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

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Abstract

Scholars have previously disagreed on the types of innovation occurring with firms in China. 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. We observe firms innovating in three distinct directions (“up”, “down”, and “sideways”) with respect to vehicle technology and organizational and business strategies in the plug-in vehicle sector. Using sales data, archival data, and 37 qualitative interviews with automotive managers and engineers, government officials, researchers, journalists, and industry consultants, we apply inductive, grounded theory building techniques to help explain the diversity of observed innovations. Our findings suggest that while national institutions such as the joint venture system may be inadvertently discouraging innovation and diffusion of electric vehicle technologies in both the foreign and domestic arms of joint venture firms, regional institutions such as local protectionism may be serving as incubators for a variety of innovations within independent domestic firms in their early development stages. In addition, the size and heterogeneity of China’s domestic market may be large enough to enable demand for the large variety of innovations. As these domestic firms begin to grow beyond their protected regional markets, China’s institutions may need to evolve to support national standardization of policies and plug-in infrastructure.

Keywords: Innovation, Plug-in Electric Vehicles, China, Institutions, Markets
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, or, as Metcalfe & Ramlogan (2008) put it, “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.” In addition, Kline & Rosenberg (1986) emphasize that a successful innovation involves an organization’s ability to balance market needs with those of a product’s design and manufacturing processes. Thus the market context is an integral component of innovation that also distinguishes it from invention. The context in which firms are innovating will be of central focus throughout this paper.

We seek to derive new theoretical insights into the factors associated with differences in the directions of innovation observed in China’s plug-in vehicle sector using inductive grounded theory-building techniques (Eisenhardt, 1989; Glaser & Strauss, 1967). Our data sources include vehicle sales data, archival data such as news reports, and 37 qualitative interviews with automotive managers and engineers, government officials, researchers, journalists, and industry consultants. We uncover four cases of highly innovative independent domestic Chinese firms developing plug-in vehicles and plug-in vehicle components in China: Chery Automotive, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies. Chery is an independent
domestic automaker designing, manufacturing, and selling gasoline and plug-in passenger vehicles; Haike is an automotive transmission start up company developing a low-cost flywheel hybrid transmission; Jiayuan is an independent domestic automaker designing, manufacturing, and selling micro low-speed electric vehicles; and Kandi is an independent domestic automaker designing and manufacturing full electric vehicles for it’s car sharing service. Since these firms are all innovating in different subsectors of plug-in vehicles, they face different regulatory constraints and target different market segments.

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 how the historical path dependencies of firms as well as how institutional and market forces might be shaping the wide variety of innovation directions we observe amongst domestic Chinese firms in the plug-in vehicle sector.

2. Literature

2.1 The Many Types of Innovation in China

China’s rapid economic growth has made it a focal nation for studying innovation and the growing role developing nations are playing in the global production of goods. 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 product imitation, cost reduction, and otherwise the scale up and commoditization of products (Brandt & Thun, 2010; Branstetter, Li, & Veloso, 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 integral role in the fractured global production of goods where opportunities for adding value are growing and coming further down stream in the commercialization process. Recent research has highlighted 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,
Some research also shows how Chinese firms are creatively taking advantage of increasingly globalized production environments to catch up and compete with global leaders (Ernst & Naughton, 2008, 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 but nonetheless remain at the low-end of the market.

Investigations into patenting in China suggest a similar narrative where domestic Chinese firms have struggled to conduct new-product innovation. For example, in recent years large multinational corporations have increasingly established large R&D centers in China due to lower costs, especially wages of researchers and engineers (Liang & Xue, 2010; Xue & Liang, 2008). The large majority of patents granted to inventors based in China and India have been granted to local teams working for these foreign firms rather than domestic Chinese firms (Branstetter et al., 2014). Thus the rapid rise in domestic patenting over the last decade is more a
reflection of an expanding division of labor within international R&D networks than it is
domestically driven innovation.

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 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*\(^1\) ("no brand") budget smart phone market (Ernst &
Naughton, 2012). These examples highlight new areas where Chinese firms are entering the
global production chain and bringing new products to the market.

More recent research has shown how the specialization of Chinese firms in mass production
and product commercialization goes beyond incremental innovation (Puga & Trefler, 2005).
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 (Nahm & Steinfeld, 2014; Nahm,
2012), making them an integral part of the innovation process in product commercialization and
changing China’s comparative advantage as a nation that can export increasingly high-quality
and sophisticated goods. Nahm & Steinfeld (2014) describe "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

\(^1\) *shanzhai*: Literally "mountain village" or "mountain stronghold," the term *shanzhai* refers to the regions where bandits
do business, far away from official control.
innovation process. These scholars argue that this ability of Chinese manufacturers to translate and integrate technology systems for mass production often goes overlooked as an important innovative capability of Chinese firms (Breznitz & Murphree, 2011; Nahm & Steinfeld, 2014; Nahm, 2012). Indeed, 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.

Despite this vast literature on innovation in China, the scholarly perspectives still largely suggest that China’s primary role in the global production of goods focuses on process innovations (e.g. Utterback & Abernathy, 1975) and product adaptations for scale-up, which in many ways strays not that far from Vernon’s original product cycle theory. In addition, these previous studies cover extreme ranges in industry maturity, market focus (export-oriented versus domestic Chinese market), and political and institutional support for industries, but do suggest a broad range of types of innovation. In this study, we unpack how these forces are associated with a wide variety of observed innovation directions within firms in China’s plug-in vehicle sector.

2.2 Institutions, Markets, and Innovation

A large volume of research\(^2\) 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). Less literature exists on how these dynamics play out in the context of a developing country, and in particular China. Two particularly important lenses for understanding innovation in the context of China are 1) the overlay of regional and national institutions (both formal and informal), and 2) market structure and dynamics.

Institutions, or “the [formal and informal] rules of the game in society” (North, 1990) can influence national and regional innovation systems and therewith the innovative performance of

national firms (Freeman, 1995; Nelson, 1993). Institutions and organizations (here the teams that coalesce to win, given the rules) are mutually influential and co-evolve over time. Path dependency can lead to “institutional competitive advantages” by some nations or regions over others (North, 1990; Coriat & Weinstein, 2002). Indeed, institutional variation has been used 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). Institutions form part of the context within which the process of innovation occurs (Srinivas & Sutz, 2005), and it remains uncertain whether the institutional context in China has enabled or hindered innovation throughout China’s rapid economic growth of the last few decades.

Research has 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). Specifically, because local governments are dependent on local businesses for revenues, they sometimes forego riskier, longer-term investments in R&D or technological upgrading in favor of investing in capital-intensive export-oriented manufacturing facilities that attract large amounts of foreign investment and promise faster financial returns (Heilmann et al., 2013). Nonetheless, this trend may not necessarily be detrimental for innovation; in fact, some argue it has played an important role in developing different and perhaps unexpected types of innovative capabilities, such as a specialization in technology scale-up and commercialization, or “innovative manufacturing” (Nahm, 2012, 2014). Thus the current national and regional institutional differences may be producing complementary outcomes for developing indigenous innovation capabilities, even though the specific capabilities may be different from those the central government anticipated. Likewise, Huang (2008) suggests that firms in China’s rural countryside have historically been more entrepreneurial and that China has remained successful in achieving phenomenal economic growth despite internal institutional inefficiencies by accessing neighboring efficient institutions, such as the financial institutions of Hong Kong (Huang, 2008).

Within the context of institutional and other constraints, most scholars see innovation as an economic activity influenced at least in some part by market structure and dynamics (Arrow, 1962; Dosi, 1982; Schumpeter, 1942). In particular, economists have documented 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. Desmet & Parente (2010) suggest that competition increases in larger markets and facilitates more process innovations, and Acemoglu & Linn (2003) empirically show how larger current and future markets have led to increases in innovation in the U.S. pharmaceutical industry. Likewise, the “replacement effect” argument by Arrow (1962) suggests that firms in more competitive markets have greater incentives to innovate. However, others argue that the monopolist faces greater incentives to innovate in order to avoid losing existing market power to new entrants (Gilbert & Newbery, 1982; Schumpeter, 1942), and that increased competition can lead to declining R&D intensities (Dasgupta & Stiglitz, 1980).

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 continues to evolve and remains to be seen. Brandt & Thun (2010) suggest that recent shifts in market focus from export-oriented to domestic consumption could be responsible for deepening the levels of technological upgrading amongst domestic Chinese firms as they fight with higher-tech foreign firms to grasp stronger holds in middle market segments. The “fight for the middle” market dynamics encourages domestic firms in low-end market segments to invest in quality upgrading and foreign firms in high-end segments to invest in more localized sourcing and local technology upgrading to bring costs down. In addition to these dynamics, the sheer size of China’s domestic market could be enabling technology upgrading. Altenburg et al. (2008) argue that having a large market has enabled Chinese 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. China’s market characteristics are also highly attractive for foreign direct investment, which can also facilitate technology transfer and upgrading (Altenburg et al., 2008).

Inevitably, institutional and market forces are mutually influential and co-evolve over time. Recent research shows how this coevolution in China may be leading to inefficiencies in technology upgrading in some industries. Brandt & Thun (2016) suggest that regulatory policy that restricts demand within certain market segments can explain observed differences in the

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3 Notably, this is not intended to dispute the argument that the size and structure of the market can be socially constructed.
levels of technology catch-up between three industries: automotive, heavy construction equipment, and motorcycles. In construction equipment, Chinese wheel loader firms experienced nearly two decades of incubation at the low-end market segment where they were naturally protected from foreign competition, enabling them to incrementally improve their capabilities. However, in automotive the low-end incubation period was much shorter due to earlier regulatory restrictions aimed at market consolidation, which left the market focused on high-end segments controlled by foreign firms through joint ventures with domestic Chinese firms. Competition for low-end segments only came after China joined the World Trade Organization in 2001, by which time foreign firms were already entering lower-end segments and competing with domestic firms. Thus the interaction between policy and demand over time restricted the important market dynamics between domestic (low-end) and foreign (high-end) firms that is needed to foster innovation (Brandt & Thun, 2016). In this study, we observe a similar co-evolution of institutional and market forces that might be contributing to longer incubation periods for firms innovating in China’s plug-in vehicle sector.

3. Background

3.1 The Joint Venture Institution and 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.
One of the most influential industrial policies that has shaped the growth of China’s automotive industry is the strategy of *yi shichang huan jishu*⁴ (‘trading the market for technology’). The strategy opened China’s vehicle market to the outside world through the Joint Venture (JV) system, which required foreign automobile manufacturers that wished to manufacture and sell vehicles in China to create JV firms with domestic JV parent firms, usually large state-owned enterprises. By limiting foreign firm ownership of the JV to less than 50%, the aim was for the JV to serve as a technology transfer vehicle from the foreign firms to JV parent firms (Gallagher, 2006; Lu & Feng, 2005; Naughton, 2007). Despite requirements to share intellectual property and technology transfer, the JV strategy is largely viewed by scholars as a failure in terms of direct technology transfer; research suggests that the Chinese JV parent firms became dependent on their foreign partners’ technology and brands and failed to develop independent R&D capabilities (Brandt & Thun, 2010; Howell, 2016; Lazonick & Li, 2012; K.-M. Nam, 2011).

China’s entrance into the World Trade Organization in 2001 opened the floodgates to foreign direct investment through the JV system. Despite fears that newly minted independent Chinese firms that had arisen during the late 1990s and early 2000s would be crushed by

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⁴以市场换技术
competition from the powerful JV firms, these smaller firms gained a foothold by focusing on the emerging lower-cost small and mini car segments. The resulting market division between foreign JV firms capturing the mid- to high-end segments and Chinese independent and JV parent firms competing for the low- to mid-end segments remains the dominant market segmentation, with foreign and domestic companies fiercely competing for middle market segments (Brandt & Thun, 2010).

3.2 The Drive for Plug-in Vehicles in China

In its 2006 medium- and long-term plan for science and technology development, the State Council emphasized *zizhu chuangxin*⁵ (“indigenous innovation”) as the central development strategy for science and technology (S&T) industries. While this effort applies to all pillar S&T industries, the focus in the automotive industry has been characterized by a newfound support for domestic Chinese brands (compared to previous focus in the 1990s on large state-owned JV firms and market consolidation) as well as an extreme push for the domestic development of *xin nengyuan che*⁶ (“new energy vehicles”), which includes plug-in hybrid vehicles (PHEVs), battery electric vehicles (BEVs), and fuel cell vehicles (FCVs).

PHEVs have a gasoline engine as well as 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.

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⁵ 自主创新：Translated as “indigenous innovation” or “independent innovation,” the strategy (as stated by the State Council) applies to all key science and technology industries.

⁶ 新能源车：Literally “new energy vehicle” as defined by the National Development and Reform Commission to include PHEVs, BEVs, and FCVs.
Figure 2: Summary of electrified vehicle technologies.

Domestic plug-in vehicle development has recently become a cornerstone of Chinese automotive policy, as illustrated by the central government’s remarkably ambitious target of deploying half a million plug-in vehicles (PHEVs and BEVs) by 2015 and 5 million by 2020 (State Council, 2012). Plug-in vehicles 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 its 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). 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, SO₂, and NOₓ (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

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7 While slightly outdated, Lee & Shalmon (2007) provide an excellent overview of the energy security implications regarding China’s search for oil.
power plants, plug-in vehicles 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).

Finally, many Chinese policy makers view plug-in vehicles as a strategic opportunity to gain a position of technological leadership. Here, they are hoping for “leapfrogging”—the idea that Chinese firms could become world leaders in plug-in vehicle 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 plug-in vehicle 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 plug-in vehicle industry (Tillemann, 2015).

3.3 Policy Support for Plug-in Vehicles in China
The drive for plug-in vehicles has led to a multitude of policy experiments from various government bureaus. Figure 3 illustrates the key policies and programs implemented since 1995 (Gong et al., 2012; Howell et al., 2014; Zheng et al., 2012).

New energy vehicle policies are primarily managed between four ministries:

1. The Ministry of Finance (MOF): Provides funding for new energy vehicle R&D and deployment of supporting infrastructure.
2. The Ministry of Science & Technology (MOST): Promotes new energy vehicle R&D primarily through national S&T projects such as the 863 program, China’s primary S&T research funding program.
3. The Ministry of Industry and Information Technology (MIIT): Responsible for vehicle emission monitoring, standards setting (including fuel economy standards), and project appraisal for the auto industry.
4. The National Development and Reform Commission (NDRC): Sets national targets; plays a coordinating role across different bureaus for the new energy vehicle industry.

Some of the earliest new energy vehicle policies came from MOST during China’s 10th five-year plan (2001 - 2005), which established the Electric Vehicle Key Project under the 863 Program and provided $290 million for new energy vehicle development. By the 11th five-year
plan (2006 - 2010), the total funding had grown $1.5 billion through a multitude of policy experiments (Gong et al., 2012). During this period, the NDRC formally defined the focal new energy vehicle technologies and enacted the 2009 Auto Industry Adjustment and Renovation Plan, which set the ambitious target of deploying 500,000 new energy vehicles by 2011.

In response, the MOF and MOST jointly launched the 2009 new energy vehicle demonstration program known as *shi cheng qian liang*\(^8\) (“Ten Cities, Thousands of Vehicles”, or TCTV), which was China’s first effort to deploy new energy vehicles in select pilot cities, focusing on public fleet vehicles such as taxis and buses (MOF, 2009, 2010a, 2010b). Through the pilot program, the central government offered vehicle purchase subsidies while leaving local governments responsible for funding supporting infrastructure such as charging stations. Actual new energy vehicle deployment during the program fell far below government targets, totaling just 52,623 by 2012 (Gong et al., 2012). Rather than establishing a national industry sector, the TCTV program proved divisive and resulted in strong local protectionism. Most participating cities viewed the program as an opportunity to support their local automotive industry, focusing incentives on new energy vehicles produced by local automakers. During the program, a total of 76 automakers and 343 models were approved to receive subsidies, compared to just 17 automakers and 44 models available in the U.S. during the same period (Zheng et al., 2012).

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\(^8\)十城千辆：The program aimed to deploy over 1,000 new energy vehicles in each pilot city, totaling over 10,000 nationwide (hence the name).
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<th>Category</th>
<th>Policy / Event</th>
<th>Government Body</th>
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<tr>
<td>Industry Support</td>
<td>EV standard technical committee set up to develop EV standards</td>
<td>MIIT</td>
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<td>Auto Industry Policy revised; developed &quot;Energy Savings Medium- and Long-Term Plan,&quot; which sets auto industry one of top 10 pillar industries for energy conservation</td>
<td>NDRC</td>
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<tr>
<td>Market Adoption</td>
<td>十城千辆 = “Ten Cities Thousand Vehicles”: Pilot program to deploy over 1,000 PEVs in each of 10 pilot cities (USD$2.5 billion)</td>
<td>MOF, MOST</td>
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<td>Subsidies offered to private buyers for PHEVs &amp; BEVs</td>
<td>MOF</td>
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<td>Credits offered for plug-in vehicles to pass the corporate average fuel consumption standard</td>
<td>MIIT</td>
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<td>R&amp;D</td>
<td>National Electric Vehicle Test and Demonstration Zone Established</td>
<td>MOST</td>
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<td>National Clean Vehicle Action Program - HEVs &amp; Natural Gas short term, BEVs mid-to-long term</td>
<td>MOST, NDRC, MIIT, MOF</td>
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<td>“EV Key Project” included in 863 national high-tech R&amp;D program (USD$130 million)</td>
<td>MOST</td>
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<td></td>
<td>“Alternative Fuel Vehicles Key Project” included in 863 national high-tech R&amp;D program (USD$165 million)</td>
<td>MOST</td>
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<td>Strategic Planning</td>
<td>“Three Transverses and Three Longitudes”: Transverses = HEVs, BEVs, &amp; FCVs; Longitudes = powertrain, motor, and battery</td>
<td>MOST</td>
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<td>State Council adopts Science and Technology Medium- and Long-Term Development Plan</td>
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<td>NDRC defines “New Energy Vehicle” (NEV) to include HEVs, BEVs, &amp; FCVs</td>
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<td>Set sales targets of 500,000 plug-in vehicles by 2011 and 1 million by 2015</td>
<td>NDRC</td>
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<td>Auto Industry Adjustment and Renovation Plan: Set target for 5% of all new vehicle sales to be NEVs</td>
<td>State Council</td>
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**Figure 3: Key Chinese new energy vehicle policies and programs (Gong et al., 2012; Zheng et al., 2012).**
Today, 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 only to vehicles that adhere to the “Three Transverses and Three Longitudes” R&D strategy implemented by MOST (MOST, 2006). The “transverses” are three strategic vehicle technologies (BEVs, PHEVs, and fuel cell vehicles) and the longitudes are core components of these technologies (batteries, motors, and battery management systems). To qualify for subsidies, the vehicle drivetrain must use one of the “transverse” technologies, and one of the “longitude” components must be manufactured in China. Given these restrictions, many foreign automakers have been unwilling to bring their most advanced plug-in vehicle technologies to the Chinese market, such as Chevrolet’s PHEV Volt (which uses an in-house manufactured motor and control system and LG Chem batteries from South Korea), or Nissan’s BEV Leaf (which uses battery technology sourced from Japan’s NEC Corporation) (Noble, 2012). LSEVs do not qualify for subsidies, but thanks to a new licensing policy firms that exclusively produce them are finally being allowed to sell LSEVs without a traditional automobile production license (NDRC, 2015).

Finally, China’s national fuel economy standards set by the MIIT also includes incentives for plug-in vehicles. The Corporate Average Fuel Consumption standard requires each automaker to meet a minimum annual average fuel economy across it’s fleet of vehicles sold. Under the current regulation, sales of plug-in vehicles can be counted multiple times to reduce the average fleet fuel consumption. The multiplier for BEVs is set at 5 for 2016–2017 and will fall to 3 in 2018–2019 and then to 2 in 2020 while other vehicles such as PHEVs with a combined fuel consumption of 2.8L/100km can be counted 3 times (ICCT, 2014).

4. Methods

We derive new theoretical insights on innovation in China's plug-in vehicle 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 plug-in vehicle sector. Our analysis explores in particular 1) the emergence of multiple forms of innovation simultaneously occurring within China's plug-in vehicle sector, and 2) the different market, policy, and institutional features that may be working 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 plug-in vehicle 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 three data sources: vehicle sales data, archival data such as news reports, and semi-structured interviews. Since vehicle sales figures are reported by the firms themselves, we collected firm level vehicle sales data by make and model from 2003 to 2014 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 (Gasgoo.com, 2015). Since the automotive yearbooks are only published in print, the data were hand-copied. 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 between the two sources 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. We also examine over thirty news reports on China’s plug-in vehicle sector as well as over thirty domestic Chinese scholarly publications on domestic Chinese automotive firms and innovation in China.

In addition, we conducted 37 semi-structured interviews between May 2014 and July 2015 with a variety of stakeholders in China’s plug-in vehicle 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 full set of interviews. The goal of these interviews was to uncover what innovation, if any, was occurring in China’s plug-in vehicle sector, and what factors might be supporting or hindering the observed innovative outcomes or lack thereof.
Table 1: List of Interviews by Type and Position

<table>
<thead>
<tr>
<th>Case Study Firm</th>
<th>Organization</th>
<th>Position</th>
<th>Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>JV Auto Firm</td>
<td>Manager</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>JV Auto Firm</td>
<td>Engineer</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Chery</td>
<td>Independent Auto Firm</td>
<td>Founder</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Independent Auto Firm</td>
<td>Manager</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Independent Auto Firm</td>
<td>Engineer</td>
<td>5</td>
</tr>
<tr>
<td>Haik</td>
<td>Independent Auto Firm</td>
<td>Co-Founder/Engineer</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Independent Auto Firm</td>
<td>Co-Founder</td>
<td>1</td>
</tr>
<tr>
<td>Jiayuan</td>
<td>Independent Auto Firm</td>
<td>Founder/CEO</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Independent Auto Firm</td>
<td>Engineer</td>
<td>1</td>
</tr>
<tr>
<td>Kandi</td>
<td>Independent Auto Firm</td>
<td>Manager</td>
<td>2</td>
</tr>
<tr>
<td>Consulting Firm</td>
<td>Consultant</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Government</td>
<td>Analyst</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Non-profit</td>
<td>Consultant</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Non-profit</td>
<td>Researcher</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>University</td>
<td>Researcher</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>News Outlet</td>
<td>Reporter</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

5. Results

5.1 Independent Chinese Firms Are Leading China’s Plug-in Vehicle Market

We first examine the vehicle sales data collected on all passenger cars and plug-in vehicles sold in China in 2014. The box sizes in Figure 4 illustrate the relative market share by manufacturer and brand and the color indicates which type of firm the sales belong to: JV, JV parents, or independent. Of the approximately 19.7 million passenger vehicles sold in 2014, the vast majority were sold by JV firms, which collectively sold 13.9 million vehicles (70.6% of the market). JV parent firms sold 3.2 million (16.2%) and independent firms sold 2.6 million (13.2%). In contrast, independent firms dominated sales within the plug-in vehicle market, selling 46,843 (87%) of the 53,827 plug-in vehicles sold. JV parents firms sold just 6,402 (12%) and JV firms sold only 582 (1%).
Figure 4: 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).
The contrast in market shares by different firms between all vehicles and just plug-in vehicles is striking. Most prominent is the lack of plug-in vehicle sales by JV firms given their dominance in the conventional gasoline vehicle market. Our interview data revealed several forces that have likely led to this situation. First, the JV firms have followed the technological and development strategies of their foreign 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 EVs] is weak. Margins [for CVs] in the west are only 3-5%, but in China they're around 10%.”\(^9\) In contrast, foreign firms perceived bringing their most advanced electrified vehicle 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 who could later become competitors. In addition, to receive subsidies they would have to domestically source one of the “three longitude” core technologies (batteries, motors, or battery management systems). Focusing on an established product line with an established supply chain in traditional vehicles is a more conservative strategy that has resulted in high profitability and lower uncertainty.\(^10\)

Of the few plug-in vehicles produced by JV firms in China, many are simply low volume demonstrations to meet a government requirement. For example, some local governments have restricted land rights to expand JV firm manufacturing facilities unless it produces a plug-in vehicle. To meet these demands, they often retrofit a few hundred existing conventional vehicles with an electric drive train. Since these plug-in vehicles are manufactured in low volume (and often by hand), they are extremely costly and often sold at a loss (even with subsidies) as taxi fleets rather than to private consumers. Such maneuvering has enabled the global automakers to, as one former JV manager put it, “check the box”\(^11\) on making plug-in vehicles while continuing to expand their businesses in conventional gasoline-powered vehicles.\(^12\)

\(^9\) Interview 7
\(^10\) Interviews 1, 2, 7, 9, 10, 13
\(^11\) Interview 13
\(^12\) Interview 2, 7, 9, 13, 14
The lack of JV involvement in the Chinese plug-in vehicle sector has left market opportunities to Chinese automakers, both JV parent firms and independent firms. Between the two types, the independent firms have captured much larger market shares relative to JV parent firms in the plug-in vehicle market. Independent firms have now had over a decade to learn and develop R&D capabilities, whereas JV parent firms have heavily relied on their foreign partners for technical know how, focusing their R&D efforts on adapting foreign technologies to Chinese consumer preferences rather than conducting ground-up product development. In addition, past research has also shown that foreign automakers have greatly limited the transfer of technology and know-how to their Chinese JV parent firm counterparts (Howell, 2016; Nam, 2011).

5.2 Independent Firms Are Innovating in Different Directions

Our in-depth interviews revealed four examples of independent Chinese firms within China’s plug-in vehicle sector with extraordinarily different forms of innovation: Chery Automotive, Haike Technologies, Jiayuan Electric Vehicles, and Kandi Technologies. In focusing on these four firms, our intent was not to identify a representative set of all independent domestic firms but rather illustrate the range of observed innovative activities. 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 plug-in vehicle market share (see Figure 4) while Haike and Jiayuan are still in start-up phases. Error! Reference source not found. summarizes the four firms’ history, technology, and current outputs. For each firm, we discuss its historical evolution and the interaction of that history with the firm’s innovation direction in China’s plug-in vehicle sector.

We observe three distinct directions and describe them as innovating up, down, and sideways. 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 5 shows how our four case study firms align with these innovation directions.
Table 2: Overview of Case Study Firms

<table>
<thead>
<tr>
<th></th>
<th>Chery</th>
<th>Haike</th>
<th>Jiayuan</th>
<th>Kandi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flagship EV Product:</strong></td>
<td>eQ BEV</td>
<td>Flywheel Hybrid Transmission</td>
<td>Lingyu LSEV</td>
<td>BEV Car Share Tower</td>
</tr>
<tr>
<td><strong>Ownership &amp; Funding:</strong></td>
<td>Wuhu Gov’t</td>
<td>Private Investors</td>
<td>Private (Crowd sourced)</td>
<td>Private Investors (KNDI)</td>
</tr>
<tr>
<td><strong>Tech. Origins:</strong></td>
<td>Auto parts</td>
<td>Formula racing</td>
<td>BEVs</td>
<td>Batteries, CVs, BEVs</td>
</tr>
<tr>
<td><strong>Products:</strong></td>
<td>CV, BEV, PHEV</td>
<td>Flywheel Hybrid Transmission</td>
<td>LSEV, BEV</td>
<td>BEV, Car Share Service</td>
</tr>
<tr>
<td><strong>2014 Domestic Sales:</strong></td>
<td>357,585 CVs</td>
<td>8,605 BEVs</td>
<td>NA</td>
<td>500 BEVs</td>
</tr>
<tr>
<td><strong>2014 Exports:</strong></td>
<td>108,238 CVs</td>
<td>NA</td>
<td>500 BEVs</td>
<td>NA</td>
</tr>
<tr>
<td><strong>2015 Milestones:</strong></td>
<td>5,337 BEVs</td>
<td>Begin pilot production</td>
<td>Obtain license, begin LSEV sales</td>
<td>~20k BEV sales, car share in 9 cities</td>
</tr>
</tbody>
</table>

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5.3 Chery Automotive

脚踏实地：“Stepping on Solid Ground”\textsuperscript{14}

5.3.1 Historical Evolution: From Leveraging Local Connections to Developing In-House R&D Capabilities

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. Their first engine assembly line, an outdated British Ford line, was purchased in 1996 for $25 million and construction of their first engine plant began in March 1997. Against the will of the central government (which at that time strictly regulated entry into the automotive industry), the local Wuhu city government supported Chery’s growth as a vehicle manufacturer in an effort to grow the local industry. 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

\textsuperscript{14} The Chinese idiom \textit{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.
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, allegedly over a dispute with SAIC’s partner GM around the Chery QQ, a nearly identical copy of the Chevrolet Spark, a model GM had purchased from South Korea’s Daewoo (Feng, 2010; Luo, 2005; Ma et al., 2006).

Chery has since grown into one of China’s largest independent automakers with six domestic production plants and 15 complete knock down plants\(^\text{15}\) in developing nations around the world. From 2003 to 2011, annual sales grew from approximately 90,000 to 630,000. They independently design their vehicles, and their company culture is characterized by a sense of pride in being a Chinese company making Chinese cars.

Chery’s technology capabilities evolved in a similar manner to many indigenous Chinese firms, transforming from a technology imitator to a technology integrator with a strong R&D force. Chery facilitated this evolution by conducting joint R&D projects with leading automotive suppliers and consultants and aggressively hiring talented, experienced engineers and managers from international automakers and suppliers. Today, its R&D force of over 6,000 engineers conducts ground-up vehicle design for conventional, hybrid, and plug-in vehicles.

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.”\(^\text{16}\) For example, Chery jointly developed its first engine brand with self-owned intellectual property rights, the ACTECO engine line, by hiring the famous 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.

\(^{15}\)Complete knock down plants assemble vehicles using kits that contain every component needed for assembly.

\(^{16}\)Interview 15.
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. 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.

In addition to learning from international suppliers, Chery has 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 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) in an automotive design and development company founded by Chery called “Jiajing Technology Company,” of which the engineers themselves owned a 20% stake.

In addition to hiring former JV employees, Chery also aggressively hired “sea turtles,” a term used to describe 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 (often with 20 or more years of experience). Sea turtles are 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-

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17 Interviews 16 & 17.
18 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.
called “Qianren,” 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. 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.

5.3.2 Innovating “Up” with BEVs

In addition to Chery’s success in developing conventional vehicles, Chery is also 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, the same year it officially received an automotive production license. 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 electric vehicles. Since then, Chery has been continuously awarded grants from the central government to support its plug-in vehicle development. With the success of previous alternative drive train vehicles such as the hybrid vehicle developed with Ricardo, Chery began developing a BEV project (the S18) in 2006, which resulted in the Riiich M1 BEV that went on the market in 2010.

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

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19 ᚰ️․gence: 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.

20 Interview 33.

21 Interview 23.

22 Interview 18.
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).

5.4 Haike Technologies

大巧若拙，大道至简：“Dumbing Down is the Way Up”

5.4.1 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, about 100 miles northwest of Shanghai. 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.

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 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).

In addition to improving conventional vehicle fuel consumption, this technology can have a major impact on plug-in vehicles. Because a kinetic energy storage system removes the need to rapidly and frequently charge and discharge a plug-in vehicle’s battery pack during acceleration and deceleration, it reduces the required number of battery cells to drive a fixed range and elongates battery life by reducing the temperature spikes, which in turn reduces the requirements.

23 The Chinese idiom da 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.

24 Interview 26.
on the battery cooling and management system. Since the batteries remains the most expensive component of plug-in vehicles, smaller and simpler battery systems can dramatically reduce the overall vehicle cost.

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. 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.”

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. During the 1990s he worked on the first generation of the GM EV1 (an early BEV) and conducted a series of clean energy automobile projects with the U.S. Department of Energy. His initial attempt to introduce the technology to Beijing Automotive’s New Energy Vehicle department, where Dr. Liao was serving as chief technology officer, failed as the Beijing Automotive’s leadership sought different technology directions.

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 Changzhou, 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. Not just us, but the other players... each city retains something like 30 percent of all the tax revenue

25 Interviews 26 & 34.
26 Interview 26.
27 Interview 33.
generated in the city... so the cities do have the freedom to back the winners they choose\textsuperscript{28}.” 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\textsuperscript{29}.

5.4.2 Innovating “Down” with Flywheel Hybrid Transmissions

Although the technology origins of Haike’s flywheel hybrid transmission dates back to the 1990s, the technology 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 flywheel hybrid system comparable to those used in racing but rather a simple and less expensive system that can achieve similar energy savings to traditional electric hybrids but at substantially reduced cost. As a result, rather than spend resources developing complex individual components like the flywheel itself, Haike is focused on designing a simple, low-cost system architecture to quickly develop a commercially ready product for China’s domestic market.

Haike’s flywheel design provides a good example of the types of tradeoffs Haike engineers are making. Existing flywheel technologies used in racing reach high rotational speeds (on the order of 50,000 rotations per minute) to maximize energy storage capacity. However, the complex manufacturing processes and lack of established 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 rotations per minute) and coupling it with an electric motor for precision control. This choice still stores an adequate amount of energy but enables a simpler, safer, and highly reliable design that is less expensive to mass produce. Dr. Liao described this type of design decision with a Chinese idiom: “da qiao ruo zhuo, dado zhijian\textsuperscript{30},” meaning “dumbing down is the way up.”

\textsuperscript{28} Interview 34.
\textsuperscript{29} Interview 26.
\textsuperscript{30} Interview 26: “大巧若拙，大道至简.”
Another key aspect of Haike’s development process is to avoid reinventing the wheel. A crucial component to successfully and safely controlling the flywheel is the planetary gearing system originally developed by Toyota for their electric hybrid drive trains. For their first prototype, Haike engineers worked for a year with a strategic alliance of Chinese suppliers to reverse engineer components that provide the same functionality as the Toyota planetary gear system without infringing on Toyota patents. Having now mastered the production of all necessary components (a list of around 50-60 individual parts), Haike can now independently produce both the flywheel and their own planetary gearing system to control it. Efforts like these have enabled Haike to rapidly build prototypes of their design by learning from the innovations of others.

5.5 Jiayuan Electric Vehicles:

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

5.5.1 Historical Evolution: Licensing and Delayed Market Entry

Jiayuan Electric Vehicles is a market-driven firm headquartered in Nanjing, Jiangsu Province, with an established history in designing and selling BEVs. Jiayuan is a father-son business. The CEO’s father, Professor Li of Zhengzhou University, began developing BEV motors and controllers in the 1970s. After studying automotive design and engineering at a Zhengzhou technical school, his son returned home to found Jiayuan, primarily to earn money to fund his father’s research. During the 1990s (a time when global automotive firms such as GM and Toyota were also experimenting with BEVs), 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, primarily to Europe. 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

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31 The Chinese idiom cun zai jiu shi heli de can be 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.
began developing a new BEV aimed at a new burgeoning domestic market—*disu diandong qiche*\(^{32}\), or “low-speed EVs” (LSEVs).

The LSEV market is by far the fastest-growing segment in China’s plug-in vehicle market, selling an order of magnitude greater in volume than highway-ready plug-in vehicles (427,000 LSEVs in 2014 compared to just 49,000 BEVs and 30,000 PHEVs). A typical LSEV is a 4-wheeled, low-priced BEV with a maximum speed of less than 80 km/h and a limited range of around 50 – 80 km. These vehicles use older technologies, such as lead acid batteries, to keep cost down and sell for as low as RMB 30,000 (< US$5,000). 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 plug-in vehicle 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 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.

\(^{32}\)低速电动汽车：Literally translate to “Low speed electric vehicle.”
5.5.2 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, not rural towns. With attractive features, such as a large flat-screen display with navigation, air conditioning, and power windows, Jiayuan’s Lingzu fills the gap between the discomfort of a bicycle or e-bike (especially in bad weather or heavy pollution) 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.

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.

5.6 Kandi Technologies:

异曲同工：“Different Tune, Equally Melodic”

5.6.1 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, approximately 110 miles south west of Shanghai. 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. From 2003 to 2005 he served as the chief scientist and project manager for the Wanxiang Pure Electric Vehicle Development project funded by the 863 National High-Tech R&D program. With his deep technical and managerial

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33 Interview 32.
34 The Chinese idiom yi qu tong gong means different approaches can also lead to equally satisfactory results.
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 deeply 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 EVs projects, it is no surprise that Kandi chose it as its headquarters. In 2005, the Hangzhou Government began assessing the viability of EV 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” EV demonstration cities, allocating subsidies to EV buyers in Hangzhou. In April 2010, State Grid was mandated by the central government to invest in EV charging infrastructure for Hangzhou, which was selected as State Grid’s EV Business Pilot Model City.

Kandi’s origins can also be traced back to earlier EV projects in the city of Hangzhou. In 1999 (before the central government began supporting EVs), 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. The center received funding from the national 863 high-tech research program to develop four electric vehicle projects. Chairman Hu led the first of these projects in 2006, one year before founding Kandi. The projects at Wanxiang set clear development goals centered on using a battery swap system to avoid a costly charging infrastructure build out in the city and region. With the strong support received from the Zhejiang Provincial government, the Hangzhou City government, and the Zhejiang Electric
Power Grid Company, 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.

5.6.2 Innovating “Sideways” with BEV Car Sharing

Rather than attempt to improve BEV technology, Kandi is overcoming BEVs’ high price and infrastructure challenges by using existing BEV technologies and innovating on the business model and infrastructure around it. Kandi has created its Micro Public Transit car sharing rental service that offers small two-seater BEVs for hourly rental or long-term lease. Since the firm manages the high battery costs associated with BEVs, customers are offered low rental prices of just 20 RMB per hour (U.S. $3.25/hour). 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 charge times. Customers low on charge can simply swap their BEV for a freshly charged one by driving to the nearest charging tower. By shifting focus away from developing vehicle technology and instead developing 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 among independent Chinese firms in the plug-in vehicle sector. Some of this diversity could be
explained by the fact that plug-in vehicles are an emerging industry that has not yet reached a "dominant design" (Utterback, 1994), motivating firms to experiment in different ways. Nonetheless, the lack of a dominant design may not by itself go far enough to explain the sustained, simultaneous growth of a variety of innovation directions in plug-in vehicles in the presence of the largest market in the world for the overwhelmingly dominant design in the overall automotive industry (i.e. the conventional gasoline car). For comparison, innovation in the plug-in vehicle sector in the U.S. has largely been in the “up” direction with a focus on advancing the technological frontier.

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 forces 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 a variety of innovations to emerge from independent Chinese firms in the plug-in vehicle sector. In particular, we theorize that three characteristics of the Chinese institutional environment help explain the observed diversity: 1) national institutions, such as the written JV licensing regulatory requirements as well as local content 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 innovations, and 3) a large, heterogeneous national market with enough demand to enable these innovations to co-exist. Table 3 summarizes the role of national institutions, local institutions, and market characteristics for each case study firm.
Table 3: Institutional and Market Forces for Case Study Firms

<table>
<thead>
<tr>
<th>Innovation Direction:</th>
<th>Chery</th>
<th>Haike</th>
<th>Jiayuan</th>
<th>Kandi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products:</td>
<td>Up</td>
<td>Down</td>
<td>Down</td>
<td>Sideways</td>
</tr>
<tr>
<td></td>
<td>Majority: CVs, SUVs, Minority: Small BEVs</td>
<td>Low-cost hybrid transmissions</td>
<td>Majority: LSEVs Minority: BEVs</td>
<td>Majority: BEV car share Minority: Small BEVs</td>
</tr>
<tr>
<td>Organizational / Business Strategy:</td>
<td>Manufacture &amp; sell vehicles</td>
<td>Manufacture &amp; sell vehicle transmissions</td>
<td>Manufacture &amp; sell vehicles</td>
<td>Manufacture, rent, and sell vehicles</td>
</tr>
<tr>
<td>National Institutions:</td>
<td>No foreign competition; design for regulation</td>
<td>No foreign competition</td>
<td>Licensing delayed entry</td>
<td>No foreign PEV competition</td>
</tr>
<tr>
<td>Local Institutions:</td>
<td>Protection while transitioning from parts to auto maker</td>
<td>Free office space, low pilot production rent</td>
<td>Regulatory gray area allowing local adoption</td>
<td>Strong relationship with Hangzhou city</td>
</tr>
<tr>
<td>Markets:</td>
<td>Simple, affordable cars priced under 100k RMB</td>
<td>Hybrid transmissions</td>
<td>In between e-bikes and gas cars (urban &amp; rural)</td>
<td>In between e-bikes and gas cars (urban)</td>
</tr>
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6.1 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 plug-in vehicle sector it may actually be (potentially inadvertently) protecting independent firms from tough foreign competition.

When asking Chery managers and engineers—including the founder of Chery’s New Energy Vehicle R&D department—why they began exploring plug-in vehicle research so early in its infancy, the consistent reply was to “capture the market opportunity” left by the international automakers that were hesitating to develop plug-in vehicles for China. Likewise, Haike employees noted how foreign automakers like Toyota and Ford that control the patents on the most dominant traditional electric hybrid drivetrains have not brought them to China due to the IP sharing requirements within the JV system, local content requirements for subsidy eligibility, and high import tariffs (25%), leaving an opportunity for domestic firms to develop low cost alternative hybrid transmissions. 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

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2000s produced a wealth of foreign-trained Chinese engineers and managers, many of whom were underutilized at their respective JV firms; this large human capital resource formed the foundation of Chery’s first automotive R&D center.

In addition to creating disincentives for foreign firms to bring emerging plug-in vehicle technologies to China, prior studies on automotive technology transfer have shown how the JV institution has limited the R&D and innovation capabilities of Chinese JV parent firms (Feng, 2010). Nam (2011) uses a case study approach to illustrate how Chinese JV parent firms are engaged in a “passive” learning mode with their foreign partners, leaving independent innovation capabilities undeveloped (K.-M. Nam, 2011). Other research has empirically shown how the JV system has even discouraged Chinese JV parent firms from investing in products that might compete with their JV partner’s products to avoid cannibalization (Howell, 2016). Referring to JV parent firms’ dependence on foreign partners for technology and brands, former machinery and industry minister He Guangyuan famously said, “It's like opium. Once you've had it you will get addicted forever” (Reuters, 2012). The experience of South Korean automakers provides an example in a different national context in which firms also were developmentally limited by their JV relationships. 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 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).

Despite JV inefficiencies in facilitating technology catch-up in the automotive sector, other industries have experienced more success. In particular, independent domestic firms in China's telecommunication equipment industry experienced far more success at gaining domestic market share than independent automotive firms. In comparing these two industries, He & Mu (2012) highlight that opening the telecommunication equipment market to intense competition motivated domestic firms to leverage low cost inputs and focus on different market segments to increase market share. In contrast, industrial policy aimed at consolidation in the automobile industry reduced competition and gave monopolistic power to only a few JV firms with little motivation to develop new technologies (He & Mu, 2012). Some aspects of the successes of
independent firms in the telecommunications equipment industry may be analogous to those by independent firms in the plug-in vehicle sector.

National licensing policy has also influenced the decisions of independent firms. Firms like Jiayuan with decades of experience designing and manufacturing BEVs but no capabilities with conventional vehicles have unable to acquire a domestic manufacturing license, restricting them to low-volume exports. Recent policy changes allowing firms that specialize in new energy vehicles to acquire a license has influenced their development strategy and finally enabled them to enter the domestic market. In interviews with Jiayuan’s leadership, news that this policy was under discussion was a central motivation to begin developing a LSEV for domestic sale.\footnote{Interview 32.} Taking a different approach, Kandi also recently formed a JV with Geely (another prominent independent Chinese automaker) to jointly develop BEVs—a mutually beneficial relationship giving Kandi access to Geely’s manufacturing license while providing Geely with an otherwise non-existent new energy vehicle business.\footnote{Interviews 31 & 32.}

### 6.2 Local Protectionism as an Innovation Incubator

Like many other industries in China, the plug-in vehicle 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 plug-in vehicle sales were BEVs and 81% of Shanghai’s plug-in vehicle sales were PHEVs.

In addition to market protection, local governments are providing 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 plug-in vehicle 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 parking and charging infrastructure. In its earliest years, 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. Local governments are also helping LSEV makers like Jiayuan (perhaps inadvertently) 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.

These results suggest that market protection and development support provided by local institutions may be serving as incubators for a variety of innovations 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 direct benefit of local businesses, the longer-term outcome has resulted in new forms of innovation capabilities. Specifically, local manufacturing firms have become specialized in “the organization of production, manufacturing techniques and technologies, delivery, design, and second-generation innovation” (Breznitz & Murphree, 2011). In a similar manner, the variety of new innovations observed in China's plug-in vehicle sector may also be an unexpected result of local institutional support for local businesses.

6.3 Domestic Market Characteristics Matter

In addition to its unique institutional environment, China is also home to a large, heterogeneous domestic market that is rapidly evolving over time. 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 plug-in vehicles to grasp a market opportunity at the technological frontier, firms like Jiayuan are focusing on LSEVs at the low-end 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 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. With a large enough population in each segment, consumer demand could be sustaining the different risks these firms are taking by entering the plug-in vehicle market in different ways, which may not be the case in smaller markets or those with more uniform market needs. Existing theory also suggests that China’s large market size and variety of segments is crucial for innovation. Brandt & Thun (2016) argue that the market dynamics between low-end domestic firms and high-end foreign firms that fosters new innovation capabilities requires large segments at both ends of the market, otherwise low-end firms cannot gain scale and high-end firms lack incentives to localize activities. However, whereas Brandt & Thun (2016) found regulatory restrictions that shortened incubation periods for domestic firms in conventional vehicles was detrimental for technology upgrading, we find in the case of plug-in vehicles that the combination of institutional and market forces might be enabling extended incubation periods, fostering a variety of innovations to emerge.

6.4 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. From an energy security perspective, the diversity of plug-in vehicle innovations may provide more alternatives to conventional vehicles, potentially reducing oil consumption in automotive industry. However, given the wide use of coal for China’s electric grid, it is disputable whether environmental goals can be achieved with plug-in vehicles in the context of China, at least in the near-term future (Gecan et al., 2012; Huo et al., 2013; Ji et al., 2011; Ma et
For electric vehicle development to have a positive effect on the environment in addition to energy security will require complementary regulation aimed at cleaning up the energy sources for China’s electric grid.

With respect to technological leadership within the plug-in vehicle industry, China’s institutions may have thus far been facilitating the advancement of the sector, but going forward these institutions may need to evolve to avoid hindering future achievements. 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). Similar arguments have been made specifically in the context of technology catch-up in China (Brandt & Thun, 2010; Feng, 2010). It is thus unclear if the current protection from JV competition in plug-in vehicles provided by national institutions may harm independent Chinese firms in the longer term by preventing them from having the incentives to compete in the global marketplace.

At the regional level, it remains unclear how local protectionism will impact firms’ capabilities for later expansion and the development of China’s overall plug-in vehicle 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 plug-in vehicle sectors such as the U.S. and Japan in implementing national charging standards. Although a uniform national standard does exist, local implementation has followed different norms. Local governments sometimes establish their own standards between local automakers and local charging station manufacturers. As a result, plug-in vehicles designed and manufactured in city A can rarely interface with charging infrastructure in city B—another reason why automakers have struggled to increase plug-in vehicle sales outside of their home cities. Finally, pilot cities for programs like TCTV have historically been selected by the central government based on size and regional significance rather than the capabilities of their automakers. Chery Auto, based in the smaller city of Wuhu in Anhui Province, did not receive support from the TCTV program; instead, support was directed to their provincial competitor Jianghuai Automobile (JAC), located

38 Interview 13.
in Hefei, the capital and largest city in Anhui province, despite the fact that Chery’s vehicle sales were nearly 2.5 times those of JAC at the time. For these reasons, we suspect that continued, unbridled local protectionism may hinder the future growth of China’s overall plug-in vehicle sector by limiting the ability of independent Chinese firms to expand to domestic regions beyond their home cities and limiting necessary national coordination efforts such as charging infrastructure build out.

7. 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 (Brandt & Thun, 2010; Branstetter et al., 2014; Ge & Fujimoto, 2004; Steinfeld, 2004, 2010), others point to an emerging and more complex form of product-process co-development that often occurs further downstream in technology commercialization and redefinition (Breznitz & Murphree, 2011; Ernst & Naughton, 2008, 2012; Herrigel, 2010; Nahm & Steinfeld, 2014; Nahm, 2012).

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 alone within one industry sector (plug-in vehicles) with firms innovating in a wide variety of directions with respect to vehicle technology and organizational and business strategies. Specifically, 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 diverse innovation environment in the plug-in vehicle sector. National institutions such as the formal JV system as well as local content requirements provide protection from foreign competition while local institutions may be providing further market protection and development support, creating incubation periods for independent domestic 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 innovations within the same industry sector.

Since institutional protection in China’s plug-in vehicle sector has co-evolved along with it’s large, heterogeneous market, it is difficult to consider how these forces individually might affect innovation. A market with more uniform needs might lead to more uniform innovation directions
whereas a more diverse market might lead to more diverse innovation directions. In addition, the market size in each situation could impact the economic feasibility of innovations, with smaller sizes limiting the variety of feasible innovations. Stronger versus weaker institutional protections for domestic firms may lead to differences in whether market needs are met by indigenous versus foreign firms but also the length of incubation time firms have to develop innovations. Examining these dimensions may help policy makers and business leaders in other developing nations that have large, emerging markets, such as the “BRIC” (Brazil, Russia, India, and China) and “MINT” (Mexico, Indonesia, Nigeria and Turkey) nation (Sinkovics et al., 2014). As juxtaposition, even though developed nations such as the United States also have large domestic markets, the personal mobility needs and available transportation infrastructure are far more homogeneous compared to those in China. Gasoline infrastructure is readily available in urban and rural environments, consumers have fewer intercity transit alternatives, and higher incomes enable the vast majority of the population to own a conventional personal vehicle. Thus even though it’s market size is large, we would still expect to observe a more uniform innovation direction in the emerging plug-in vehicle sector (in this case, “up”).

It is also unclear whether our findings can be extended to other sectors. Whereas existing literature on technology catch-up focuses on how firms in developing nations learn and acquire existing know-how and technologies (Brandt & Thun, 2010; Feng, 2010; K. Lee, 2013; K. M. Nam, 2015), plug-in vehicles are relatively new to the world everywhere. Unlike with conventional vehicles, established global automotive firms have not had decades to master plug-in vehicle design, production, and marketing, and these firms all largely face similar technological challenges in terms of improving battery and motor performance while reducing cost. Thus given the newness of this sector, there may be less existing technology and know-how for domestic firms to acquire.

While national and local institutions may have allowed independent Chinese firms to capture the majority of the emerging plug-in vehicle market, continuing in this direction could undermine extended domestic and even 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 that might restrict market
entry, such as the joint venture ownership system and automobile manufacturing licensing restrictions.
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