Paper to be presented at
the DRUID16 20th Anniversary Conference
Copenhagen, June 13-15, 2016

Up, Down, and Sideways: Innovation in China and the Case of Plug-in Vehicles

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Abstract

Scholars have previously disagreed on the types of innovation occurring with firms in China; while some suggest firms predominantly conduct process innovations in mass manufacturing, others point to emerging forms of product-process co-development occurring further downstream in technology commercialization and redefinition. Our findings suggest that the innovation environment in China may be richer and more diverse than these previous scholars have suggested. We conduct four case studies on firms developing plug-in vehicles (PEVs) and components in China. Using sales data, news reports, and 34 qualitative interviews with automotive managers and engineers, government officials, researchers, journalists, and industry consultants, we identify three distinct directions of innovation with respect to the frontiers of vehicle technology and organizational and business strategies. Our findings suggest that the interaction between national and regional regulatory regimes, a large heterogeneous market, and historical path dependencies of firms may be supporting a rich and diverse innovation environment in China's PEV sector. Specifically, while national institutions such as the joint venture system may be inadvertently discouraging innovation and diffusion of PEV technologies in both the foreign and domestic arms of joint ventures, regional institutions may be insulating independent domestic Chinese firms from foreign and domestic competition, allowing a wide variety of

innovations to flourish. The size and heterogeneity of China's market may be large enough to sustain demand for the large variety of innovations. As domestic firms grow beyond their protected regional markets, national institutions may need to evolve to support national standardization of policies and PEV infrastructure.

Jelcodes:O31,L10

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Submission for the DRUID 2016 Conference

February 29, 2016

1. Introduction

In recent years, the Chinese government, motivated by rapidly increasing energy demand and limited oil and natural gas reserves, has promoted policies for energy efficiency and research investments in new energy-saving technologies. At the same time, China has also become home to distinct forms of industrial innovation that often occurs downstream in technology commercialization and redefinition (Breznitz & Murphree, 2011; Ernst & Naughton, 2008, 2012; Herrigel, 2010; Nahm & Steinfeld, 2014; Nahm, 2012). Some evidence suggests that these two themes could be synergistic; that is, despite having less stringent requirements in WTO negotiations (WTO, 1979), developing nations like China that receive large amounts of foreign investment may be able to successfully reduce pollution while contributing to advances in industrial innovation (Wheeler, 2001).

Given this context, this paper describes how institutional and market forces within an industry (automotive) are associated with the directions of innovation that firms are taking with respect to an emerging technology sector (plug-in vehicles). In this study, we are not interested in *invention*, or the creation of new ideas, but rather *innovation*, defined as "a continuous learning process in which firms master and implement the design, production and marketing of goods and services that are new to them, although not necessarily new to their competitors—domestic or foreign" (Metcalfe & Ramlogan, 2008). This definition of innovation follows closely to that of Nahm & Steinfeld (2014) who suggest that innovations are not about the "newness" of an idea, technology, process, or organizational strategy, but rather about their ability to command commercial value in the marketplace. Indeed the context in which firms are innovating will be of central focus throughout this paper.

With this broader definition of innovation, we aim to bring attention to the richness of China's innovation environment for plug-in vehicles (PEVs) which, in combination with potential greater consumer willingness to accept PEVs (Helveston et al., 2015), could yield some distinct advantages in terms of realizing the potential energy and environmental benefits of PEV adoption (Lang et al., 2013; Zhou et al., 2013) while also developing industrial leadership in emerging technologies and business models. Our goal is not to make causal claims but rather to derive new theoretical insights on what factors are associated with differences in the directions of

innovation observed in China's PEV sector using inductive grounded theory-building techniques (Eisenhardt, 1989; Glaser & Strauss, 1967).

To explore China's PEV innovation environment, we conduct four case studies on firms developing PEVs and PEV components in China. Our data sources include numerous news reports and 34 qualitative interviews with automotive managers and engineers, government officials, researchers, journalists, and industry consultants. In addition to identifying three distinct directions of innovation ("up", "down", and "sideways") with respect to the frontiers of automotive technology and organizational and business strategies, this study investigates the historical path dependencies of firms as well as the roles of institutional and market forces in shaping the innovation environment.

2. Literature

2.1 The Influence of Institutions and Markets on Innovation

A large volume of research[1] has investigated a variety of factors that shape the innovative activity and performance of firms, including market characteristics (Altenburg et al., 2008; Arrow, 1962), industry dynamics (Brandt & Thun, 2010, 2016; Chang & Wu, 2014), organizational structure and firm size (Schumpeter, 1942; Teece, 1996), national and regional institutions (Casson et al., 2010; Kafouros et al., 2015; Li, 2009; Nelson, 1993; North, 1990), resource availability (Rosenberg, 1994; Srinivas & Sutz, 2008), and combinations of these (Chang & Wu, 2014; Coriat & Weinstein, 2002; Kline & Rosenberg, 1986). While diverse and rich in its findings, this literature provides two particularly helpful lenses with which to study innovation in the context of China: 1) market structure and dynamics and 2) institutions (both formal and informal).

Most scholars see innovation as an economic activity influenced at least in some part by market structure and dynamics within the context of other constraints (Arrow, 1962; Dosi, 1982; Schumpeter, 1942). Kline & Rosenberg (1986) suggest that a successful innovation involves an organization's ability to balance market needs with those of a product's design and manufacturing processes. Since innovation is a tool used to satisfy market needs, it is no surprise

[1] Cohen (2010) provides a comprehensive review of the empirical studies on factors that influence firm innovative activity and performance.

that characteristics of the targeted market, such as its size (Acemoglu & Linn, 2003; Altenburg et al., 2008; Desmet & Parente, 2010) and the number of firm or product competitors competing for that sized market (Arrow, 1962), can determine firms' gains from innovation.[2] While these studies suggest that larger, more competitive markets lead to increased innovation, others argue that the monopolist faces greater incentives to innovate in order to avoid losing its market power to new entrants (Gilbert & Newbery, 1982; Schumpeter, 1942), and increased competition can lead to declining R&D intensities (Dasgupta & Stiglitz, 1980). Importantly, innovation need not necessarily be about developing new technologies; it can also be about identifying "new perceptions of market opportunity" (Metcalfe & Ramlogan, 2008). The significance of the market on innovation becomes perhaps even more apparent in conditions of scarcity; Srinivas & Sutz (2005) show examples of how innovations can sometimes occur *because of* rather than *despite* scarcities. Since the market in China is large and heterogeneous yet exists in the context of a developing nation, its role in shaping the innovative behavior of firms remains uncertain.

The literature on institutions argues that institutions, or "the [formal and informal] rules of the game in society" (North, 1990) influence national and regional innovation systems and therewith the innovative performance of national firms (Freeman, 1995; Nelson, 1993). The basic premise is that institutions and organizations (here the teams that coalesce to win, given the rules) are mutually influential and co-evolve over time. This complex co-evolution can lead to an "institutional competitive advantage" by some nations or regions over others (North, 1990; Coriat & Weinstein, 2002). Past studies compare institutional variation to explain corresponding variation in the innovative performance of firms (Kafouros et al., 2015; Li, 2009), variation in entrepreneurial outcomes (Armanios et al., 2012; Eesley et al., 2013; Eesley, 2009), and variation in the rate and direction of innovation in general (Scherer, 1980). As Srinivas & Sutz (2005) write, "Innovation in isolation, if it ever existed, is a rare event: innovation is not only contextual in the sense of being, eventually, specific to a context, but in the sense that the process of innovation takes place within a context." In studying innovation in China, it remains uncertain whether the institutional context within which innovation occurs has enabled or hindered innovation throughout China's rapid economic growth of the last few decades.

[2] Notably, this is not intended to dispute the argument that the size and structure of the market can be socially constructed.

In the context of China, there is evidence that market and institutional forces are both playing a significant role in shaping the innovation environment. On the market side, Brandt & Thun (2010) suggest that recent shifts in market focus from export-oriented to domestic consumption could be responsible for the deepening levels of technological upgrading amongst domestic Chinese firms as they fight with higher-tech foreign firms to grasp stronger holds in middle market segments. Altenburg et al. (2008) suggest that the shear size of China's domestic market has enabled firms to accumulate more capital and therefore be able to invest more in R&D, hire highly skilled workers, and purchase large amounts of embodied knowledge. They also point out that China's market characteristics are highly attractive for foreign direct investment (FDI), which can also facilitate technology transfer and upgrading.

On the institutional side, Herrigel (2010) discusses how China is developing an environment of "industrial co-development" through the emerging capabilities of Chinese manufacturers to add value during the process of translating and integrating technology systems from idea to mass production (Nahm & Steinfeld, 2014; Nahm, 2012). Research has also suggested that differences and conflicting interests between China's national and regional innovation systems (Breznitz & Murphree, 2011) can lead to decisions that support local businesses at the expense of national-level plans for industrial upgrading and increased innovative capabilities (Marquis et al., 2013; Nahm, 2014). In contrast, our findings suggest these institutional differences may also be *encouraging* innovation by insulating local firms during early incubation periods. Huang (2008) argues that China has remained successful in achieving phenomenal economic growth despite such institutional inefficiencies by accessing neighboring efficient institutions, such as the financial institutions of Hong Kong.

Inevitably, market and institutional forces are mutually influential and co-evolve over time. Recent research in China provides evidence of this co-evolution. Brandt & Thun (2016) illustrate how regulatory policy in China that restricts demand within certain market segments can (perhaps inadvertently) "knock a rung out of the developmental ladder" by inhibiting market dynamics important for fostering innovation. In this paper, we find the opposite effect in that by restricting the behavior of foreign automakers, China's automotive regulatory policies may be providing market protection for independent domestic firms in the PEV sector, allowing for a variety of innovations to flourish.

2.2 The Many Types of Innovation in China

China's rapid economic growth has made it a focal nation for studying innovation and the evolving role developing nations are playing in the global production of goods. A review of the literature on this topic suggests that scholars disagree on the types of innovation occurring in China. One body of research suggests that China is playing the typical developing nation role in Vernon's classic product cycle (Vernon, 1966) where innovation centers around imitation, product modularization, and cost reduction (Brandt & Thun, 2010; Branstetter et al., 2014; Ge & Fujimoto, 2004; Steinfeld, 2004, 2010). These observations remain consistent with the theory that the most sophisticated and technologically advanced products tend to originate in the most industrially advanced nations and later become standardized and commoditized in developing countries. However, an emerging body of literature is now challenging this traditional view, suggesting that China is playing a larger, more complex, and more important role in the fractured global production of goods where opportunities for adding value are growing, often coming further down stream in the commercialization process. Some show how Chinese firms are creatively taking advantage of increasingly globalized production environments to catch up and compete with global leaders (Ernst & Naughton, 2008, 2012). Others highlight how Chinese firms are adding value along the production chain through incremental process innovations (Puga & Trefler, 2005) as well as by becoming an integral part of the commercialization process of new products (Breznitz & Murphree, 2011; Herrigel, 2010; Nahm & Steinfeld, 2014; Nahm, 2012).

The studies supporting the traditional product cycle argument suggest that China is trapped in the lowest value segments of global supply chains where new-product innovation is rare. Steinfeld (2004, 2010) argues that the ability of global firms to increasingly codify, digitize, modularize, and transmit complex design information has left Chinese firms operating in "shallow networks" where competition revolves around cost cutting rather than innovation. Ge & Fujimoto (2004) illustrate how the "quasi-open" architecture of motorcycles manufactured by Chinese firms has paradoxically led them to achieve the largest production volume in the world yet remain technologically stuck imitating focal models of Japanese firms. Bottom-up coordination efforts of suppliers enabled Chinese motorcycle assemblers to acquire imitated "components transformed as standard parts that can be ordered via catalogues," resulting in lowered production costs, new opportunities for parts interoperability, and weakened incentives

to conduct long-term R&D (Ge & Fujimoto, 2004). Furthermore, a network failure (Amsden & Chu, 2003) amongst Chinese motorcycle assemblers left knowledge about components dispersed amongst suppliers, leaving the industry victim to the "modularity trap" posed by Chesbrough (2003) where manufacturers lack the collective knowledge of how to evolve the overall system. Albeit through different mechanisms, Brandt & Thun (2010) identify similar behavior where indigenous Chinese firms in automotive, construction equipment, and machine tool industries have reengineered focal models of foreign competitors to create products with "good enough" functionality and substantially lower cost, allowing them to slowly gain market share and deepen their technological capabilities.

These previous examples of Chinese firms "down marketing" global products suggest that Chinese firms still lag behind the most advanced industrial economies in new-product innovation capabilities. Rather than dispute these claims, other researchers have drawn attention to different types of innovative behavior in China. For example, Ernst & Naughton (2008) describe how Huawei, a giant Chinese information technology (IT) company, capitalized on it's competitive advantage of lower cost R&D labor to become a leader in the Chinese IT market. Rather than compete at the technological frontier, Huawei combined incremental and architectural innovations to develop integrated communications systems that met the essential needs of operators at lower cost than higher performing mainstream competitors. By remaining flexible and open, Huawei also accelerated it's learning through collaborative agreements with universities and global industry leaders (Ernst & Naughton, 2008). Modular transformations in the global telecommunications industry have also provided Chinese Integrated Circuit (IC) firms the ability to "source" technological know how and services from Taiwanese semiconductor firms to enter China's thriving *shanzhai*[3] ("no brand") budget smart phone market (Ernst & Naughton, 2012). These examples highlight new areas where Chinese firms are entering the global production chain and brining new products to the market.

More recent research has shown how the specialization of Chinese firms in mass production and product commercialization goes beyond process or incremental innovation (Puga & Trefler, 2005) and has led to an entirely new environment of industrial co-development (Herrigel, 2010) where Chinese producers have become an integral part of the innovation process from invention

[3] 山寨： Literally "mountain village" or "mountain stronghold," the term *shanzhai* refers to the regions where bandits conduct business, far away from official control.

to commercialization, changing China's comparative advantage as a nation that can export increasingly high-quality and sophisticated goods. Indeed the ability of Chinese manufacturers to translate and integrate technology systems from idea to mass production often goes overlooked as an important innovative capability of Chinese firms (Breznitz & Murphree, 2011; Nahm & Steinfeld, 2014; Nahm, 2012). Breznitz & Murphree (2011) argue that it is precisely these innovative capabilities in product commercialization that may be the key to sustainable economic growth for China's future. In addition, Nahm & Steinfeld (2014) have observed "multidirectional, simultaneous learning...as overseas and Chinese firms cooperate to overcome challenges associated with the commercialization of emergent technologies," suggesting that these relationships go far beyond limited views of "inventor" and "manufacturing contractor" and rather towards partners in the innovation process.

Throughout the whole literature on innovation, the scholarly perspectives still largely suggest that China's primary role in innovation is the scale-up of products and their production. Indeed, this focus on China's key role in process innovation (e.g. Utterback & Abernathy, 1975) and product adaptations for scale-up in many ways strays not that far from Vernon's original product cycle. Other common themes across this literature, such as the interplay between the modularization (Baldwin & Clark, 2000; Henderson & Clark, 1990) and globalization of production, likewise stay in this vein of process innovation for scale-up and commercialization, and thus in a sense, the latter part of the product cycle.

This investigation into theory on innovation in China illustrates the diverse views of China's role in the global production of goods. While such theories have clear differences, perhaps the most interesting aspect is that they all very well could be simultaneously true within China. These previous studies cover extreme ranges in industry maturity, market focus (export-oriented versus domestic Chinese market), and political and institutional support for industries, yet they often leave out the historical evolution that has lead to current market and institutional conditions. In a nation with such large, diverse, and rapidly changing markets and institutions, considering the impact of historical contexts and market-institution co-evolution could help explain the observed diversity of innovative activity, ranging from the traditional product cycle role of low-end mass manufacturing to complex new product commercialization and co-

development with leading global inventors. In this study, we unpack how these forces co-evolve to examine the variety of innovative behavior within one industry sector— PEVs.

3. Background

3.1 The Rise of China's Automotive Industry

Over the last decade, China has rapidly grown to become the largest passenger car market in the world, with annual sales growing from approximately 4 million in 2005 to nearly 20 million in 2014 (OICA, 2015). The size and growth of China's vehicle market should not be expected to stop soon; with approximately one-fifth of the world's population, China has just 80 vehicles per thousand people compared to the U.S. which holds less than five percent of the world's population but nearly 800 vehicles per thousand people (National Bureau of Statistics of China, 2014; The World Bank, 2014; Worldometers, 2015). Figure 1 shows the rapid growth rate of China's automotive industry relative to that of the United States, the world's second largest auto market.

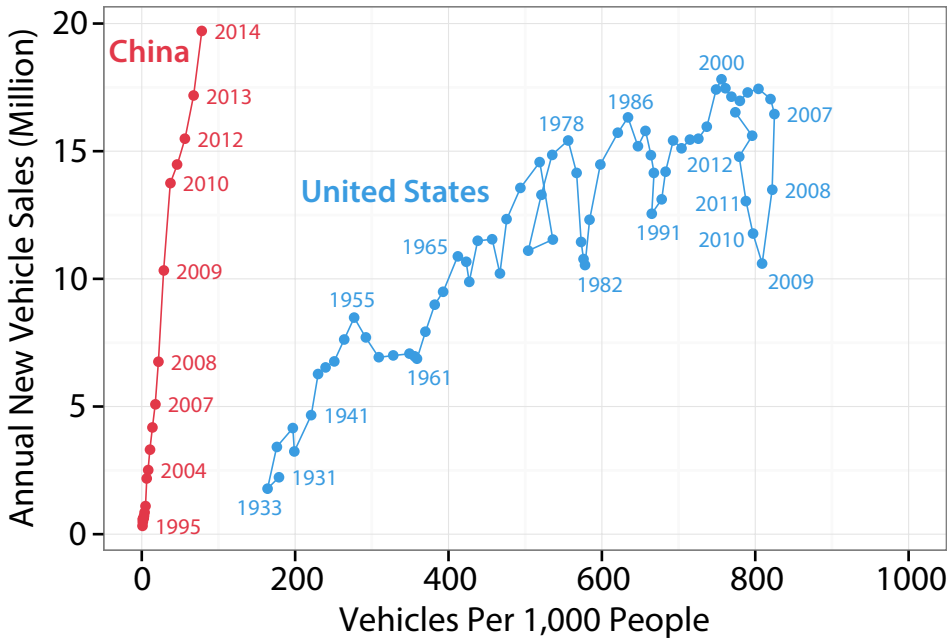


Figure 1: Growth in Chinese and U.S. passenger vehicle sales and ownership (National Bureau of Statistics of China, 2014; The World Bank, 2014).

3.2 The Drive for Plug-in Vehicles in China

Domestic PEV development has become a cornerstone of recent Chinese automotive policy, as illustrated by the central government's remarkably ambitious target of deploying half a million PEVs by 2015 and 5 million by 2020. PHEVs have a gasoline engine and small to medium battery pack and electric motor used to improve fuel efficiency, mostly through regenerative braking, engine downsizing, engine shutoff at idle, and power management. The battery can be charged by plugging into an electrical outlet, providing a short range (usually less than 40 miles) of electric-only driving before switching to gasoline for an extended range. BEVs run purely on electricity and do not use gasoline. They have large battery packs and large electric motors and must be plugged in to an electrical outlet to charge. Low-speed EVs (LSEVs) are a particular subset of BEVs that use older technologies, such as lead acid batteries, and sell at lower prices, often around RMB 30,000 (< USD$5,000). These vehicles do not qualify for any government incentives and typically have maximum speeds of less than 80 km/h and driving ranges of around 50 – 80 km. Figure 2 summarizes these technologies.

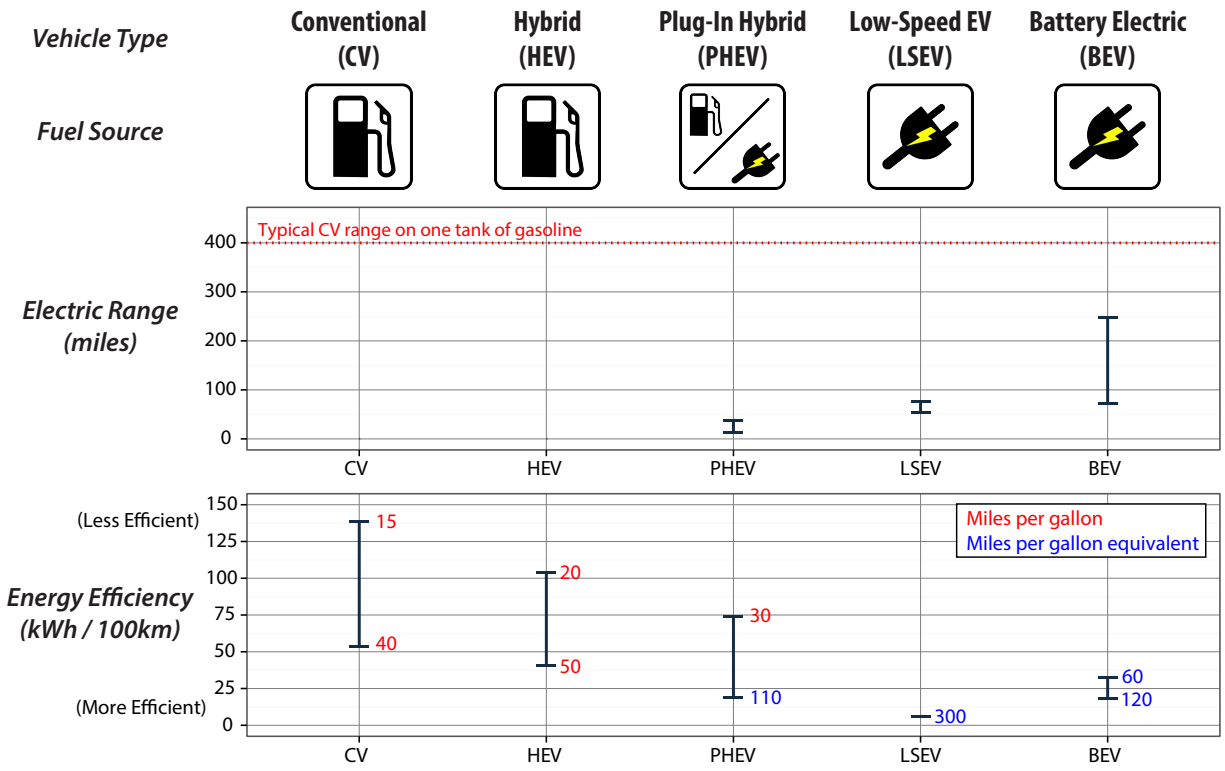


Figure 2: Summary of electrified vehicle technologies.

PEVs have become strategically attractive due to their unique position as a technology that promises solutions to three critical national priorities: energy security, environmental sustainability, and technological leadership. Passenger vehicles are the largest driver of China's rapidly increasing demand for oil and consume approximately half of all crude oil used in China (Ma et al., 2012). China also now imports approximately 55% of it's annual oil usage (U.S. EIA, 2014b), the majority of which comes from the Middle East and travels through the Malacca Straits, leaving China in a strategically risky situation (U.S. EIA, 2014a)[4]. Shifting the primary vehicle fuel source from oil to electricity could change this trajectory. Passenger cars are a major source of harmful local pollutants such as volatile organic compounds, SO_2, and NO_x (Lang et al., 2013) and also contribute to China's rising greenhouse gas emissions. However, with seventy-five percent of China's electricity coming from coal-fired power plants, PEVs may actually on average increase greenhouse gas emissions (Huo et al., 2013; Shen et al., 2014), although results would vary widely by region (Zhou et al., 2013). .

[4] While slightly outdated, Lee & Shalmon (2007) provide an excellent overview of the energy security implications regarding China's search for oil.

Many Chinese policy makers view PEVs as a strategic opportunity to gain a position of technological leadership. In essence, this is the concept of "leapfrogging"—the idea that Chinese firms could become world leaders in PEV technologies without the costly need to develop technical capabilities in traditional vehicle technologies. China's State Council has linked this vision to its economic development plans, which emphasize industrial upgrading to higher technologies and higher value added roles in global production chains (Howell et al., 2014; State Council, 2012). The fulfillment of this vision rests on the innovative capabilities of Chinese firms. Previous studies challenge whether China's fragmented auto industry has the capacity to develop world-class PEV technologies (Howell et al., 2014), while others suggest that China may be just as close as other nations in the global race to develop a PEV industry (Tillemann, 2015).

4. Methods

We derive new theoretical insights on innovation in China's PEV industry through inductive grounded theory-building, iterating between theory and quantitative and qualitative data (Eisenhardt, 1989; Glaser & Strauss, 1967). Our unit of analysis is firms in China's PEV sector. Our analysis explores in particular 1) the emergence of multiple forms of innovation simultaneously occurring within China's PEV sector, 2) the dynamics of these patterns of innovation, and 3) the different market, policy, and institutional features that may work to support or oppose these patterns. Rather than seek causal relationships, our purpose is to build theory. By describing the multiple innovation patterns observed in China's PEV sector, we aim to contribute to the ongoing debate on the innovative capabilities of Chinese firms and the interplay between markets, policy, institutions, and innovation in China.

Our analysis rests on two data sources: news reports and semi-structured interviews. We conducted 34 semi-structured interviews between May 2014 and July 2015 with a variety of stakeholders in China's PEV industry, including managers and engineers at automotive firms (including JV, JV Parent, and independent firms), university researchers, non-profits, government experts, consultants, and reporters. Interviewees were contacted through a combination of a snowball technique (previous interviewees introduced future interviewees) and cold-calling different sources. Table 1 below summarizes the set of interviewees.

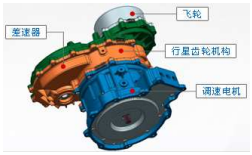
Table 1: List of Interviewees by Category, Position, and Date

Organization	Position	Summer 2014	Summer 2015	Total
Automotive Firm	Founder/CEO		2	**2**
	Manager	4	7	**11**
	Senior Engineer		6	**6**
	Engineer		4	**4**
	Researcher	1		**1**
Consulting Firm	Consultant		2	**2**
Government Org.	Analyst	2		**2**
News Outlet	Reporter		1	**1**
Non-profit	Consultant	1	1	**2**
	Researcher	1		**1**
University	Researcher	2		**2**
Total:		**11**	**23**	**34**

5. Case Studies

We examine four domestic Chinese firms innovating in the PEV sector. The firms represent the three previously described innovation directions and 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). Table 2 summarizes the four firms. For each firm, we discuss its historical evolution and innovation direction in China's PEV sector.

Table 2: Overview of Case Study Firms

	Chery	Haike	Jiayuan	Kandi
	eQ BEV	Flywheel Hybrid Transmission[5]	*Lingzu* LSEV	BEV Car Share Tower
Flagship EV Product:				
Year Est.:	1997	2012	1982	2012
Ownership & Funding:	Wuhu Gov't	Private Investors	Private (Crowd sourced)	Private Investors (KNDI)
Tech. Origins:	Auto parts	Formula racing	BEVs	Batteries, CVs, BEVs
Products:	CV, BEV, PHEV	Flywheel Hybrid Transmission	LSEV, BEV	BEV, Car Share Service
2014 Domestic Sales:	357,585 CVs 8,605 BEVs	NA	NA	BEV Car share: Hangzhou (20k), 9 other cities (14k) BEV Sales: 11k
2014 Exports:	108,238 CVs	NA	500 BEVs	NA
2015 Milestones:	5,337 BEVs Jan. – Jun.	Begin pilot production	Obtain license, begin LSEV sales	~20k BEV sales, car share in 9 cities

Within these cases, we observe three distinct innovation directions. Firms innovating "up" are those that advance the technological frontier to enter new markets; firms innovating "down" are those that combine or redefine older technologies in innovative ways to enter new markets; and firms innovating "sideways" are those that combine technology with new organizational and business strategies to enter new markets. Figure 3 shows how our four case study firms as well as JV firms[6] align with these innovation directions.

[5] Image from http://www.chk-net.com/en/images/productbanner.jpg

[6] While some JV firms are innovating in different ways, we refer to the majority of them as a general category here.

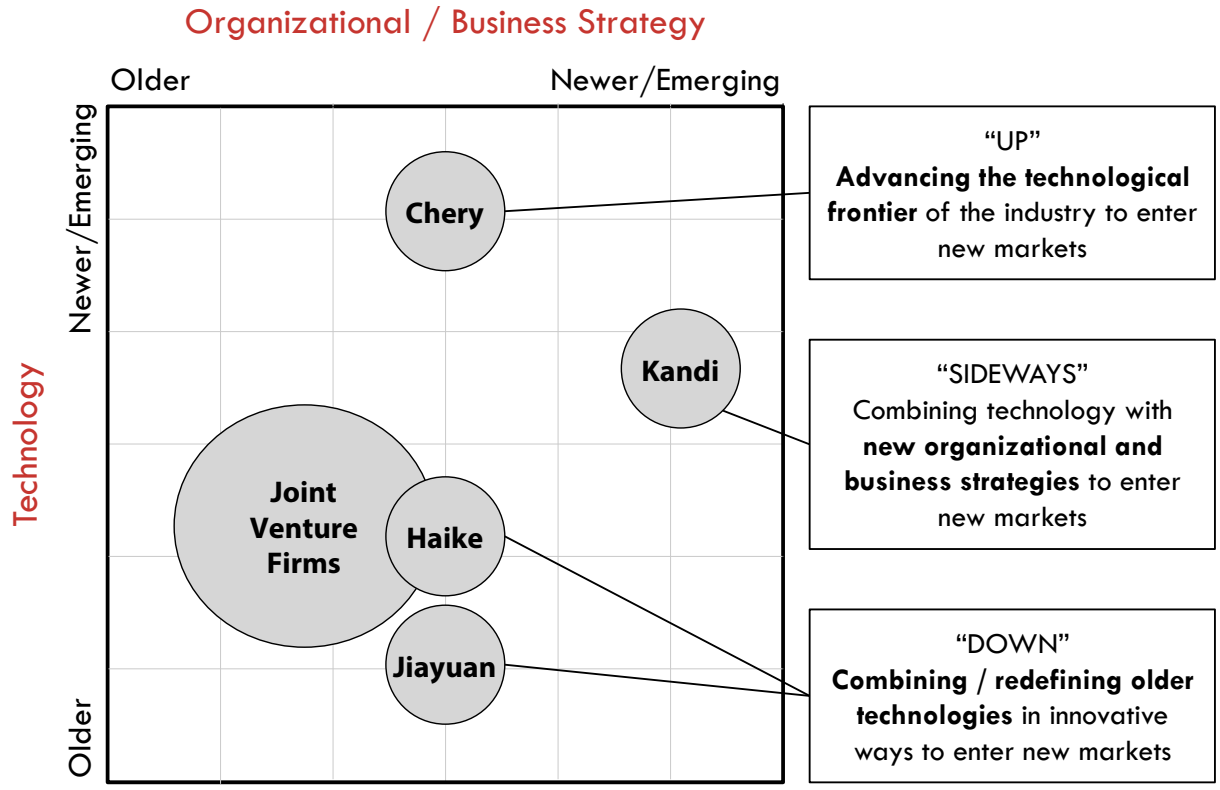


Figure 3: Case study firms innovating in different directions: Up, Down, and Sideways.

5.1 Chery Automotive

脚踏实地: "Stepping on Solid Ground"[7]

5.1.1 Historical Evolution: From Leveraging Local Connections to Developing Technical Capabilities by Learning by Doing and Hiring

Chery was founded on January 8, 1997 as Anhui Automotive Part Industrial Company (AAPIC) with a registered capital of 4.8 billion Yuan, headquartered in Wuhu, Anhui Province. Without a license from the central government, Chery illegally began producing vehicles in 1999, and since they could not be sold elsewhere, the Wuhu government required local taxi fleets to purchase them. After discovering this, the central government ordered Chery to shut down. To maintain legitimacy, Chery partnered with Shanghai Automotive (SAIC) to use their license, giving up 20% ownership to SAIC and re-naming the firm "SAIC-Chery Automobile Company." After acquiring it's own production license, Chery broke ties with SAIC in 2003 to regain independence (Feng, 2010; Luo, 2005; Ma et al., 2006). Chery has since grown into one of

[7] The Chinese idiom *jiao ta shi di* literally means "to step on solid ground"; figuratively, the phrase means working hard and focusing on the fundamentals will lead to steady, continual improvement.

China's largest independent 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. With an R&D force of over 6,000 engineers, Chery conducts ground-up vehicle design for conventional, hybrid, and PEVs.

Chery's technology capabilities evolved from a technology imitator to a technology integrator with a strong R&D force. Rather than simply outsourcing design work to automotive suppliers, Chery used its relationships with global auto suppliers as conduits for gaining technical skills and know how. As one assistant manager to the president put it, "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 first engine brand with self-owned intellectual property rights, the ACTECO engine line, by hiring 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 most R&D was managed and conducted within Chery's automotive R&D center in Wuhu with AVL supplying technical assistance when needed (Feng, 2010). The collaboration produced 3 engine designs developed for 18 vehicle models. During that same period, Chery's R&D grew from approximately 500 engineers to nearly 3,000 (Luo, 2005). Other examples of successful collaborations include their first hybrid vehicle developed with British automotive consulting firm Ricardo in 2006, leading Chery to be the only Chinese automaker to showcase a hybrid vehicle in the 2008 Beijing Olympics[10]. 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. Chery has also co-developed exterior designs with Italy-based Pininfarina, designers for Ferrari, and Bertone, designers for Lamborghini.

Chery also acquired skills and know how by aggressively hiring experienced technical experts and managers in the automotive industry. Many of Chery's early engineers came from the R&D centers of large state-owned enterprises (the Chinese parent firms of foreign JV firms). Since the foreign half of the JV firms conducted the majority of technical R&D, the underutilized

[8] Complete knock down plants assemble vehicles using kits that contain every component needed for assembly.
[9] Interview 15.
[10] Interviews 16 & 17.

Chinese engineers at the JV parent firms were eager to join Chery to take on the challenge of independently developing Chinese vehicles. Even Chery's president and CEO, Tongyao Yin, was a 12 year veteran and star engineer at FAW as manager of the FAW-VW Jetta plant (Luo, 2005). Over 100 FAW workers left to join Chery to develop the A11 *Fengyun*, Chery's first model, a variant of the SEAT *Toledo* based on the VW *Jetta*. Much of the R&D work for the three initial models released in 2003 was done by engineers from Dongfeng (another large state-owned automaker with whom Volkswagen shares a joint venture).

Chery also aggressively hired "sea turtles,[11]" or highly talented Chinese engineers and managers who left China in their youth to study or work abroad before returning to China later in life bringing deep technical and managerial know how. Sea turtles were often hired as high-level managers. 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). Some of these sea turtles, the so-called "*Qianren*,[12]" which a former senior engineer at Chery referred to as, "secret weapons," were actually given 1 million RMB by the central government after an extensive application in exchange for returning to China to help domestic Chinese firms[13]. These individuals proved critical when making decisions on where to focus their technical efforts and prioritizing what problems to solve in order to achieve rapid timelines to the start of production.

5.1.2 Innovating "Up" with BEVs

Chery is one of the few firms in China successfully mass-producing and selling an independently developed BEV. Chery began its first electric vehicle project in 2001. When just 4 years old, the firm received a 100,000 RMB research grant from China's 863 national R&D program administered by the Ministry of Science & Technology to conduct R&D on PEVs[14]. Since then, Chery has been continuously awarded grants from the central government to support its PEV development. With the success of previous alternative drive train vehicles such as the

[11] The name refers to the fact that sea turtles always return to their home beach where they were born to reproduce after living a long life away at sea.

[12] 千人: Literally "Thousand Person," the term means people who have a "thousand" talents or capabilities—a very experienced or senior-level engineer or manager often with a highly technical background.

[13] Interview 33.

[14] Interview 23.

hybrid vehicle developed with Ricardo, Chery began developing a BEV project (the S18) in 2006, which resulted in the Riich *M1* BEV that went on the market in 2010[15].

Targeting city people who only need a simple car, Chery has focused on making a smaller, affordable BEV that would be priced with other smaller cars (under 100,000 RMB, after subsidies). To achieve lower costs, Chery has developed a common platform for their *eQ* BEV and *QQ5* conventional gasoline vehicle that share components, including the chassis. They also follow the Toyota Production System, employing a mixed production line and integrating BEV assembly into the same line with gasoline vehicles to utilize existing plant capacity, enabling higher economies of scale in the production of many components despite low overall BEV volumes. The combination of common platform designs with flexible use of production lines has enabled Chery to develop and deliver a serious BEV. While high battery costs from two different Chinese suppliers still make the BEV *eQ* more expensive than similarly sized conventional vehicles, current subsidies bring the price down to under 100,000 RMB (~USD$15,000) and even lower in some cities with the addition of local subsidies. For comparison, Chery's gasoline-powered QQ sells for 40,000 – 55,000 RMB (~USD$6,000 - $8,300).

5.2 Haike Technologies

大巧若拙, 大道至简: "Dumbing Down is the Way Up"[16]

5.2.1 Historical Evolution: Redefining and Commercializing Technology for China's Market

Haike Technology is a hybrid transmission startup firm founded in 2012 based in Changzhou, Jiangsu Province. Although the startup has just 15 employees, nearly all came from senior level engineering positions and have Ph.D. degrees, and 4 of them are *qianren* sea turtles. For comparison, Haike has more *qianren* sea turtles than many of the large state-owned enterprises that have thousands of employees[17].

Haike is commercializing a hybrid transmission that uses a mechanical flywheel and electric motor to recover energy losses during vehicle braking. When decelerating, the transmission

[15] Interview 18.
[16] The Chinese idiom d*a qiao ruo zhuo, dadao zhijian* means intelligent people often seem slow-witted. Haike's founder used the phrase to describe their commercialization strategy of "dumbing down" to meet market needs.
[17] Interview 26.

transfers the vehicle's kinetic energy to a heavy flywheel, spinning it up to a high rotation per minute. The flywheel keeps spinning while the vehicle is stopped, and then during acceleration energy is transferred from the flywheel back to the transmission to power the wheels, accelerating the vehicle without use of its engine. The system is capable of achieving similar energy savings to those of more common hybrid vehicles such as that of the Toyota *Prius*, which uses an electric motor and battery to reduce fuel consumption by as much as 30% compared to conventional gasoline vehicles, but the flywheel does it at substantially lower cost (as much as 50% less than a conventional electric hybrid).

Early applications of the flywheel hybrid technology were originally developed for large stationary energy storage used in accelerating and decelerating light rail systems. In 1991, Chrysler developed an early vehicle application in a racing hybrid called the *Patriot* that utilized a flywheel as an energy storage device. During the 1990s, concerns over safety ultimately led to western governments, including the United States and England, refusing to grant research funding on the technology in favor of focusing instead on battery technology for energy storage.[18] The primary concern was the ability to safely control the extreme amounts of energy stored in the spinning flywheel that, as one of Haike's engineers put it, "…was like taming a wild animal…and if it gets out of control it could kill people.[19]"

Frustrated with the lack of interest in the technology in the west, Haike Technologies founder Dr. Frank Liao, brought the idea to China along with the technology's inventor and patent holder from the U.K., Chris Ellis, to commercialize it for China's vehicle market. Dr. Liao is a "*Qianren* sea turtle" with over 20 years of experience in automotive engineering in the U.S. His initial attempt to introduce the technology to Beijing Automotive's New Energy Vehicle department, where he was serving as chief technology officer, failed as the Beijing Automotive's leadership sought different technology directions[20].

Confident in the technology, Dr. Liao looked to the favorable environment in Changzhou to establish Haike New Energy Technology as a new high-tech startup. While discussing the decision to locate their headquarters in Changhzou, one of Haike's senior managers said, "When

[18] Interviews 26 & 34
[19] Interview 26
[20] Interview 33.

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. Not just us, but the other players…the cities do have the freedom to back the winners they choose.[21]" Haike Technologies rent their pilot production plant from the Changzhou government at a highly reduced rate and also have been given free office space from which to run their business in the startup phase.[22]

5.2.2 Innovating "Down" with Flywheel Hybrid Transmissions

Although the technology origins dates back to the 1990s, the flywheel hybrid transmission has never been commercialized for the passenger vehicle market and is exclusively used in Formula racing in the U.S. 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 design to mass production. The goal is not to develop a system comparable to those used in racing but rather a simple system that can achieve energy savings at substantially reduced cost compared to existing electric hybrids. As a result, Haike is focused on designing the system architecture rather than high-end components.

Haike's flywheel design provides a good example of the types of tradeoffs Haike engineers are making. Racing flywheels reach high rotational speeds on the order of 50,000 rotations per minute (RPM); however, the complex manufacturing processes and lack of reliability associated with these designs has made them a challenge for mass production and safety over the product's lifetime. Instead, Haike is using a much simpler flywheel with a lower rotational speed (just 20,000 RPMs) and coupling it with an electric motor for precision control. This choice still stores an adequate amount of energy but enables a simple, safe, and highly reliable design that is less expensive to mass-produce. Dr. Liao described this type of design innovation with a Chinese idiom: "*da qiao ruo zhuo, dado zhijian*," meaning "dumbing down is the way up.[23]"

[21] Interview 34.
[22] Interview 26.
[23] Interview 26: "大巧若拙, 大道至简。"

5.3 Jiayuan Electric Vehicles:

存在就是合理的：“If It Exists, It Must be Reasonable”[24]

5.3.1 Historical Evolution: Licensing and Delayed Market Entry

Jiayuan Electric Vehicles is a father-son business headquartered in Nanjing, Jiangsu Province, with an established history in designing and selling BEVs. The CEO’s father, Professor Li, began developing BEV motors and controllers in the 1970s. After studying automotive engineering and manufacturing, his son returned home to found Jiayuan, to earn money to fund his father’s research. During the 1990s, Jiayuan expanded and began developing a number of BEVs, ranging from small sedans and SUVs to mini buses. During this period, 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. In the 2000s, Jiayuan explored other domestic markets that did not require an automobile production license, such as electric sightseeing buses for tourism. In 2012, Jiayuan began developing a new BEV aimed at a new burgeoning domestic market—*disu diandong qiche*[25], or “low-speed EVs” (LSEVs).

The LSEV market is by far the fastest-growing segment in China’s PEV market, selling an order of magnitude greater in volume than highway-ready PEVs (427,000 LSEVs in 2014 compared to just 49,000 BEVs and 30,000 PHEVs). Firms entering the LSEV market vary widely in their technical, engineering, and design capabilities, ranging from rural farmers with limited manufacturing experience to firms with decades of experience in PEV development. Many (if not all) of these vehicles do not fall into any particular regulatory category for motor vehicles, and as a result most can be operated without a license plate or even a driver’s license, streamlining their rapid adoption. They are usually limited to local roads and restricted from highway use. Due to their rapid sales, local governments are simply allowing them to be bought, sold, and operated without regulatory oversight. One senior engineer at Shanghai Automotive

[24] The Chinese idiom *cun zai jiu shi heli de* is often translated as "what is rational is real, and what is real is rational," meaning that if it exists then it must be reasonable. The phrase is also often used to describe the current regulatory approach to LSEVs.

[25] 低俗电动汽车：Literally translate to “Low speed electric vehicle.”

used a Chinese idiom to explain the government's view towards LSEVs: "*cun zai jiu shi heli de*," meaning "if it exists, then it must be reasonable."

LSEVs are particularly popular in two areas: rural towns (in particular in Shandong province) and in inner cities. The relatively low incomes, lack gasoline infrastructure, and broad availability of electricity in China's rural areas make LSEVs well suited to meet the needs of farmers and other rural citizens. In inner cities, even with higher incomes and abundant fueling stations, vehicle ownership can be onerous and expensive. Many large, Tier I cities restrict driving in certain areas to only every other day and limit vehicle registrations with monthly caps, employing lottery or auction systems to distribute license plates. In Shanghai, for example, license plates can be auctioned for as much as 100,000 RMB (USD $15,600), higher than the price of many cars. Since LSEVs do not require license plates (at least for now), they are a popular option for city dwellers that want personal mobility but cannot afford the price or hassle of owning a conventional gasoline vehicle.

5.3.2 Innovating "Down" with Low-Speed EVs

By combining existing technologies in a new way, Jiayuan is capitalizing on their years of experience designing BEVs and entering the emerging LSEV market with an attractive 2-seater, the *Lingzu*, aimed at urban centers. With attractive features, Jiayuan's *Lingzu* falls between the discomfort of a bicycle or e-bike and the expense and hassle of owning a conventional gasoline vehicle. Jiayuan is also not only focused on China's domestic market. Their LSEV was intentionally designed to be 2.2 meters long to maximize how many can be fit into a standard international shipping container and 1.2 meters wide to be able to fit between standard sidewalk and bike lane barriers[26].

Perhaps one of the most interesting aspects of Jiayuan is their funding structure. Jiayuan used crowdsourcing to raise 20 million RMB (USD$3.1 million) to construct its pilot production facilities. Calling their structure a "McDonalds model," early investors can later operate their own small franchised manufacturing facilities and sell their own Jiayuan LSEVs. Thus rather than offer investors stock options, they instead are given full franchises, from manufacturing to sales, leaving the parent firm's responsibility to only new product development.

[26] Interview 32.

5.4 Kandi Technologies:

异曲同工：“Different Tune, Equally Melodic”[27]

5.4.1 Historical Evolution: Right Place at the Right Time

Kandi Technologies is a relatively new BEV firm founded by chairman and CEO Xiaoming Hu in 2007 and headquartered in Hangzhou. Prior to founding Kandi Technologies, Chairman Hu had over two decades of experience in China’s automotive industry, climbing the ladder from engineer to top-level management. He served as the General Manager of the Yongkang Vehicle Company, the Wanxiang Electric Vehicle Developing Center, and the Wanxiang Battery Company, the Chinese firm that purchased American lithium ion battery manufacturer A123. With his deep technical and managerial experience in the BEV industry, Chairman Hu developed a vision for China’s BEV industry focused on solving the infrastructure and business model challenges associated with BEVs.

Originally manufacturing go-karts and all-terrain vehicles, Kandi Technologies began manufacturing BEVs in 2012 with a strategic plan to operate a car-sharing rental service. The traditional model of selling BEVs has faced several important barriers to adoption in China such as high prices (primarily due to high battery costs) and a lack of parking and charging availability. While the central government has attempted to overcome the former challenge with heavy subsidies, the latter remains unsolved since most city dwellers live in high-rise apartments and are limited to street parking or underground garages. As a result, owning and operating a BEV remains impractical in many Chinese cities since fully charging a BEV can take as much as 10 hours or more, depending on the battery capacity and charging rate.

Kandi’s success has relied upon the support of local governments as well as the state-owned State Grid Corporation of China, China’s largest power supplier. In fact, considering Hangzhou’s extensive history of experimenting with PEV projects, it is no surprise that Kandi chose it as its headquarters. In 1999, the Zhejiang Provincial government established the Zhejiang Electric Car Project Working Group, which in 2002 was inherited by the Zhejiang Wanxiang Electric Vehicle Development Center. Chairman Hu led the first of these projects in 2006, one year before founding Kandi. In 2005, the Hangzhou Government began assessing the viability of EV

[27] The Chinese idiom *yi qu tong gong* means different approaches can also lead to equally satisfactory results.

demonstration programs. In 2006, the Hangzhou Power Authority began constructing charging stations for EVs. In 2009, Hangzhou was selected by the central government as one of the "Ten Cities, Thousand Vehicles" PEV demonstration cities, allocating subsidies to PEV buyers in Hangzhou.

With this strong local support, Chairman Hu had the backing needed to implement the ideas developed at the Wanxiang EV Development Center into a BEV startup (M. Chang, 2011). Some of the center's research can directly be seen in Kandi today, such as the vehicle swap system (based on the battery swap system) as well as a patented side-loading battery swap system in Kandi's K10 two-seater BEV. In 2011, Kandi was awarded a contract to lease 20,000 of its BEVs in the city of Hangzhou as a pilot car-sharing program. In addition to subsidies received by the central government in the amount of 60,000 RMB (U.S.$9,400) per BEV, the Hangzhou Government also provided 800 million RMB (U.S. $126 million) in subsidies to purchase the cars.

5.4.2 Innovating "Sideways" with BEV Car Sharing

Rather than attempt to improve BEV technology, Kandi is overcoming high prices and infrastructure challenges by innovating on the business model and infrastructure around BEVs. Kandi's "Micro Public Transit" car-sharing rental service offers small two-seater BEVs for hourly rentals at just 20 RMB per hour (U.S. $3.25/hour) or long-term leases. Perhaps their most interesting innovation is the towered vehicle "vending machines" Kandi has developed to vertically store and charge their BEVs, solving both problems of parking availability and long charging times. Customers can simply swap a BEV for a freshly charged one by driving to the nearest charging tower. By focusing on business model, infrastructure, and software innovations, Kandi is taking a different pathway to introduce BEVs into the market.

In addition to Kandi's local success in Hangzhou, demand in for car sharing services should not be expected to slow down. In 2014, the city of Hangzhou followed the precedent set by Beijing and Shanghai by announcing it will restrict annual vehicle sales to just 80,000 (Bloomberg News, 2014). As other cities follow suit in China's efforts to reduce pollution, car sharing services and other alternatives to car ownership are likely to grow.

6. Discussion

The four case studies illustrate a sample of the large variety in innovative behavior amongst independent Chinese firms in the PEV sector. These observations suggest that there may be something different about China's market and innovation environment that could lead to this diversity of innovation within one sector. Based on our interview data, we hypothesize that the complex co-evolution of institutional and market characteristics as well as the historical path dependencies of firms in China's automotive industry has created an environment of constraints and incentives that have encouraged the innovations of independent Chinese firms to flourish in the PEV sector. In particular, three characteristics of this innovation environment help explain the observed diversity: 1) national institutions, such as the written JV regulatory requirements, that have inadvertently removed foreign competition, 2) local institutions, such as extreme protectionism at the local or regional level, that have supported the incubation of a diverse set of models, and 3) a large, heterogeneous market. Table 3 summarizes the impact of these characteristics for each case study firm.

Table 3: Institutional and Market Forces for Case Study Firms

	Chery	Haike	Jiayuan	Kandi
Innovation Direction:	Up	Down	Down	Sideways
Organizational / Business Strategy:	Manufacture & sell vehicles	Manufacture & sell vehicle components	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:	Early sales to Wuhu taxi fleets	Free office space, low pilot production rent	Regulatory gray area, accelerated market adoption	Relationship with Hangzhou city
Markets:	Majority: CVs, SUVs, Minority: Small BEVs	Low-cost hybrid transmissions	Majority: LSEVs Minority: BEVs	Majority: BEV car share Minority: Small BEVs

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

Ironically, while the formal JV institution was originally created to facilitate the transfer of foreign technology to domestic Chinese firms, we find that it may actually be protecting independent firms from tough foreign competition within the PEV sector. This protection is the indirect result of the interaction between the different market strategies and historical

backgrounds of the three types of automotive firms in China: JV, JV parent, and independent. The historical path dependent evolutions of these different firm types have resulted in different innovative capabilities as well as different incentives for choosing to enter the PEV sector.

While JV firms have the *potential* technical capabilities to produce PEVs, their foreign partners lack the incentives to bring that technology to China. With record profits selling traditional gasoline vehicle technologies and highly uncertain investment and intellectual property risk of bringing their PEV technologies to China, the foreign JV partners have thus far taken a minimalist approach to China's PEV sector, producing as few PEVs as necessary to meet regulatory requirements while otherwise focusing on traditional vehicles. The JV parent firms lack the technical capabilities to do so because they have based their R&D centers on the development strategies of their foreign partners. This historical interaction between foreign and JV parent firms through the JV institution has left independent Chinese firms the opportunity to enter the PEV sector with limited competition from foreign technology. With strong technical capabilities, these firms have capitalized on this opportunity and are leading in China's PEV market.

When asking Chery managers and engineers why they began exploring PEV research so early in its infancy, the consistent reply was to "capture the market opportunity" left by the international automakers.[28] Likewise, Haike employees noted how foreign automakers like Toyota that control the IP on traditional electric hybrids have not brought them to China due to the IP sharing requirements of the JV system and high import tariffs, leaving an opportunity for domestic firms to develop a low cost hybrid transmission system. In addition, the influx of nearly all of the world's most experienced automakers into China through multiple JV firms during the late 1990s and early 2000s produced a wealth of foreign-trained Chinese engineers and managers—many of which were underutilized at their respective JV firms. When Chery began searching for talent, this large human capital resource formed the foundation of its first automotive R&D center.

In addition to the national JV system, national licensing policy has also impacted the decisions of independent firms. As of July 2015, the central government passed a new licensing policy that allows firms that exclusively manufacture new energy vehicles (including LSEVs) to

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

sell their vehicles in China without a traditional automobile production license (NDRC, 2015). The introduction of this new licensing policy has enabled firms like Jiayuan with decades of experience designing BEVs to finally enter the domestic market. In interviews with Jiayuan's leadership, news that this policy was under discussion as far back as 2012 was central in their decision to begin developing a LSEV. In a similar manner to how Chery "piggy-backed" off of SAIC's license in its early phases, Kandi has also recently formed a JV with Geely, another independent Chinese automaker, to jointly develop cars and gain access to their production license.[29]

6.2 Local Protectionism and Extended Incubation

Like many other industries, China's PEV sector has been marked by extreme local protectionism, with local governments instituting policies that favor local players. By protecting the local market from outside competition and providing development support, these practices have provided local firms with extended incubation environments for many years. For example, during and immediately following the 2009 TCTV program, many of the cities and provinces protected their local markets from domestic competition by restricting incentives, such as subsidies, to locally produced models. Although today the central government is denouncing these practices, some cities still maintain them in more subtle forms. In Beijing (where Beijing Auto only makes a BEV), many of the incentives are restricted to BEVs and exclude PHEVs, while in Shanghai (where Shanghai Auto is strongly pushing it's PHEV) incentives are available to both BEVs and PHEVs. It is no surprise that in 2014 99% of Beijing's PEV sales were BEVs and 81% of Shanghai's PEV sales were PHEVs.

In addition to market protection, local governments are providing extreme development support for new energy vehicle firms. One of the reasons the founders of Haike Technologies chose to locate in Changzhou was to benefit from the local support such as reduced pilot production plant rent and free office space. Kandi's entire history is marked with strong relationships to both the city government of Hangzhou as well as many PEV R&D projects supported by local government organizations. These strong relationships have enabled Kandi to secure the necessary land and infrastructure required to successfully run their rental service, which heavily depends on developing parking and charging infrastructure. In it's earliest years,

[29] Interviews 31 & 32.

Chery also benefited from strong support by the local Wuhu city government. The city not only gave Chery an early captive market by requiring taxi companies to purchase its gasoline vehicles, but also helped insulate Chery from central government investigation while illegally producing vehicles without a production license. Without this early protection, Chery may not have transformed from an automotive parts company into a fully-fledged automaker. In contrast to direct support, local governments are (perhaps inadvertently) also helping LSEV makers like Jiayuan by allowing them to exist in a regulatory gray area. With LSEV sales booming, local governments have allowed continued LSEV sales without requiring consumers to have a driver's license or a license plate, enabling rapid market adoption.

6.3 Size Matters

In addition to its unique institutional environment, China is also home to a large, heterogeneous domestic market that is rapidly evolving over time. Both the size and diversity of consumer needs and income levels provide firms the opportunity to experiment with new ideas and products to meet the needs of a large variety of market segments. While independent Chinese firms like Chery are pursuing PEVs to grasp a market opportunity at the technological frontier, firms like Jiayuan are focusing on LSEVs at the "bottom" market segments targeting urban and rural consumers who want motorized mobility but cannot afford a traditional car. Others like Kandi are targeting urban consumers who want the conveniences of driving a car but without the cost or hassle of owning one in crowded Chinese cities. Haike is taking a different approach altogether and focusing on a low-cost hybrid transmission that could supply multiple segments of plug-in and hybrid vehicles.

The variety and, importantly, size of so many different types of consumers with different needs in China may partially explain why these firms can co-exist while innovating in different ways and directions. With a large enough population in each segment, consumer demand could be sustaining the different risks these firms are taking by entering the PEV market in different ways, which may not be the case in smaller markets.

7. Policy Implications

Our results have conflicting policy implications at the national and local levels. These conflicting tensions may be even more extreme in the context of China's goals with respect to new energy

vehicle development, namely energy security, environmental sustainability, and technological leadership. Although it is disputable whether energy and environmental goals can be achieved with PEVs (Gecan, Kile, & Beider, 2012; Huo et al., 2013; Ji, Cherry, Bechle, Wu, & Marshall, 2011; L. Ma et al., 2012; Shen et al., 2014), we propose that China's institutions may be both facilitating and hindering the achievement of China's goal of technological leadership within the PEV industry.

Unless the relationship between foreign automakers and JV parent firms changes, continuing forward with the JV institution may lead to even further gains by independent Chinese firms in this sector. Nonetheless, while protection from foreign competition may be helpful in early development stages, researchers have argued that eventually exposing firms to global competition is important for sustaining a strong national innovation system (Amsden & Chu, 2003; Nelson, 1993). Therefore while apparently helpful in the immediate term, it is uncertain how this protection will affect independent firms in the long term. Importantly, formally removing the JV regulatory *requirements* may not necessarily by itself remove the JV *institution*. Foreign automakers have been deeply invested in a path-dependent tradition of bringing conventional vehicle technologies and designs to China through JV firms for nearly two decades now with enormous investments in domestic production facilities and supply chains; as such, these highly profitable relationships between foreign and JV parent firms may continue long after the formal regulation is dissolved.

At the local level, it remains unclear how local protectionism will impact firms' capabilities for later expansion and the development of China's overall PEV sector. Although tight collaborations with local governments and power suppliers have helped new business models like Kandi's car share service, expansion into other cities could be limited by local governments restricting necessary land or infrastructure in the interest of their own local players. China has also lagged behind many other nations with emerging PEV sectors in developing national charging standards. Rather than creating a uniform standard across the country, local governments have established standards between local automakers and local charging station manufacturers. As a result, PEVs designed and manufactured in city A can rarely interface with charging infrastructure in city B—another reason why automakers have struggled to increase PEV sales outside of their home cities.

Depending on the goals of policy makers, the multiple innovation directions within China's PEV sector may or may not be desirable. If the goal is to substitute gasoline kilometers driven with electric kilometers driven, then the diversity of innovations may be a positive outcome as more market segments can be electrified. However, if the goal is to get a specific type of electric kilometers driven (such as those from BEVs or PHEVs that are closer to the technological frontier), then China may need to re-evaluate its current policies since LSEVs are currently out-selling BEVs and PHEVs by an order of magnitude. If the goal is to encourage technology "leapfrogging," then policy makers should reconsider the current automobile manufacturing license requirements that have traditionally required proven capabilities in manufacturing conventional gasoline vehicles first, delaying the market entry of firms that exclusively make PEVs. While some of these firms may not be innovating at the technological frontier, their products could play an important role in motorizing the rest of China's enormous rural population on electricity rather than gasoline, which could have greater long-term benefits in terms of reducing oil consumption and emissions as well as the economic benefits of a more mobilized population.

8. Conclusions

Scholars have previously disagreed on the type of innovation occurring with firms in China; while some suggest firms predominantly conduct process innovations in mass manufacturing, others point to an emerging and more complex form of product-process co-development that often occurs further downstream in technology commercialization and redefinition. Our findings suggest that the innovation environment in China may be richer and more diverse than these previous scholars have suggested. Specifically, we find a large heterogeneity of innovative activities within one industry sector (PEVs) with firms innovating in different directions with respect to the frontiers of vehicle technology and organizational and business strategies.

Based on news reports and 34 qualitative interviews with automotive managers and engineers, government officials, researchers, journalists, and industry consultants, we hypothesize that the historical path dependencies of firms as well as China's unique institutions and large, heterogeneous domestic market may together be providing just the right conditions for a rich and diverse innovation environment in the PEV sector. The formal JV institution provides protection from foreign competition while local protectionism provides insulation from domestic

competition, allowing multiple firms to grow in different directions during development stages. At the same time, China's domestic market is both diverse enough in consumer needs and large enough in size to sustain such a variety of products and firms within the same industry sector.

Our results suggest that China's institutions may be both facilitating and hindering the achievement of China's national goal of technological leadership within the PEV sector. While national and local institutions may have allowed independent Chinese firms to capture the majority of the emerging PEV market, continuing in this direction could undermine extended domestic and international growth. The lack of functional national charging standards could inhibit the ability of firms to expand to other domestic markets, and the lack of foreign competition could inhibit their expansion into international markets. Depending on national and local goals, policy makers should reconsider policies such as the joint venture ownership system and automobile manufacturing licensing requirements.

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