]—high-level, the mayor, etc.—and how interested they seemed to be in what we were doing…each city retains something like 30 percent of all the tax revenue generated in the city, so the cities do have the freedom to back the winners they choose.*"[25] In addition, the startup's strategy was to initially target China's domestic market where they face virtually no competition from conventional electric hybrids. Finally, downstream engineering costs are lower in China due to lower wages for R&D engineers, and Changzhou is located in the heart of the Yangze River Basin automotive hub with one of the world's largest supplies of automotive engineers.[26]

For their first prototype, Haike engineers worked for one year with an alliance of Chinese suppliers to reverse engineer and locally source approximately 60 components for a planetary gearing system. Originally developed by Toyota, the system is critical for controlling the flywheel-motor interface, and by reverse engineering and locally sourcing components Haike was able to build its first prototype without infringing on others' patents. In July 2012, they completed a

[25] Interview 35.
[26] Interview 52.

100km-range prototype transmission test, and in December 2012 they installed their first fully-functional prototype transmission on a BEV mid-size industrial truck that was able to achieve the same driving range using only two-thirds of its original battery pack. In 2015, they installed an improved prototype in two other pilot vehicles: a Beijing Motor all-electric sports car and a Great Wall *K50* sports car. Results showed a 50% reduction in the overall drivetrain cost, a 50-80% improvement in acceleration performance, and a 30-50% improvement in energy savings.

In order to bring the technology to China's passenger vehicle market, Haike engineers are balancing tradeoffs between performance, reliability, safety, cost, and a rapid timeline from prototyping to mass production. Their goal is to design a simple, low-cost system architecture to quickly develop a commercially ready product for China's domestic market. Dr. Liao referred to Haike's commercialization strategy of simplifying the technology to meet China's market needs with the Chinese idiom "大巧若拙, 大道至简" (*dà qiǎo ruò zhuō, dàdào zhì jiǎn*), which literally means, "intelligent people can often seem slow-witted"; Dr. Liao translated the phrase as "dumbing down is the way up."[27]

5.3 Jiayuan Electric Vehicles[28]: 存在就是合理的 (If It Exists, It Must be Reasonable)

Jiayuan Electric Vehicles is an electric vehicle technology firm founded in 1990 based in Nanjing, Jiangsu Province. One of the oldest PEV firms in China, Jiayuan's origins go back to the late 1970s and early 1980s when the co-founder, Professor Li of Zhengzhou University, began conducting R&D on electronic motors and controllers. A professor of physics, Professor Li was awarded several research grants in the late 1970s to research electric vehicle technology. In 1985, he established China Electric Vehicle Society in Henan Province, and in 1989 he became the first director of the Electric Vehicle R&D Institute, which was in charge of overseeing national electric vehicle technology development. Professor Li wrote China's earliest policy recommendations on establishing technical standards for electric vehicles in the 8th five-year plan (1991-1995).

In 1990, Professor Li and his son who studied automotive design and engineering in college founded Zhengzhou Jiayuan Technology Co., Ltd. Their original plan was to supply China's automakers with BEV motors and controllers Professor Li had developed. However, since China's

[27] Interview 27.
[28] Official name: 南京嘉远特种电动车制造有限公司 (Nanjing Jiayuan Special Electric Vehicles Manufacturing Co., Ltd.).

automobile industry was still in its infancy, they were unable to find automakers developing PEVs. As a result, they designed their own research vehicles to continue R&D on BEV component technologies. Their first BEV in 1993, which used an asynchronous motor and lead-acid batteries, had a 90-mile range, which is comparable to GM's *EV1* that came out three years later in 1996. In 2001, Jiayuan completed a BEV conversion of a conventional Xiali sedan with a range of 276 miles and a top speed of 60 mph using a lithium cobalt oxide battery pack (EVUK, 2003).

That same year, Chinese policy makers established China's first national standards for BEVs (75 mph minimum top speed, 125-mile minimum range, and usage of lithium ion batteries), which at the time no automakers had achieved. In addition to these restrictions, obtaining an automobile manufacturing license from the central government to domestically sell vehicles required proof of billions of RMB in investment and the ability to produce conventional gasoline vehicles. Unable to meet these requirements, Jiayuan was limited to exporting their BEVs to Europe. During this period, Jiayuan developed a number of different BEVs, ranging from small sedans and SUVs (mostly as research vehicles) to mini buses and electric sightseeing buses for tourism. Exporting these small projects provided enough revenue to continue a small R&D effort, but without a license they were unable to expand their company.[29]

In 2006-2007, low-speed vehicle manufacturers began producing low-speed electric vehicles (LSEVs) as low-cost vehicles for China's rural countryside. Shifeng Group, founded in 1993 as a producer of low-speed, three-wheeled diesel trucks, began producing LSEVs in 2007. Their sales have grown from 10,000 in 2009 to 60,000 by 2014, and their annual production reached 100,000 units in 2015 (Research and Markets, 2016; J. Wang, 2015). The rural countryside of Shandong Province is home to an estimated 22 LSEV manufacturers (including Shifeng) that comprised approximately 60% of the 300,000 LSEVs sold in China in 2014, generating an estimated RMB 6.5 billion ($1.1 billion) in revenue (Perkowski, 2015).

LSEVs do not fall into any particular regulatory category, and because supply chains, factories, and workers are localized, many local governments have allowed LSEV manufacturers to produce and sell their vehicles with little to no regulatory oversight. Reflecting on the emergence of LSEVs, one senior engineer at Shanghai Automotive (China's largest automaker and JV partner

[29] Interview 33.

with GM and VW) said, "存在就是合理的" (*cún zài jiùshì hélǐ de*), meaning "if it exists, then it must be reasonable."[30] In this regulatory grey area, Jiayuan has found an opportunity to expand and domestically sell electric vehicles. While many of the Shandong manufacturers are marketing LSEVs towards rural households, Jiayuan is marketing their LSEV towards younger, urban consumers by adding amenities like air conditioning, navigation, and mobile phone connectivity, and they use a steel rather than fiberglass chassis for improved safety.

While Jiayuan has technical and aesthetic vehicle design capabilities, they lack mass production capabilities and investment funding. To overcome these challenges, Jiayuan has relied on localized investment and government support to gradually develop what they internally (and others externally) call a "McDonalds model."[31] Rather than building few, large capacity production plants, Jiayuan is establishing many small capacity, localized production plants. With this model, local investors own the entire production facility and earn a return on all LSEVs sold from that plant. With a RMB 20 million ($3.1 million) investment, Jiayuan can establish a local plant with an annual capacity of 10,000 LSEVs. While such low production capacities and initial investments are unheard of in the traditional automotive industry, the relative simplicity[32] of LSEVs makes economic sense at low production volumes.

In synergy with their localized investment strategy, Jiayuan has benefited from many favorable policies from local governments that are happy to provide support in the name of local economic development and the buildout of "green" products. For example, the local government in Chuzhou[33] in Anhui Province provided a refurbished factory free of charge minus small repair costs, and local investors have provided approximately RMB 200 million ($29 million) in funding. The city of Puyang in Henan Province also provided support for land and factory costs and is also providing a RMB 7,000 (~$1,000) subsidy for each LSEV sold. Jiayuan's CEO claimed, "*When I call other places and say I want to build a factory there, they ask, 'What sorts of favorable policies*

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[30] Interview 30. The Chinese phrase *cun zai jiu shi heli de* can also be translated as "what is rational is real, and what is real is rational."
[31] Interviews 30, 32, 33, 53, & 54.
[32] Modern conventional vehicles are typically comprised of approximately 30,000 individual components whereas LSEVs typically have just 1,000; in addition, all production (stamping, welding, and assembly) can be housed in one factory, whereas conventional vehicles typically require separate factories for each major production step.
[33] Chuzhou is the home town of the current Premier of China's State Council Li Keqiang and highly supportive of local Chinese firms developing "green" or sustainable products.

have local governments given you at other locations? We'll give you the same, and then we'll add more.'"[34] Research has reported similar localized support for Shifeng Group, which contributes 76% of all taxes in its local county (Wang & Kimble, 2012). Jiayuan is currently working with provincial governments in Gansu, Guangxi, and Hubei, and city governments in Xingtai, Shijiazhuang, and Tangshan to establish new factories.

One challenge of a low-volume franchise production model is the lack of standardized, quality LSEV parts suppliers due to sourcing from different locations. Many LSEV manufacturers have grown out of 2- and 3-wheeled vehicle manufacturers, but component performance requirements and quality control from suppliers in these sectors are relatively low. Discussing component sourcing, a manager at Jiayuan said, "*From the beginning, about 90% of our problems were with the supply chain. The failure rates for car parts need to be only a few bad parts out of a million, but in this industry it's in the tens of percents!*"[35] With one particular switch component, failure rates were so bad they issued a recall and then contracted with Bosch to get failure rates down to acceptable levels. Nonetheless, rapid LSEV growth has fostered a rising number of suppliers of LSEV components such as electric power brake systems and electric air conditioning systems that did not exist five years ago (Paglee, 2014).

The lack of regulatory oversight may at the same time be creating barriers to establishing standards for LSEVs. Professor Ouyang Minggao, Director of Tsinghua University's New Energy Vehicle Center, suggested as a starting point adhering to a principle of "三的三" (Three 3's): 三米一下， 三人以下，三万以下 (Less than 3 meters long, less than 3 passengers, and a price less than RMB 30,000).[36] Notably, such standards say nothing about quality, performance, or safety. In addition, the lack of quality suppliers has made it difficult to standardize or modularize components which could improve quality and safety across the industry.

The many uncertainties about the future of China's LSEV industry challenge investor confidence. In September 2015 Jiayuan began selling the *Lingzu*, a 4-wheeled two-seater with a top speed of 50 km/hr (31 mph)[37] and a driving range of 150km (93 miles). To prepare for the risk

[34] Interview 53.
[35] Interview 54.
[36] Interview 53.
[37] The *Lingzu* LSEVs exported to Europe have a speed of 75 km/hr (46 mph).

of no domestic sales, it was intentionally designed to be 2.2 meters long to maximize how many can be fit into a standard international shipping container for export.[38] Priced at RMB 30,000 (<$5,000), Jiayuan has sold 10,000 *Lingzu* LSEVs (including exports) as of October 2016.

5.4 Kandi Technologies[39]: 异曲同工 (Different tune, but equally melodic)

Kandi Technologies was founded by chairman and CEO Xiaoming Hu in 2002 in Jinhua City, Zhejiang Province, as a producer of gasoline-powered two-, three-, and four-wheeled off road vehicles. Their first products were exclusively exported to the U.S., and by 2007 Kandi had become China's largest exporter of high-end gasoline-powered go karts.

Throughout its history, Kandi has undergone several transitions towards becoming an electric vehicle manufacturer that have coincided with local and national electric vehicle and battery R&D projects. In 1999, the Zhejiang Provincial government established the Zhejiang Electric Car Project Working Group which in 2002 became the Zhejiang Wanxiang Electric Vehicle Development Center, a state-level center funded by the 863 National High-Tech R&D program. From October 2003 to April 2005, Mr. Hu served as the center's general manager, and in 2006 he led the first of four projects to assess the viability of using BEVs in a Hangzhou demonstration program. The project concluded that the city should invest in battery exchange infrastructure that can rapidly refuel BEVs by swapping depleted vehicle battery packs for freshly-charged packs. The battery swap system was preferred over traditional charging infrastructure, which requires dedicated parking spots and long charging times. In the same year, Kandi gained formal approval as a "Special Vehicle Manufacturer" by the National Development and Reform Commission after demonstrating Mr. Hu's patented side-loading battery swap technology in the Kandi *KD5010*, a two-seater BEV designed to operate with the battery exchange infrastructure.

In 2010, Kandi first piloted battery swapping with its *KD5010* in nearby Jinhua through a joint agreement with the Jinhua Municipal Government and the provincial branch of State Grid, China's largest and state-owned power provider. Construction on the first Jinhua battery charging and swapping stations began in July 2010, and by September 2010 Kandi formalized the cooperation by establishing a joint venture with State Grid and Tianneng Power, one of China's largest battery manufacturers. Kandi's first public vehicle sales began in late November, 2010. That same year

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[38] Interview 33.
[39] Official name: 康迪科技公司 (Kandi Technologies Group, Inc.).

Kandi also delivered 60 BEVs to the Hangzhou Postal Service and released an improved BEV, the *KD5011*, that uses lithium ion batteries with a 250 km (155 mile) driving range.

These early sales were "naked" BEVs, meaning they were sold without a battery and used the battery exchange infrastructure to refuel. They were also heavily subsidized. The Jinhua Municipal Government provided local subsidies of RMB 32,000 ($5,000) for the first 500 of Kandi's sales, bringing the price down to RMB 17,000 ($2,700). In 2009, the city of Hangzhou was chosen as one of the pilot cities in the "Ten Cities, Thousand Vehicles" program, which provided subsidies of RMB 60,000 RMB ($9,400) from the central government to private PEV buyers for each local electric vehicle sold in the city.

In 2012, Kandi modified its business model from swapping batteries to swapping the entire car through a car sharing mobility service where BEVs are available for hourly rental or long-term (annual) lease. The model is similar to Hangzhou's bicycle sharing program—the first in China and largest in the world—in which users pay by the hour to rent a bike that can be returned to any station in the network. To implement the service with limited parking space, Kandi developed towered vehicle "vending machines" that vertically park and charge vehicles and automatically swaps them when customers need a freshly-charged vehicle. So far, Kandi has constructed just two towered garages, and the rest of the vehicles in the system are parked at large businesses or hotels throughout the city.

The city of Hangzhou ordered 20,000 Kandi BEVs to implement the electric car sharing service. The project received RMB 5.4 billion ($850 million) in funding from three sources: the Hangzhou government provided RMB 800 million yuan ($126 million) in subsidies for the purchase of the cars (without batteries), the company Lithium in The Air invested RMB 2.4 billion ($378 million) to provide the batteries, and State Grid invested RMB 2.2 billion ($347 million) to provide the local battery swapping infrastructure. After launching in the second half of 2013, the car sharing program has rapidly expanded. As of the end of 2014, Kandi delivered a total of 14,398 electric vehicles to nine cities: 9,852 in Hangzhou, 686 in Shanghai, 1,020 in Chengdu, 340 in Nanjing, 700 in Guangzhou, 612 in Wuhan, 388 in Changsha, 500 in Changzhou, and 300 in Rugao. Reflecting on the Hangzhou model, a former general manager of multiple automotive firms in China said, "异曲同工" (*yìqǔtónggōng*), which literally translates to, "different tune, equally melodic"[40]; figuratively, the idiom means that different approaches can also lead to equally satisfactory results.

Today, Kandi is still modifying its business model as both a manufacturer of electric vehicles and a provider of electric mobility services. In June 2014, Kandi established a "group rent" service where a fleet of Kandi electric cars are sold to a high-rise community and shared across all 400 residents for an annual fee of RMB 9,600 ($1,300) each. In January 2015, Kandi directly sold 60 BEVs to the Hangzhou city police—its first direct vehicle sales with batteries. These fleet sales and leasing opportunities may provide other growth opportunities beyond Kandi's city car sharing businesses. In addition, in March 2013 Kandi established a RMB 1 billion ($164 million) joint venture with Geely Auto, one of China's largest independent domestic automakers and owner of Volvo. Kandi's recent SEC filings show that as of the end of 2014 all vehicle manufacturing has been transferred to the joint venture, leaving Kandi's main revenue source the sale of electric vehicle parts to the joint venture.

Nonetheless, Kandi's dependence on subsidies to remain profitable is a vulnerability. In January 2016, the Ministry of Industry and Information Technology increased the requirements to qualify for subsidies so that cars must have a minimum top speed of 100 kph (62 mph), which Kandi's current BEVs do not meet. As a result, Kandi's sales came to a halt in the first quarter of 2016 while the central government conducted a nation-wide review of subsidy policies.

6. Discussion

6.1 Independent Firms Are Innovating in Different Directions

We observe independent domestic firms in China's PEV industry pursuing a much greater variety of innovation strategies than those being pursued within large, established automotive firms with JV partners. The four case studies provide a snapshot of the variety of these innovations. Based on these cases, we suggest a typology involving three distinct innovation directions and describe these directions as innovating up, down, and sideways. Firms innovating "up" are those whose innovation strategy is to approach and eventually advance the technological frontier to compete in the market. Chery NEV has over time evolved into this innovation strategy by accumulating capabilities in R&D, technology integration, and advanced vehicle design and production

[40] Interview 41.

techniques. Kandi is also innovating up by developing new technologies that support its car sharing service, such as a patented side-loading battery exchange system and vehicle charging towers. Firms innovating "down" are those that combine or redefine existing technologies in innovative ways to compete in the market, a direction similar to much of the innovation observed in other industries where products are redesigned for "cost out" (Brandt & Thun, 2010; Ge & Fujimoto, 2004; Nahm & Steinfeld, 2014; Steinfeld, 2015). Jiayuan and Haike are both innovating in this direction—Jiayuan by designing a new product using mature lead acid batteries and existing motors and controllers and Haike by simplifying an advanced racing technology for cost reduction and mass production. Finally, firms innovating "sideways" apply new organizational and business models to compete in the market. Kandi's BEV car sharing business model exemplifies this innovation direction, as does Jiayuan's application of a localized "McDonalds" production model. Figure 2 illustrates how our four case study firms align with these innovation directions.

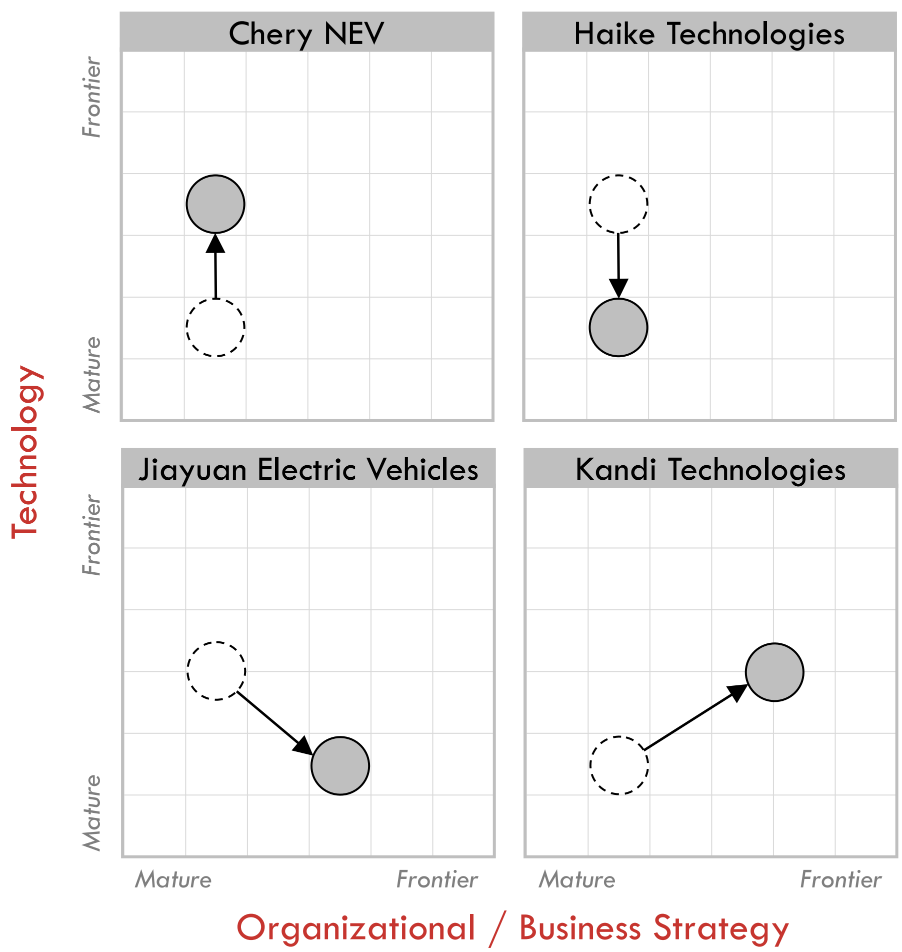

Figure 2: Case study firms innovating in different directions: Up, Down, and Sideways.

Given that PEVs are still an emerging industry and no "dominant design" (Utterback, 1994) has emerged, this diversity of innovation among independent domestic firms is perhaps to be expected. However, *how* to encourage such diversity in any nation (no less in an industrializing one) is a holy grail sought world-wide by academics and policy-makers alike (Acemoglu et al., 2005; Acemoglu & Robinson, 2013; Amsden, 2001; Breznitz, 2007; Lewin et al., 2016; McGregor, 2010; State Council, 2006; Taylor, 2016).

Prior work does not explain why PEV innovation is abundant in domestic independent firms but scarce in joint ventures and their local partners. Past findings by Howell (2016) and Nam (2011) only show that innovation in conventional gasoline vehicles is limited in joint ventures and their local partners. Our results suggest that the differences in innovative behavior between independent domestic firms and that of JV firms and their Chinese partners in the PEV industry is due to the co-evolution of national and local institutions with the historical path dependencies of firms in China's automotive industry. Specifically, our results suggest that: 1) national institutions, such as the written JV licensing regulatory requirements as well as local content requirements, have (inadvertently) removed foreign competition while national incentive policies have rewarded domestic firm PEV innovations; 2) local institutional support for local firms, such as market protection and subsidies, have extended the incubation periods for firm innovations. Table 3 summarizes the role of national and local institutions for each case study firm.

Table 3: Summary of Case Study Firms

	Chery	**Haike**	**Jiayuan**	**Kandi**
Innovation Direction:	Up	Down	Down-Sideways	Up-Sideways
Products:	Majority: CVs, SUVs, Minority: Small BEVs	Low-cost hybrid transmissions	Majority: LSEVs Minority: BEVs	Majority: BEV car share Minority: Small BEVs
Organizational / Business Strategy:	Manufacture & sell vehicles	Manufacture & sell vehicle transmissions	Manufacture & sell vehicles	Manufacture, rent, and sell vehicles
National Institutions:	No foreign PEV competition; design for regulation	No foreign competition	Licensing delayed entry	No foreign PEV competition
Local Institutions:	Protected local market	Free office space, low pilot production rent	Regulatory gray area allowing local adoption	Infrastructure support through relationship with Hangzhou city

6.2 Removing Foreign Competition: The (Inadvertent?) Bait and Switch

While the formal JV institution was originally implemented to facilitate the transfer of foreign conventional vehicle technologies to domestic Chinese firms, we find that within the emerging PEV industry it may actually be inadvertently serving to enable the innovations of independent domestic firms by providing a protected market in which independent domestic firm innovations can be incubated. In addition, given their intimate knowledge of local market needs and connections with domestic providers of related services, such as access to the electricity grid, independent domestic firms are arguably better-positioned to take advantage of local support. With strong network ties to local businesses and government institutions, independent domestic firms have the opportunity to leverage their inherent competitive advantage at combining different local resources, including local incentives for entering the PEV industry.

When asking Chery managers and engineers (including the founder of Chery NEV's R&D department) why they began exploring PEV research so early in its infancy, the consistent reply was to "*capture the market opportunity*" created by international automakers that were hesitating to develop PEVs for China and further supported by national and local subsidies.[41] Likewise, Haike employees noted how foreign automakers like Toyota and Ford that control the patents on traditional electric hybrid drivetrains have not brought them to China. Our interviews with managers at multiple JV firms reveal that IP sharing requirements within the JV institution, local content requirements for subsidy eligibility, and high import tariffs (25%) have all contributed to the hesitation of multinational firms to bring hybrid technologies to their JV partners in China. This lack of entry by global leaders in electric and hybrid drivetrains has left an opportunity for domestic firms like Haike to develop low cost alternative hybrid transmissions.

Past research has also found that JV restrictions can have direct impact on business strategies. The experience of South Korean automakers provides an example from a different national context in which restrictions of JV relationships led domestic firms to seek alternative partnership models that would further their innovation goals. Lee and Lim (2001) discuss how early joint ventures between South Korea's Hyundai and Japan's Mitsubishi restricted Hyundai's ability to learn how to develop and manufacture engines. To grow as a firm, Hyundai instead formed collaborative relationships with external suppliers such as Ricardo to co-develop engines, enabling Hyundai to

[41] Interviews 15, 16, 17, 20, 22, 23, & 33.

not only develop its own capabilities in engine design, but also skip past older carburetor-based engines in favor of emerging electronic injection-based engines (Lee & Lim, 2001). In contrast, Chinese industrial policy aimed at building national champions and upgrading the technological capabilities of domestic firms through the JV system backfired (Howell, 2016) by creating a dependency on multinational technology and know-how within JV firms. However, our findings unpack how this same policy seems to have inadvertently succeeded in accelerating independent domestic firm experimentation in a technology that in the Chinese context does not interest multinational or domestic JV partner firms, precisely because of their preexisting advantage in—and interest in maintaining the benefits from—the incumbent technology under the current institutional regime.

In addition to shaping the incentives to innovate in China's PEV industry, the JV system also helped create incentives for a wealth of foreign-trained Chinese engineers and managers to return to China. While many of the "sea turtles" may have returned to capitalize on the rapidly expanding domestic market or take advantage of national incentive programs to return, the large JV firms had the resources to initially hire them. Over time, independent domestic firms have successfully been able to recruit and combine this JV-trained and returnee talent with domestic connections and resources to innovate. The majority of Chery's original R&D engineers came from large joint venture firms with Volkswagen, and senior engineers in Haike and Jiayuan were talented sea turtles from some of the world's largest automotive firms and suppliers. Of course, that innovative independent domestic Chinese firms employ many foreign-trained workers is no surprise. Past research suggests that the most successful spin off firms may originate from employees of the most successful incumbent firms (Klepper, 2007). Likewise, in their study of the rise of Japan's cotton spinning industry, Braguinsky and Hounshell (2016) find that the dominant players were ultimately "private entrants with visionary entrepreneurs guided by the first generation of educated engineers that stemmed from direct contact with state-of-the-art sources in England." Of course whether this spillover of human capital was an indirect result of the JV system is debatable as market forces could have also driven multinational firms to localize R&D and production activities and train local engineers (Brandt & Thun, 2010).

6.3 Local Institutional Support Has Cultivated Diverse Laboratories of Innovation

As they have in many other industries in China (as well as other countries), local governments have provided preferential support for local firms in the PEV industry. Our cases reveal that these practices may be providing protected, often physically distinct incubation environments where firms are incentivized to experiment with a greater variety of innovations. Each case study firm has combined their capabilities with the support from their local governments to support entry and sustained existence in local markets. The specific mechanisms of support and the histories and thus existing capabilities of each case firm are quite different, which at least partially explains some of the diversity of observed innovations.

Chery is responding to both national and local incentives, such as subsidies, to produce a highway ready BEV to compete with conventional vehicles in lower-tier cities where prices may be more influential than brand. While most BEVs designed by foreign automakers are priced in higher segments, Chery is focusing its R&D on designing and producing a compact, lower-cost BEV that, when combined with subsidies, is priced lower than many gasoline vehicles in the market. Chery has benefited from the support of the local Wuhu city government which has helped maintain a protected local market. For example, local taxi companies have been required to purchase Chery gasoline vehicles, and when Chery was transitioning from a parts manufacturer to an automaker, the local government helped insulate Chery from central government investigation while it (illegally) produced vehicles without a production license. During and immediately following the 2009 "Ten Cities Thousand Cars" program, many of the cities and provinces carried out similar local market protection by restricting subsidies to locally-produced models (Wan et al., 2015). Although today the central government now denounces these practices, some cities still maintain them in more subtle forms. For example, given that Beijing Auto makes a BEV but not a PHEV, it is no surprise that local Beijing subsidies are restricted only to BEVs.

Haike is responding to demand for higher energy efficiency hybrid drivetrains at lower cost than conventional hybrid electric drivetrains that have not yet been brought to China and are protected by strong patent thickets. They are adapting an existing high-tech, niche (formula racing) product for low-cost mass production, and they have been able to tap into many local resources, including city-level government support in free office rent and low-cost pilot production facilities. By locating in Changzhou, they have also gained access to a wealth of experienced, low-cost R&D

engineers and an experienced, low-cost local supply chain that has been able to reverse engineer critical components at low cost within a very short time frame.

Jiayuan is responding to demand for low-cost personal mobility that provides greater comfort and flexibility over less expensive alternatives, such as electric two-wheelers, but at dramatically lower cost and greater convenience than conventional vehicles. The needs of this low-cost micro vehicle segment have historically not been able to be served with conventional internal combustion engine technologies (with perhaps the exception of India's Tata *Nano*). Jiayuan is combining its decades-long experience in vehicle, motor, and controller design with localized production support in the form of free or subsidized production facilities provided by local governments to serve local markets. In addition, local governments are allowing LSEV makers like Jiayuan to operate in a regulatory gray area where LSEVs can be manufactured, sold, and operated on local roads without requiring consumers to have a driver's license or a license plate. This lack of regulatory engagement at the city and, in some cases, provincial (e.g. Shandong) level is enabling rapid adoption of LSEVs.

Kandi is responding to demand by urban consumers who want the conveniences of *driving* a car but without the cost or inconveniences (such as obtaining a license plate and parking space) of *owning* one in crowded Chinese cities. Kandi is well-positioned to build relationships with local electric power providers and regulators that have been critical for establishing their business model, such as the historical ties between Kandi's CEO and local PEV and car sharing initiatives in Hangzhou. These relationships have enabled Kandi to secure access to parking and charging infrastructure that is necessary to operate their innovative business model. Kandi has also benefited from national and local subsidies for its BEVs, including those operated in the car sharing service.

These results suggest that local institutional support such as market protection and numerous forms of subsidies may be serving as incubators for a variety of innovations by independent domestic firms in their early development stages. While the longer-term effect of this incubation is uncertain, past literature on differences between national and regional innovation systems has suggested that there may be opportunities for complementary outcomes. Breznitz & Murphree (2011) and Nahm (2014) both find that although investments made by local governments in manufacturing capabilities instead of riskier R&D capabilities were made for the more immediate benefit of local businesses, the longer-term outcome has resulted in new forms of innovation capabilities in mass manufacturing. In a similar manner, the variety of new innovations observed in China's PEV industry may also be an unexpected result of institutional support for local businesses and opportunism on the part of entrepreneurial independent domestic firms. Of course, whether *more* or *more successful* innovations would have emerged in the absence of local protection remains unknown.

6.4 Policy Implications

Past research makes compelling arguments for the benefits of greater experimentation in early phases of R&D efforts (Nelson, 1961; Scherer, 2011). Nelson (1961) argues that conducting parallel efforts may be an efficient strategy "in situations where there is considerable uncertainty—generally situations in which major technological breakthroughs are being sought," and also that there are many advantages to having multiple decision making units. While Nelson and Scherer's work is targeted at R&D efforts within large firms, past historical examples suggest that the idea of parallel experimentation could be important for reaching breakthroughs in whole industries. For example, in their examination of the emergence of the semiconductor industry, Holbrook et al. (2000) found having multiple, different firms distinguished by their capabilities and approaches in the market enhanced the rate of technical advance as a whole. Similar parallel R&D efforts are on-going across multiple nations (including in multiple U.S. national labs) in the race to develop the next "super battery" (Levine, 2015).

In China's PEV industry, we have observed an innovation landscape made up of many regional markets characterized by heterogeneous consumer needs and local institutional protection of local firms. Combined with a national JV institution that creates disincentives for multinational firms to enter the industry, these regional markets have become protected laboratories for independent domestic Chinese firms to experiment with a variety of innovations. While this wide variety of experimentation may have been an unintentional result of idiosyncratic features of China's setting, arguably fostering a diversity of innovation by cost effectively deploying public resources is a desirable aim. Other industrializing nations could consider encouraging greater experimentation by providing regions greater autonomy in supporting local players for local markets as a strategy for taking a first step from imitation to innovation in emerging industries.

Nonetheless, researchers have also argued that eventually exposing firms to global competition is important for sustaining a strong national innovation system in the long term

(Amsden & Chu, 2003; Nelson, 1993). Similar arguments have been made specifically in the context of technology catch-up (Brandt & Thun, 2010; Feng, 2010) and the need to transition from regional to national markets in China (Meyer, 2008). In some cases, the challenges to expanding beyond China's protected regional economies has led firms to strategically enter foreign markets before expanding domestically in pursuit of more efficient institutions (Boisot & Meyer, 2008). It is thus unclear if the current protection from JV firms in the PEV industry will harm independent domestic firms in the longer term by preventing them from gaining exposure to foreign competition or incentives to compete in the global marketplace. One pathway towards greater national market integration may be to facilitate standardization at the national level, similar to the cases of wind and solar energy (Lewis & Wiser, 2007), but this approach must be weighed against the potential to prematurely limit promising innovations. For example, research has shown that mandating the use of specific technologies (perhaps as an effort to standardize an industry) can constrain innovation and even destroy important markets for the development and adoption of new technologies (Dudek, Stewart, & Wiener, 1992; Jaffe & Stavins, 1995; La Pierre, 1976; Stewart, 1991). If such local laboratories for experimentation as found in this paper indeed prove fruitful, further work needs to be done in identifying pathways for transitioning from local experimentation to national integration.

7. Conclusions

A vast literature has attempted to understand the factors necessary to enable and encourage experimentation and innovation in technologically sophisticated emerging industries, but less is known about how these processes unfold in industrializing nations. Industries in these nations often lag behind the technological frontier for incumbent technologies and processes, focusing industrial policy on how to achieve "leapfrogging" to gain market share in the domestic and eventually global market. We apply inductive, grounded theory-building techniques to capture and better understand the emergence of divergent innovation trajectories in China's PEV industry. We find that national and local institutions combined with the historical path dependencies of firms has constructed a domestic market characterized by local laboratories of experimentation by independent domestic firms in China's emerging PEV industry.

Vehicle sales, archival, and interview data reveal that independent domestic Chinese firms are leading China's PEV industry, and four in-depth case studies illustrate a diversity of innovation and experimentation with respect to vehicle technology and organizational and business strategies. This experimentation contrasts with that of the multinational and Chinese arms of JV firms in the same industry. In contrast to past research that finds national JV regulations are hindering domestic innovation in the established automotive industry (Howell, 2016; Nam, 2011), we find evidence that national institutions, in particular, the formal JV system and local content requirements, are creating disincentives for multinational firms to bring PEV technologies to their JV firms and inhibiting the capabilities of Chinese JV partner firms to independently develop their own PEVs. Independent domestic firms have capitalized on the resulting protected PEV market. In parallel, local institutional support such as additional market protection and multiple forms of subsidies have turned regional markets into protected laboratories, extending incubation periods for independent domestic firms to experiment with a variety of innovations. China's domestic market is both diverse enough in consumer needs and large enough in size to sustain such a variety of innovations within the same industry.

While China's market and institutional environment may have (perhaps even unintentionally) enabled independent domestic Chinese firms to capture the majority of the emerging PEV market, continuing in this direction could undermine extended domestic and even international growth (Barwick et al., 2016). Researchers have argued for the need to transition from regional to national markets in China (Boisot & Meyer, 2008; Meyer, 2008; Wei, Xie, & Zhang, 2017). The lack of functional national charging standards, for example, could inhibit the ability of firms to expand to other domestic markets, and the lack of exposure to foreign competition could inhibit their expansion into international markets. Future research should identify pathways for making the transition from regional experimentation to national integration. In addition, it is important to note that modern PEVs are relatively new to the world, and established global automotive firms have not had decades to master PEV design, production, and marketing. Recognizing the important role that institutions can inadvertently play in shaping the decisions of would-be innovators has implications for industrial policy design. It can also shed light on conditions that could enable (or inhibit) large-scale technology transitions led by new or unexpected players from the developing world.

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Appendix

Table 4: Summary of Interviews by Organization and Interviewee Position

Category	Organization	Position	Number of Interviews	Total Length of Interview(s) (min)
Case Study Firms	Chery NEV	CEO	2	90
		Founder / Former CEO	1	80
		CTO	1	200
		Chery Vice President	1	60
		Senior Engineer	1	60
		Vehicle Platform Technology Director	1	60
		Project Manager	1	60
		Engineer, Project Manager	1	60
		Engineer, Project Manager	1	60
		Program Executive Director	1	120
		Program Manager	1	120
		Program Manager	1	60
		Production Manager	1	60
		Production Manager	1	60
	Jiayuan EVs	Co-Founder / CEO	2	150
		Co-Founder / CTO	2	315
		Senior Engineer	2	85
	Haike Technologies	Co-Founder / CEO	2	410
		Co-Founder / CTO	1	50
		Production Manager	1	30
	Kandi Technologies	Manager	1	120
		Charging Facilities Manager	1	60
JV Firms	JV Firm 1	Senior Manager	1	80
		Senior Manager	1	60
		Senior Manager	1	70
		Senior Manager	2	165
	JV Firm 2	Senior Manager	1	120
	JV Firm 3	Researcher	1	60
		Production Manager	1	120
	JV Firm 4	Production Manager	1	120
	JV Firm 5	Senior Engineer	1	80
Other	University	Professor	1	60
		Researcher	1	60
		Researcher	1	50

		Researcher	1	45
	Non-profit	Director	1	60
		Researcher	1	60
		Researcher	1	60
	NDRC (Gov't)	Researcher	1	60
Other	SIC (Gov't)	Researcher	1	60
	Consultant	Battery Technology Expert	1	90
		Senior Manager, Electric Motor Supplier	1	60
		Technology Sourcing Manger	1	120
		Industry Expert / Former Automotive CEO	1	70
	Newspaper	Reporter	1	35