The Rise of Chinese Leadership in the Plug-in Electric Vehicle Industry

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China is the world's largest market for plug-in electric vehicles (PEVs), comprising approximately half of all PEVs sold worldwide. Chinese firms also dominate China's domestic PEV market, with Tesla being the only foreign competitor able to obtain an appreciable share of the market. This outcome is the result of multiple factors that have occurred over multiple decades, including a series of strategic industrial policies going back to the 1980s as well as how those policies interacted with China's unique institutional environment. Combined with favorable market conditions, rapid infrastructure construction, and the ambition of innovative Chinese firms, China's PEV industry has rapidly evolved to become a world-leading market. This paper chronicles these various factors and discusses some implications for the future of China's PEV industry.

China is the world's largest market for plug-in electric vehicles (PEVs), which includes plug-in hybrid vehicles (PHEVs) that have electric motors and gasoline engines as well as battery electric vehicles (BEVs) that only have electric motors. In 2021, half of all PEVs sold worldwide were sold in China, the majority of which were made by Chinese automakers; in contrast, only 25% of global PEV sales were in Europe and just 9% were in the U.S. (EV-Volumes 2021). According to Bloomberg New Energy Finance, Chinese firms are also set to increase their control of the world's supply of lithium-ion batteries powering all these PEVs from 69% to 76% in the near future (BNEF 2020).

China's ascendance to a position of leadership in the global PEV industry is the outcome of multiple factors, including decades of strategic industrial policies along side a unique institutional arrangement between local and national governments and favorable market conditions for accelerating

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PEV adoption. At the same time, industry incumbents and governments in other countries with large automotive industries have under-invested in PEV technologies, components, and infrastructure, providing Chinese competitors an opportunity to grasp a first-mover advantage in multiple areas of the PEV supply chain, including raw materials, lithium-ion batteries, electronics, and electric motors. This paper chronicles these various factors and discusses implications for the future of China's PEV industry.

1 The PEV Promise: Energy Security, Pollution Reduction, and Technology Leadership

When China joining the World Trade Organization in 2001, foreign and domestic automakers raced to capture China's massive market. In just eight years, China surpassed the U.S. to become the largest vehicle market in the world, growing from selling less than 1 million vehicles in 2001 to 10 million in 2009 (OICA 2021). China also quickly became the largest *producer* of passenger vehicles, from manufacturing just 2% of the world's vehicles in 2001 to 39% in 2021 according to data from the International Organization of Motor Vehicle Manufacturers (OICA 2021).

While this rapid development was a boon for automakers and China's economy, it also introduced several important concerns for Chinese leaders. Oil consumption rapidly accelerated, and today motor vehicles consume more than half of all crude oil used in China. Nearly 75% of that oil is imported, and the majority of it comes from the Middle East via the Malacca Straits, leaving China vulnerable to disruptions in oil supplies (BP 2020). Passenger vehicles are also a major source of air pollution and carbon emissions in China. It is estimated that over half of all volatile organic compound (VOC), carbon monoxide (CO), and nitrogen dioxide NO_x now come from passenger vehicles in China (Lang et al. 2013). Transitioning from internal combustion engine vehicles (ICEVs) to PEVs promises to improve both of these negative externalities from motor vehicles: most PEVs don't consume oil, and they emit less air pollution than ICEVs in many parts of the country (with the exception being areas with primarily coal-fired electricity).

PEVs also promise an opportunity to become a global leader in the automotive industry. Since the founding of the People's Republic of China in 1949, Chinese leaders have coveted the global automotive giants like Japan's Toyota, Germany's Volkswagen, and the U.S.'s General Motors. They understood that leadership in the automotive industry is a sign of industrial might and economic prowess as well as a powerful engine of economic growth that spurs innovation, investment, and job creation. Despite their best efforts, no Chinese automakers have risen to a position of global leadership in the traditional ICEV industry. PEVs, on the other hand, offer the opportunity to produce vehicles on a leveler playing field with industry incumbents. In fact, given China's relatively mature supply chain in battery and electronics manufacturing, Chinese automakers arguably had some advantages over foreign automakers in developing early PEV models.

Given the energy security, pollution reduction, and technology leadership opportunities provided by PEVs, it is perhaps unsurprising that the Chinese government prioritized the domestic development of 新能源车 (*xin nengyuan che*, or "new energy vehicles"), which includes PHEVs, BEVs, and fuel cell electric vehicles (FCEVs). Indeed, obtaining a leading position in the PEV industry and "leapfrogging" the traditional ICEV market has been a long-standing goal going back decades and supported by several of China's most influential ministries, including the Ministry of Science and Technology (MOST) and the National Development and Reform Commission (NDRC). For example, one of the earliest PEV policies from MOST under China's 10th five-year plan (2001 - 2005) established the Electric Vehicle Key Project under the 863 Program, providing $290 million for PEV research and development. This budget grew to $1.5 billion in the 11th five-year plan (2006 - 2010) and supported a multitude of policy experiments (Gong, Wang, and Wang 2012). These early investments were followed by a series of industrial policies that have consistently aimed to accelerate the PEV industry and market.

2 Industrial Policy, Institutions, & Experimentation

The vehicle electrification effort was a centerpiece of multiple industrial policies implemented over the past several decades. But how these policies were implemented in China's unique institutional framework resulted in unexpected outcomes. While China's leaders wanted Chinese automakers to absorb PEV technology from foreign firms, the opposite happened—the suite of industrial policies implemented interacted with China's institutions in such a way to create strong incentives for foreign firms to *avoid* bringing PEV technologies to China and for domestic Chinese firms to experiment and innovate with new PEV technologies and business models (Helveston et al. 2019). This has led to a domestic PEV market and supply chain dominated by Chinese firms, with all but Tesla now playing catch up.

2.1 The Legacy of the Joint Venture System

Ironically, one of the most consequential industrial policies that impacted the composition of China's PEV market was one aimed at the traditional ICEV market: the joint venture (JV) system. Rooted in the 1980s industrial policy strategy of 以市场换技术 (*yi shichang huan jishu*, or "exchanging the market for technology"), the JV system required foreign automakers to establish separate JV firms with a domestic partner (usually a large state-owned enterprise). The goal was for the JV firm to serve as a vehicle to transfer technology from the foreign firm to the Chinese partner.

Despite technology transfer requirements like forced intellectual property sharing, research suggests that the JV system did not have its intended effect, at least in the automotive industry. Given the maturity of the traditional ICEV industry and the lack of technological uncertainty, foreign firms were able to successfully limit technology transfer to Chinese partners (Prud'homme et al. 2018; Prud'homme, Zhang, et al. 2019). Rather than absorbing technology and manufacturing know-how, Chinese partners became dependent on foreign firms for vehicle technologies and R&D expertise, leaving most Chinese partners without their own independent R&D capabilities (Brandt and Thun 2010; Lazonick and Li 2012; Nam 2011; Howell 2018; Huang et al. 2003). The failure of the JV system to transfer technology became so prominent that the former Minister of Machinery and Industry He Guangyuan said, "It's like opium—once you've had it, you will get addicted forever," referring to Chinese firms' "addiction" for foreign know-how (Reuters 2012).

While the JV system did not produce Chinese champions in the ICEV market, it laid a foundation for domestic Chinese firms to thrive in the PEV market. Given the maturity of the ICEV market, automakers were more than willing to form JV firms with Chinese partners to produce and sell ICEVs as these partners did not pose a competitive threat and in fact provided a valuable partnership for establishing a domestic, lower-cost supply chain and distribution network. But most multinational automakers were much more protective of their expensive and immature PEV technologies. This left a vacuum of foreign PEV technology in China that was ultimately filled by independent Chinese firms (those operating without a foreign JV partner). These firms had struggled for years to compete with the multinational giants in the ICEV market, but PEVs did not require the same expertise, such as complex engine and transmission design. Domestic firms like BYD, Geely, and eventually newer entrants like XPeng and NIO (often referred to as 新势力, or "the new force") quickly developed PEVs and established a market for key PEV components such as batteries and motors.

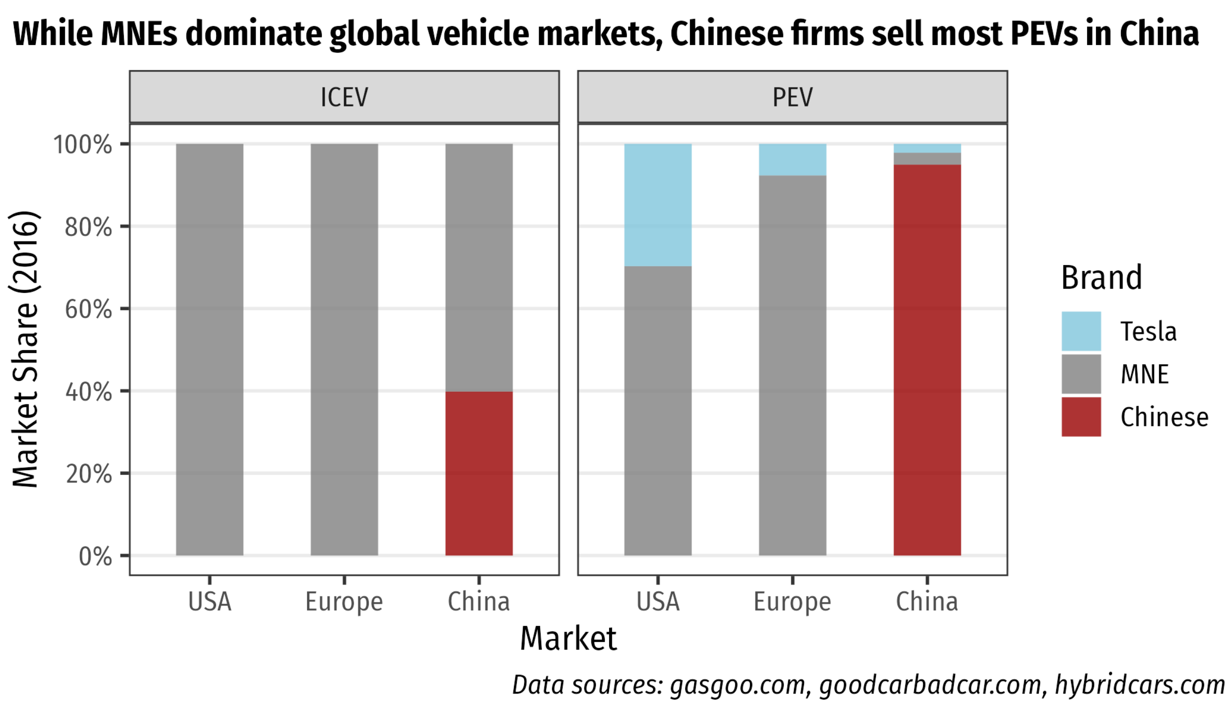

Figure 1: 2016 ICEV and PEV market breakdown by brand in the United States, Europe, and China. While MNE automakers sell most vehicles in the ICEV market worldwide as well as the PEV markets in the U.S. and Europe, Chinese firms dominate China's PEV market.

The impact of the JV system is apparent in the market shares of different categories of brands. For example, Figure 1 shows the 2016 market share breakdown of the ICEV and PEV markets by brand in the United States, Europe, and China. While multinational (MNE) firms (e.g., Volkswagen, General Motors, Toyota, etc.) sell the majority of vehicles in the ICEV market worldwide as well as the PEV markets in the U.S. and Europe, China's PEV market stands as an outlier where Chinese firms sell the vast majority of PEVs.

This trend persists today (see Figure 2), with the notable exception of Tesla's more recent success in China. Despite the allure of China's PEV market, Tesla notoriously refused to enter into a JV agreement with a Chinese automaker, resulting in low sales via imports (which face a 25% import tariff). However, when the central government announced the removal of the JV requirement for PEV manufacturing in 2018, Tesla quickly established its second gigafactory outside of Shanghai to begin mass producing BEVs. Today, Tesla is China's third-largest BEV producer, and sales in China account for approximately half of all of Tesla's annual sales worldwide (Lu 2022).

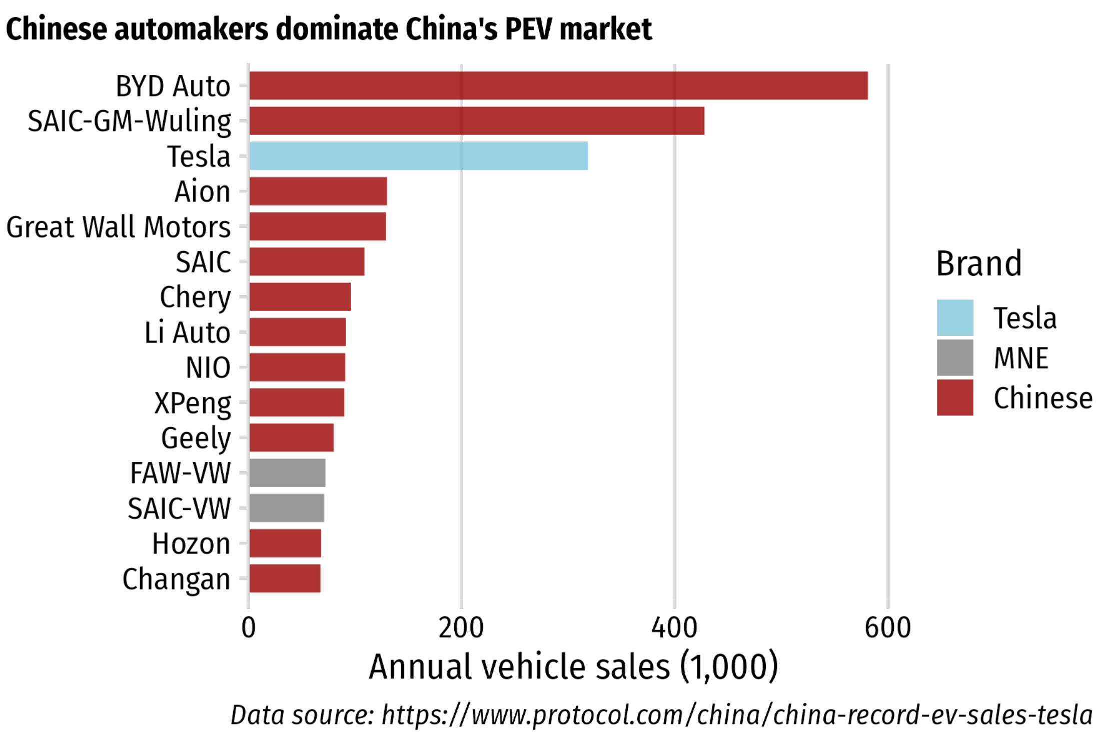

Figure 2: 2021 PEV sales in China from the top-selling PEV manufacturers. Except for Tesla, Chinese automakers control most of China's PEV market share.

2.2 Local Protectionism & Indiginous Experimentation

Local protectionism is a well-known feature of China's institutional environment, and its presence in the PEV industry should not be surprising. But rather than hinder growth, local protectionism played an important role in the early development of China's PEV industry by encouraging experimentation and market entry by new firms. In combination with national level policies like the JV requirement that kept foreign PEV technologies out of China, the support of local governments enabled new ideas to enter the market that may otherwise have been stamped out by tough competition, a phenomenon my colleagues and I have called "Institutional Complementarities" (Helveston et al. 2019).

One of the earliest indicators of strong local protectionism in the PEV industry arose from the 十城千辆 (*shi cheng qian liang*, or "ten cities, thousand vehicles") demonstration program, which aimed to deploy over 1,000 NEVs in ten pilot cities totaling over 10,000 nationwide (MOF 2009). Launched by the NDRC in 2009, the program proved divisive as most participating cities used the funding to almost exclusively support NEVs produced by local automakers. During this experiment, 76 automakers producing 343 models were approved to receive subsidies (Zheng et al. 2012). While the central government criticized this behavior and quickly moved to ban it, some cities still managed to support local players in indirect ways. For example, Shanghai Motors makes both BEVs and PHEVs, and in Shanghai both types of vehicles are eligible for incentives; in contrast, Beijing Motors only makes BEVs, and in Beijing only BEVs are eligible for incentives.

While protectionism can result in inefficiencies, such as lower economies of scale, it can be beneficial in the early stages of a new industry if it insulates immature start ups from harsh competition. In China's early PEV industry, local protectionism helped form an incubation period where firms could experiment with new technologies and business models (Helveston et al. 2019). Indeed, over the past decade a remarkable amount of experimentation has occurred across the PEV technology platform, including new components, vehicles, and business models. Automakers have used a variety of lithium-ion battery chemistries to achieve different cost-performance tradeoffs, and a wide range of BEV types have been introduced ranging from micro cars to SUVs. Car sharing firms have experimented with small, shared BEVs distributed throughout multiple cities, and taxi fleets in multiple cities have implemented battery swapping models where BEVs can quickly swap a depleted battery pack for a fully-charged one in a matter of minutes. These innovations require coordination across multiple parties for success (e.g. automakers and grid operators), and local governments have helped facilitate such coordination by providing preferential rents, local infrastructure support, and support in attaining automotive production licenses for industries related to NEVs, often at the expense of competition from non-local firms. Local governments have also exploited their purchasing power to purchase larger quantities of BEVs from local automakers, including city buses and taxi fleets.

The success of domestic Chinese PEV manufacturers has relied on both of these institutional features. Without the legacy of the JV system, domestic firms may have struggled to keep up with the technologies and products brought by MNEs to China (as they have in the ICEV industry). Likewise, without the support of local governments, many domestic PEV firms may not have had the resources necessary to enter the market.

3 Market Conditions & Adoption

Government support for an industry will not produce successful outcomes without end users that are willing to purchase the products produced by that industry. In the case of China's PEV industry, the market conditions for PEV adoption are more favorable than in many other parts of the world, and in particular compared to North America. These conditions are in part due to differences in preferences of Chinese car buyers and also due to the efforts by China's leaders to build reliable and affordable infrastructure that reduces the burdens associated with purchasing, owning, and operating a PEV.

3.1 Meeting a Lower Bar

Research has shown that Chinese car buyers are more willing to adopt PEVs (and BEVs in particular) with lower driving ranges than consumers in Europe and North America. An early survey study in 2012 comparing the preferences of car buyers in China and the U.S. found that Chinese car buyers were on average equally likely to purchase a BEV with a 150-mile driving range compared to a comparable ICEV, all all being equal; in contrast, American car buyers valued the ICEV by $12,500 more than the BEV (Helveston et al. 2015). This difference in preferences has consistently appeared in multiple studies. For example, a recent global automotive consumer study conducted by Deloitte found that the minimum driving range needed for a Chinese car buyer to consider purchasing a BEV was 258 miles—about half as much as the American car buyers who participated in the study (see Figure 3) (Deloitte 2022).

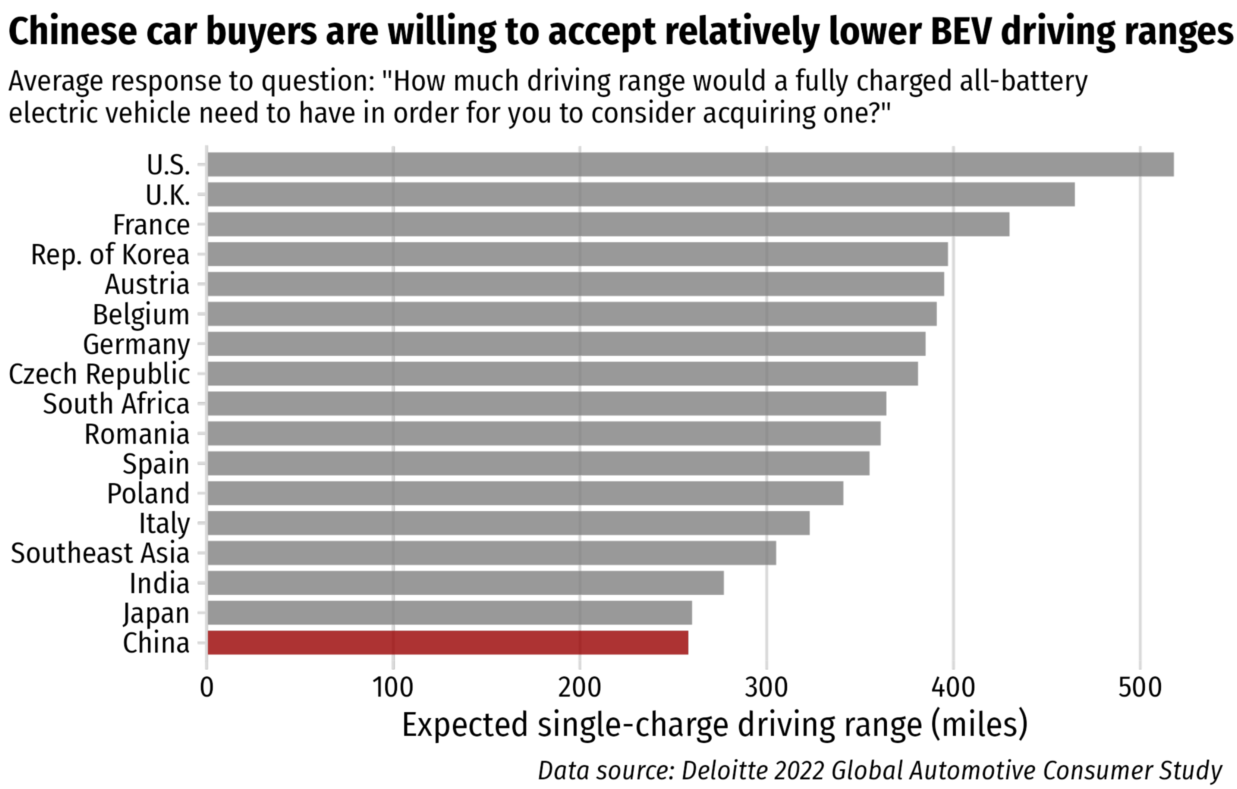

Figure 3: Average response to question, "How much driving range would a fully charged all-battery electric vehicle need to have in order for you to consider acquiring one?" Data source: Deloitte 2022 Global Automotive Consumer Study.

One hypothesized reason for this outcome is that many Chinese car buyers are first-time buyers and therefore may not have had as much experience owning and operating a personal vehicle. In the same 2012 survey by Helveston et al., 65.4% of the respondents reported being first-time buyers compared to just 4.4% in the U.S. sample (Helveston et al. 2015). This lack of experience may have yielded an "anchoring" effect where the driving ranges of BEVs that first-time buyers see first may appear reasonable.

Another reason is that Chinese citizens simply don't *need* to drive as far as people in other countries due to the availability of affordable, reliable alternatives to driving, such as city subway systems and high-speed rail. China now has over 5,000 kilometers of subway lines in 25 cities, and of 7 of the 12 longest metro systems in the world are in China (Freemark 2018). China's high-speed rail network recently surpassed the length of the equator at just over 40,000 km long (Yang 2021). In comparison, most U.S. cities have relatively underdeveloped public transit systems, and the only inter-city travel alternatives to driving in most parts of the country are flying or long-distance buses.

Finally, shorter driving ranges are only an inconvenience if recharging the vehicle is slow or unavailable. While most BEVs today take considerably longer to recharge than refueling a ICEV (as much as 30 minutes with a fast charger and several hours otherwise), the *availability* of chargers is increasingly less of a problem. China has now built the world's largest network of PEV charging stations with over 800,000 chargers installed as of the end of 2020. The rate of growth has been astounding; China installed 112,000 charging stations in the month of December 2020 alone—more than the total number of chargers in the U.S. at the time (Hill 2021). One reason China has been able to deploy chargers so rapidly is because the government usually controls all parties involved, including the state-owned grid operators like State Grid. Thus, the government serves a critical coordinating role necessary when drawing plans to install and maintain charging infrastructure. In countries like the U.S., coordination challenges abound and frictions between local electric utilities, municipal governments, land owners, and other stakeholders slow down infrastructure development (Hatch and Helveston 2017).

Without the need to make exclusively long-range BEVs, Chinese automakers have had more flexibility in how they size battery packs for their vehicles. Since the battery is the most expensive component in a BEV, reducing the battery size can substantially reduce manufacturing costs and, subsequently, prices for consumers. Figure 4 illustrates this flexibility by comparing the manufacturer-suggested retail price (MSRP) and the driving range of all PEV models available in China, Europe, and the U.S. in 2017. Compared to the offerings in the European and American markets, Chinese automakers offer a greater variety of PEVs at more affordable prices and driving ranges.

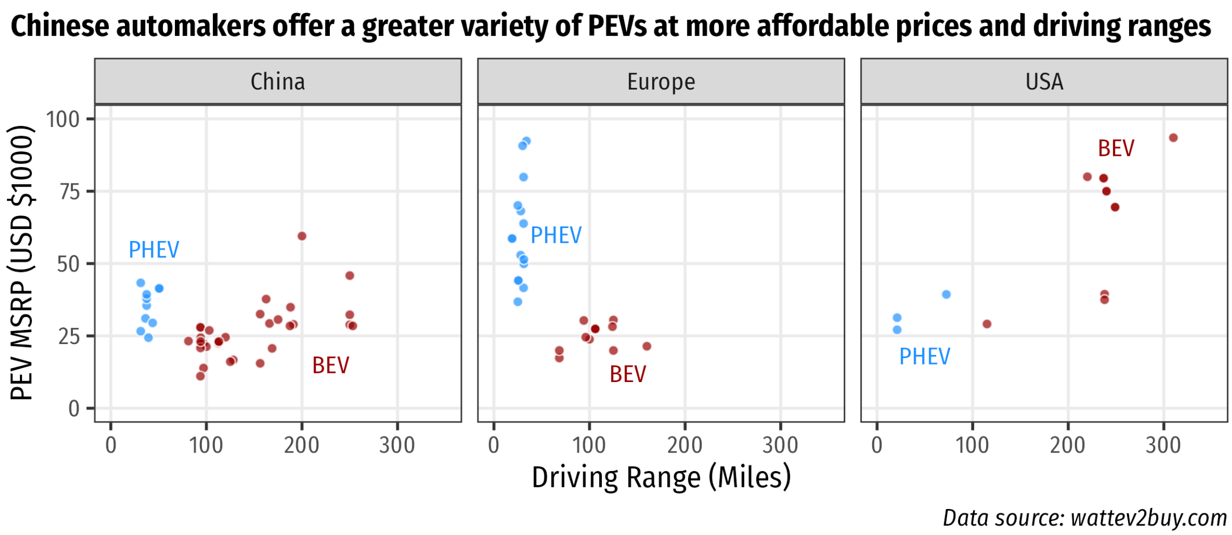

Figure 4: PEV manufacturer-suggested sales price (MSRP) versus driving range for PEVs in 2017. Chinese automakers offer a greater variety of PEVs at more affordable prices and driving ranges. Data webscraped from wattev2buy.com.

Finally, with so much entry by Chinese firms into the PEV market, consumers in China have far more options to choose from compared to the PEVs available in other markets. Figure 5 shows that more BEV models were available in China than in other large vehicle markets as early as 2014, and that availability has rapidly accelerated. According to wattev2buy.com, there are now more than 400 PEV models available for sale in China as of 2022 (wattev2buy 2022).

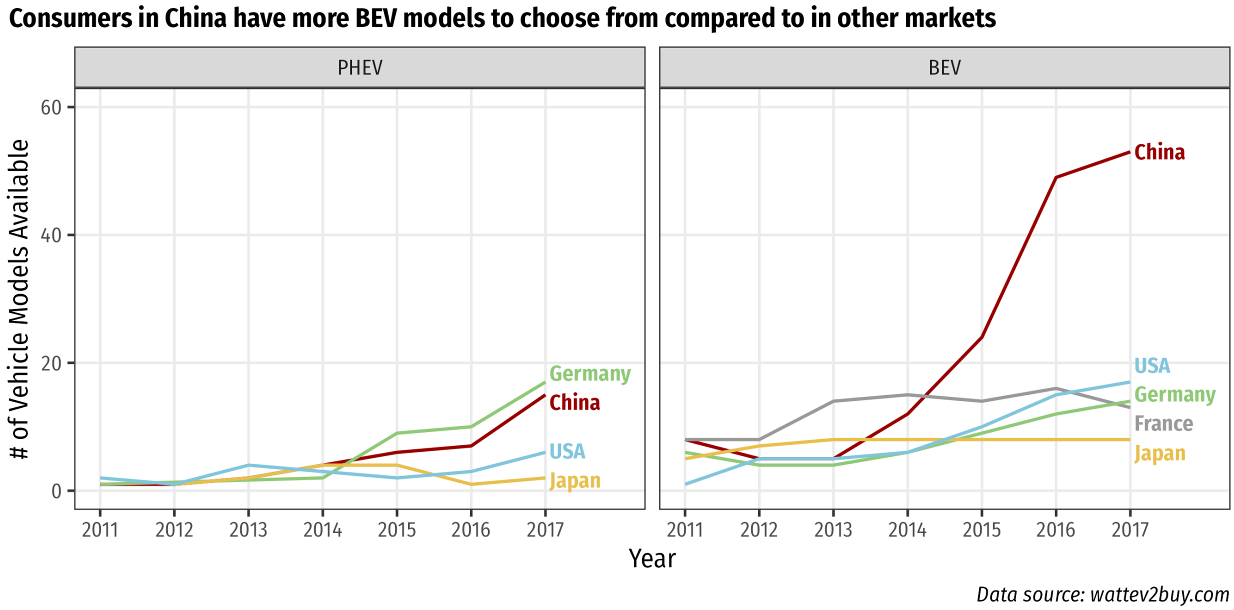

Figure 5: Number of PEV models available in select countries from 2011 - 2017. Consumers in China have more BEV models to choose from compared to in other markets. Data web-scraped from wattev2buy.com.

3.2 Bigger Sticks & Carrots

Like in the U.S. and other countries, China's government has implemented a variety of consumer incentives to spark greater demand for PEVs, including direct purchase subsidies to private consumers. The initial central government subsidies scaled with battery capacity (RMB 3,000 per kWh) up to a maximum value of RMB 50,000 (USD $8,200) for PHEVs and RMB 60,000 (USD $9,800) for BEVs, similar in magnitude to those in the U.S. But unlike U.S. subsidies, China used these subsidies to bolster the domestic supply chain by linking them to local content requirements. Subsidies were only available for PEVs that source one of three major components from within China: batteries, motors, or battery management systems (the control software). This further reinforced the hesitancy of foreign firms to introduce their most advanced PEV technologies to China (Nam 2011), again leaving the opportunity for domestic firms to pursue PEVs with less foreign competition.

Despite the greater media attention that subsidies tend to receive, multiple studies have found that local policies have been far more influential in increasing PEV adoption in China. PEV exemptions for vehicle restriction policies have been particularly influential (W. Li et al. 2019; Rietmann and Lieven 2019; S. Li et al. 2021). In some cities (typically Tier 1), local governments have implemented various restrictions on vehicle ownership and operation, such as placing quotas on monthly vehicle registrations and limiting driving in certain areas to specific days or time periods. Many of these cities have relaxed or exempted those restrictions for PEV owners, and those exemptions can be substantially more valuable to consumers than subsidies. For example, in Shanghai where license plates are auctioned, winning bids can be as high as $15,000, but PEV plates are free. Likewise, the odds of winning the license plate lottery system in Beijing can keep car buyers waiting for years for a plate, but PEVs have a separate lottery with shorter wait times. Given these policies, PEV adoption in China has accelerated faster in larger cities with restrictive vehicle policies compared to smaller cities.

Along with incentives to purchase PEVs, automakers are facing increasingly strict standards on pollution and fuel efficiency, which has also motivated automakers to sell more PEVs. The "Dual Credit System", which has been in effect since April 1, 2018, created a market where automakers earn credits for meeting the average fuel economy standards as well as selling PEVs, providing flexibility in how each automaker meets the required number of credits each year. This policy contains a combined "carrot & stick" in that automakers who earn excess credits can sell them for additional revenue while automakers that earn negative credits will be barred from selling vehicles that do not meet the fuel consumption standards until they zero out the negative credits. Automakers that sell more PEVs have arguably benefited the most from the dual credit policy. Tesla for example, which only sells PEVs, earned $1.58 billion in revenue from credit sales in 2020; without these credit sales, their reported profit of $721 million for the year would have instead been a loss of $859 million (Kang 2021).

The effectiveness of the suite of policies China has implemented is not unique to China. For example, in Norway (where PEVs comprised 65% of new vehicle sales in 2021), vehicle taxes are computed as a combination of the vehicle weight and emissions (including carbon dioxide and nitrogen oxide), making larger, higher-polluting ICEVs significantly more expensive than smaller, lower-polluting vehicles like PEVs (which are also exempt from a 25% value added tax, annual road taxes, and most parking and toll fees). The bottom line is this: *policies that make ICEVs* *significantly more expensive to own and operate are effective at increasing PEV adoption*. It is unsurprising that PEVs have been adopted at the fastest rates in China's largest cities where local governments have implemented the strictest restrictions on ICEV ownership.

But there may be limits on how far local governments can push ICEV restrictions. For one, these policies are *expensive*. A 2014 study estimated that the set of policies implemented to promote PEV adoption cost the Norwegian government $8,100 in lost tax revenue per PEV sold, which translates to a total of $1.62 billion in tax revenue losses from just 200,000 PEVs registered in 2018 (Holtsmark and Skonhoft 2014). Many local governments that depend on local vehicle manufacturing and sales for tax revenue may not be willing to make financial sacrifices of this magnitude. Smaller tier cities that lack established subway systems or other alternatives to ICEV travel may also be less willing to restrict ICEV use. Unfortunately, it is difficult to measure these potential effects as most smaller cities in China have not yet implemented substantial ICEV restrictions.

4 The Future of China's PEV Industry

Despite China's relative success in developing a robust domestic PEV industry and market, it is important to emphasize that the PEV industry is still relatively young and dynamic compared to the more than century old ICEV industry. Depending on how several important factors play out, the future evolution of the industry may look quite different than the industry today.

4.1 What if the JVs break up?

With the 2018 relaxation of the JV requirement for PEVs and the eventual relaxation for all vehicle types set to occur over the coming decade, some have predicted that the existing JV partnerships that dominate the traditional vehicle market will inevitably split up. After all, why would MNEs like Volkswagen and General Motors voluntarily continue sharing revenue and intellectual property with large Chinese partners?

While breaking up may seem inevitable, there are several important forces that may keep them together even after they are no longer required to do so. First, while MNEs do share revenues with their Chinese JV partners, they also share costs. Given the maturity of these partnerships (some of which go back to the 1980s), the costs of splitting up may be quite high. The established JVs have billions of dollars in fixed assets (e.g. manufacturing facilities, dealership networks, etc.) all across the country and share operating expenses (labor, advertising campaigns, etc.) with their Chinese partners. Many of the existing assets are likely supported by local governments in various ways, such as tax breaks or direct subsidies to support local manufacturing, and that support may go to only the local partner if the MNE breaks off from the JV. The Chinese partner firms also provide important knowledge of local preferences that support the customization of global vehicle platforms to the Chinese market. And while MNEs have complained about forced IP sharing, research has shown that at least within the ICEV technology platform they have been relatively successful at preventing knowledge spillover to their partners (Nam 2011; Howell 2018).

It is also important to note that the vehicles that Chinese partners develop and sell through the JVs can help MNEs meet other policy requirements, such as the dual credit policy. The vehicles developed by Chinese automakers tend to be smaller and more fuel efficient than those designed by MNEs, which serve to improve the average fuel economy of all vehicles sold through the JV. These partners have also been somewhat successful in developing smaller BEVs, which again help meet the dual credit requirements. So long as their Chinese partners do not pose a true competitive threat to the core business of making and selling ICEVs, MNEs will be able to continue selling larger, more luxurious, and more profitable vehicles while still meeting annual fuel economy and PEV sales requirements if they continue to participate in a JV.

But even if China's largest JVs *did* split up into their foreign and domestic counterparts, it is hard to say whether the market would be dramatically reshaped. The most successful domestic Chinese firms in the PEV industry are those without JV partnerships, such as BYD, Geely, XPeng, and NIO. These firms face enormous incentives to continue to innovate and invest in BEV development. MNEs, on the other hand, would face greater incentives to bring their latest PEVs to China, and given the size and trajectory of China's PEV industry, they may also invest in more R&D within China. MNEs would also need to work with local supply chains to ramp up production, especially local battery suppliers. This latter aspect of MNEs having greater autonomy in China's PEV market could have perhaps the largest implications. Since MNEs develop vehicles around platforms designed for multiple markets, establishing new partnerships with Chinese battery suppliers may impact global sourcing strategies for PEV development in other markets.

The most likely losers from JV break ups are the domestic Chinese partners, which are mostly large state-owned enterprises. These firms have struggled to develop their own R&D capabilities independent from their MNE partners and may not be able to compete with the leading MNEs and other domestic firms. But given their relative significance to local economies, it is unlikely that local governments would let these firms outright fail.

4.2 Will local protectionism hinder growth?

Over the past decade when PEVs were less established, local government insulation from competition was arguably helpful for enabling firms to experiment with new technologies and business models (Helveston et al. 2019). But continued protectionism as the industry matures could be harmful for future innovation and growth. At this stage, bringing costs down is an important goal, which will require greater production volumes and standardization across key components to achieve greater scale economies (Iversen 2017; Lewis and Wiser 2007). The electric bicycle industry serves as an interesting comparison in this regard; while regional clusters supported by local governments was important in the early phases of the industry, research has shown that the establishment of national standards was a critical step for greater industry maturation (Ruan, Hang, and Wang 2014). From a perspective of National Innovation Systems, researchers have also argued that firms must be exposed to global competition to produce national champions capable of competing in multiple markets worldwide (Amsden and Chu 2003; Nelson 1993).

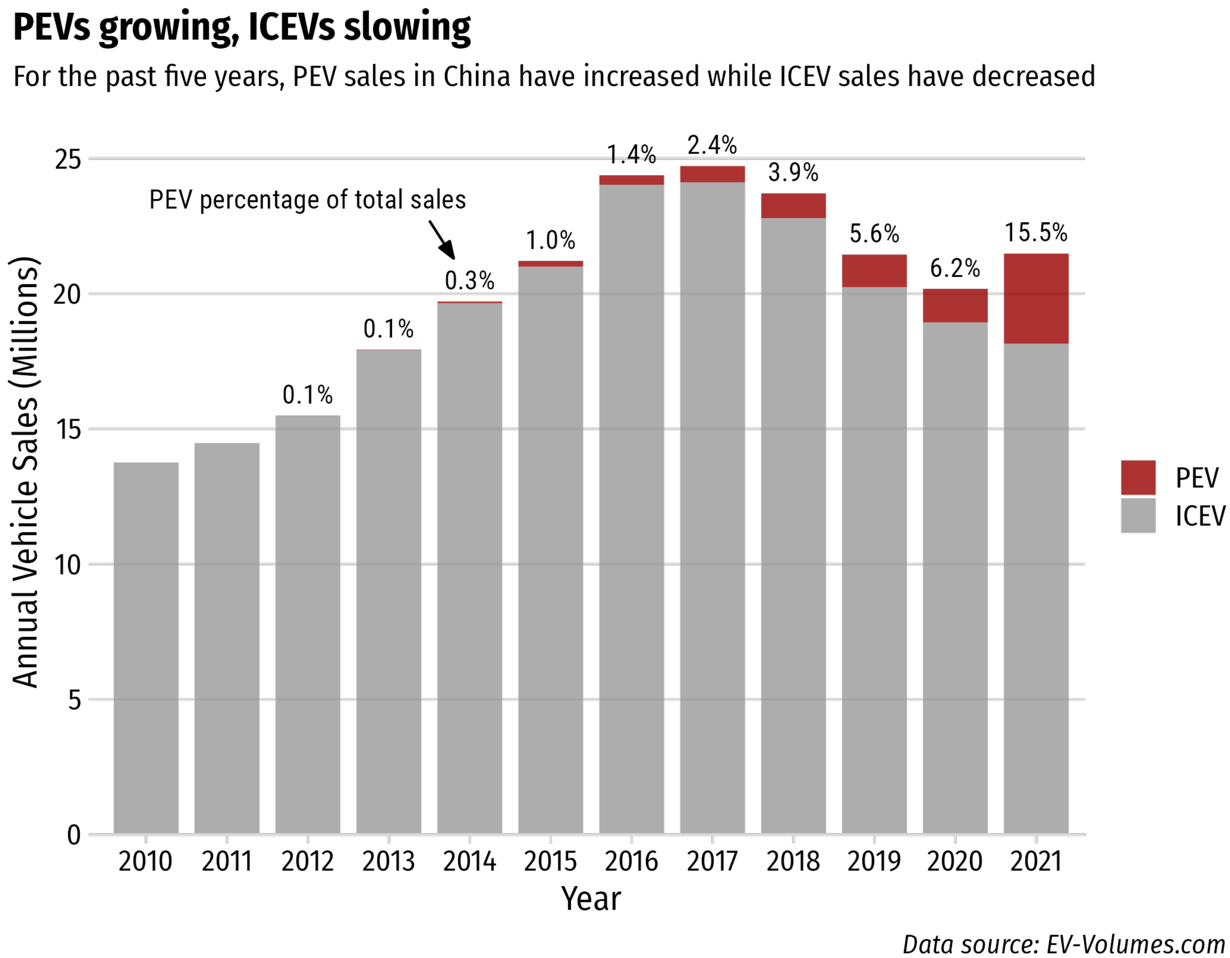

Figure 6: Annual PEV and ICEV sales in China from 2010 - 2021. For the past five years, PEV sales in China have increased while ICEV sales have decreased. Data from EV-Volumes.com.

Nonetheless, there are now several signs that local government protectionism may not be as significant a barrier to prevent the emergence of national champions in China's PEV industry. With the entry of Tesla and other successful PEV startups, China's domestic PEV market is arguably already more competitive than those in other global markets. Furthermore, the central government has already eliminated some of the most blunt protectionism strategies, such as restricting subsidies to only locally-made vehicles. The industry overall is on a rather clear trajectory towards PEVs and away from ICEVs. Even during the past two years when the COVID19 pandemic wreaked havoc on the automotive supply chains, PEV sales grew while ICEV sales fell—a consistent trend for the past five years in a row (see Figure 6). For these reasons, even though China's automotive industry remains heavily fractured with well over 100 automakers, it appears local protectionism is unlikely to play a significant enough role to hinder overall industry expansion.

4.3 An Emerging PEV Category: The Mini EV

China's vehicle market is much more diverse than that of many other nations. While PEVs and ICEVs compete at the upper end of the vehicle spectrum, the lower end of China's vehicle market is packed with a wide variety of electrified vehicles, including two-wheel e-bikes and three- and four-wheel low speed electric vehicles (LSEVs). Despite their popularity, LSEVs have become somewhat controversial as they lack many safety features and use relatively outdated technology such as lead-acid batteries. LSEVs also do not evoke the image of technology leadership that China's leaders desire (see Figure 7a).

(a) An example of a Low-speed EV (LSEV) (b) The Wuling Hongguang Mini EV

Figure 7: Examples of an LSEV and Mini EV: (a) Photo of an LSEV in Beijing taken in 2016 (original photo by John Paul Helveston) (b) A 2020 Wuling Hongguang Mini EV (image from https://en.wikipedia.org/wiki/Wuling_Hongguang_Mini_EV)

In response to government criticism of LSEVs, some Chinese automakers have begun producing a new category of PEV that is intended to be nearly as affordable as an LSEV but with the technology and performance standards necessary to qualify for government subsidies. These "Mini EVs" (similar in size to Japan's popular Kei cars, or *keijidōsha*) are now emerging as some of the most popular vehicles in China. Mini EVs offer a much more affordable alternative to a full-size car but with many of the same amenities, such as an air-conditioned cabin, power windows, and GPS navigation (see Figure 7b). With a selling price of just $5,000 USD (after subsidies), the Wuling

Hongguang Mini EV in particular has emerged as the poster child of the Mini EV movement. In December of 2021, the Hongguang became the top-selling PEV with just over 55,000 units sold, beating other popular leaders such as Tesla's Model 3 and Model Y as well as BYD's Qin PHEV (Pontes 2022).

Table 1: Comparison of features for LSEVs, Mini EVs, and BEVs.

Feature	Low-speed EV	Mini EV	BEV
Battery Chemistry	Lead-acid	Lithium-ion	Lithium-ion
Driving Range (km)	< 120	120 - 200	> 200
Top Speed (kph)	< 60	60 - 80	80 - 120
Price (1,000 RMB, after subsidies)	< 30	40 - 80	> 80

While they have not received as much media attention as full-size BEVs, Mini EVs are a potentially more disruptive product category for the traditional ICEV industry. Mini EVs are far simpler products with orders of magnitude fewer components. Furthermore, while traditional ICEVs require annual production volumes in the hundreds of thousands to achieve lower costs, Mini EVs achieve full economies of scale at an order of magnitude lower volumes. With such comparatively lower barriers to entry, Mini EVs could become another major vehicle category that poses a substantial competitive threat to ICEVs. Depending on their success (and the government's tolerance of them), Mini EVs could further accelerate the transition away from ICEVs towards PEVs.

5 Concluding Remarks

China's success in developing a leading PEV industry and market is the result of multiple important factors. Industrial policy has played a substantial role in shaping how the industry and market has evolved, but perhaps not as initially intended. Policies aimed at transferring foreign technology to Chinese firms ended up creating incentives for MNEs to *not* bring PEV technology to China while domestic firms experimented and innovated in locally-protected markets. The governments of China's largest cities have been willing (and politically able) to implement extreme restrictions on ICEV ownership and use to promote PEV adoption. China's decades-long investment in transportation infrastructure (including its world-renowned high-speed rail network and rapidly expanding PEV charging network) has made PEV ownership less onerous compared to in other countries.

And while American consumers have lived in a century-long culture of car ownership with well-established preferences, most Chinese car buyers are buying their first vehicle and remain more willing to consider purchasing a PEV, even ones with lower driving ranges.

Of course, China is certainly not the only major PEV market, nor are Chinese automakers the only major PEV manufacturers. In recent years, several European nations (namely Germany and Norway) have also made significant progress towards vehicle electrification. Similar to China, these nations have done so via a suite of policies that ultimately make ICEV ownership more onerous and expensive while offering PEV buyers exemptions on vehicle restrictions and additional incentives. European nations also have invested in the infrastructure necessary to support more widespread PEV adoption, including both charging infrastructure as well as reliable and affordable alternatives to driving for longer-distance trips, such as high-speed rail.

In contrast, outside of several large Californian cities, the U.S. has largely struggled to achieve the level of PEV adoption experienced in China and Europe. While the federal government and some states offer subsidies, U.S. policy makers have been unwilling to implement the level of ICEV restrictions like those in some Chinese cities, which would almost certainly incur severe political costs. Calculations of the "Total Cost of Ownership" (TCO) conducted by Argonne National Lab show that even after accounting for PEVs' lower operating costs, PEVs are still relatively more expensive on average compared to ICEVs in the U.S. (Burnham et al. 2021). American consumers also have far higher driving range expectations for PEVs compared to their Chinese and European counterparts (see Figure 3), which is to be expected given the relatively few affordable alternatives to driving for long distance trips and limited charging infrastructure.

Whether the U.S. will succeed in spurring a dynamic PEV industry remains to be seen. It is also unclear whether the same policies that have worked in China would work in the U.S. The recently passed Inflation Reduction Act, for example, implements several industry policy strategies from China's playbook, such as restricting portions of the available PEV subsidies to materials and components that are sourced from either the U.S. or its allies. But one of the reasons local content requirements were successful in China is that much of the supply chain for PEV components already existed, such as lithium-ion batteries for the electronics industry; this is not the case in the U.S. Nonetheless, China (as well as every other nation with a sizeable PEV market) serve as clear examples that accelerating the transition to PEVs has required (and will continue to require) substantial policy interventions.

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