Leapfrogging to electric vehicles: patterns and scenarios for China's automobile industry

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Abstract: The idea of leapfrogging, where a newly industrialising nation moves directly to the use of advanced technologies without needing to follow the trajectory of its predecessors, is an attractive one, particularly for the automobile industry where there is an urgent need to develop more sustainable technologies. China now has the highest level of automobile production and sales in the world; thus, the question we address in this article is, can China 'leapfrog' to the development of clean and economically viable electric vehicles? The existing literature on leapfrogging is ambiguous and ill defined; we review the literature and identify four generic patterns for leapfrogging. We then present some empirical data on the factors that might influence China's ability to leapfrog to electric vehicles. We conclude with an evaluation of the likelihood of it actually being able to do so and propose three leapfrogging scenarios that it might follow.

Keywords: automobile industry; China; electric vehicles; EVs; leapfrogging; sustainable technologies.

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1 Introduction

The notion of leapfrogging in the process of industrialisation, where a nation is able to move directly to the use of more advanced technologies without needing to follow the same technological trajectory as its more established industrialised predecessors, is undoubtedly an attractive one. While this notion has relevance to all sorts of areas, it has a particular resonance in the field of sustainable development, where the need to use cleaner, more energy efficient and less environmentally damaging technologies has never been more urgent (Goldemberg, 1998). The question that we address in this article is, can China 'leapfrog' Western nations and develop clean, energy efficient and economically viable electric vehicles (EVs).

The article is organised into three main sections. The first presents a review of the literature on leapfrogging and examines the relationship between leapfrogging and what is sometimes termed 'catching-up'. It identifies four generic patterns associated with leapfrogging. Following this, we will present some empirical data related specifically to factors that might influence the likelihood of China's automobile industry being able to leapfrog to EVs. These factors include the influence of the Chinese Government's policy towards EVs; developments specific to the local dynamics of the Chinese market for EVs, and the current 'state of the art' in the production of EVs and their components in China. The final section presents a summary of China's strengths and weaknesses in relation to the production of EVs and outlines three potential scenarios by which China could leapfrog other nations that are pursuing a similar goal.

2 Leapfrogging as a path to industrial development

Leapfrogging is a complex term that can be found in a variety of literatures relating to strategy, industrialisation and economic development. Steinmueller (2001, p.194) simply defines leapfrogging as:

> "... bypassing stages in capability building or investment through which countries were previously required to pass during the process of economic development."

Thus, in its most general sense, the term is used to refer to the idea that a newly industrialising nation need not follow the same path to technological development as existing industrialised economies, but can bypass older technologies and jump straight to the use of the most recent. However, beyond this rather general idea of 'skipping a stage' in an existing developmental path, the notion of leapfrogging remains ambiguous and ill defined.

Perkins (2003) for example, notes that despite the term being applied to a wide range of topics by academics, politicians and journalists' alike, very little work has actually been done to look at what it means in practice. Authors such as Gallagher (2006), and Lee and Lim (2001) (Lee et al., 2005), seek to draw a distinction between different types of leapfrogging based upon differences in developmental trajectory. Others (Lau and Wan, 1994; Peri and Urban, 2006) seek to clarify the differences between ‘catching-up’, which implies accelerated development leading to some form of parity and ‘leapfrogging’, which implies a developmental discontinuity leading to some form of competitive advantage.

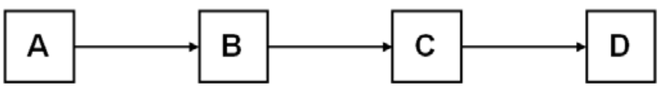
Even the origins of the term itself are unclear. Lee et al. (2005) claim it stems from early work on industrialisation in Russia. Soete (1985) states that the idea came from a synthesis of theories of technology diffusion and theories of economic growth in the 1930s. Brezis et al. (1993) argue its origins lie in attempts to explain anomalies in endogenous growth theory. There are similar disagreements about the scope of the phenomena for which the term can be used. Some authors, such as Zhao (2006), use it for relatively ‘local’ innovations made to specific technologies in specific circumstances, whereas others, such as Fan (2006) view it more as a strategy to achieve broader national objectives, such as becoming the leader in a particular industry or industrial sector.

In this article, we will focus mainly on the latter interpretation of leapfrogging as a strategy; however, even here the nature of the strategic goal can vary. Some authors (Fan, 2006; Lee et al., 2005; Mu and Lee, 2005) focus on leapfrogging in ‘hi-tech’ sectors such as telecommunications, where the actors from more established nations are seen as being handicapped by the legacy of their industrial history. Others (Gallagher, 2006; Goldemberg, 1998) focus more on the environmental concerns such as avoiding the pollution and high levels of energy consumption caused by the use of the dirty and inefficient technologies of an earlier era.

However, despite all of these disagreements and differences of emphasis, it is possible to identify some common themes in the literature on leapfrogging.

Underlying the notion of leapfrogging is the idea that particular technologies have particular trajectories or paths that define their development. Dosi (1982) describes technologies as being characterised by the accumulation of the practical and theoretical knowledge that has gone into their development and use. He argues that, in the same way that a scientific paradigm defines what is and is not acceptable as ‘normal science’, so technological paradigms come to define the ‘normal’ path of development for a technology. Thus, we might represent the normal path of development as Figure 1.

Figure 1 The normal path of development of a technology

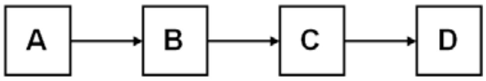


With this as our starting point, we are now in a position to begin to differentiate between the different notions of catching up and leapfrogging.

2.1 Catching up

Put simply, catching up involves following the normal route to economic and technological development but at an accelerated pace, usually as the result of some form of technology transfer (Figure 2).

Figure 2 Catching up as accelerated development or path following



Lee and Lim (2001, p.426) describe it thus:

> "... latecomer firms follow the same path as that taken by the forerunners. However, the latecomer firms go along the path in a shorter period of time."

'Catching up' does not necessarily equate to the notion that all that is required to achieve an accelerated rate of technological growth is to acquire the requisite tools, techniques and machinery from a foreign investor/donor. As Steinmueller (2001, p.195) notes,

> "... few (if any) process technologies are so well specified that the equipment needs only to be installed and switched on, for purchased inputs to be transformed into finished outputs."

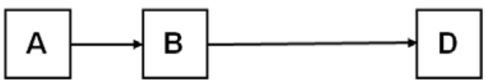
Consequently, while studies such as Peri and Urban (2006) provide data to show that foreign direct investment can be of benefit to domestic firms, the results are usually qualified in some way. Most of the literature on catching up stresses the role of other factors, such as the absorptive capacity of the host nation, as much as it does the direct effects of technology and/or knowledge transfer (Fan, 2006; Soete, 1985; Steinmueller, 2001; Wei et al., 2005).

2.2 Leapfrogging

As we have seen, the literature on leapfrogging is often piecemeal and lacking an empirical base, Lee and Lim's (2001) work (Lee et al., 2005) on leapfrogging in a handful of Korean industries is a notable exception to this. They developed a model of 'catching up' based on technological capabilities and applied it to a small number of selected industries in Korea in an attempt to discover the conditions under which this phenomenon occurs (Lee and Lim, 2001). They examined six different industries: the automobile industry, the consumer electronics industry, the production of dynamic random access memory (DRAM) chips, the machine tool industry, mobile phones based on code division multiple access (CDMA) technology and the production of personal computers. What they found was that there appeared to be three different patterns of development.

They labelled the first pattern, which broadly corresponds to the notion of catching up illustrated in Figure 2, 'path following'. The second, involved an industry 'leapfrogging' over a 'normal' stage of development and moving straight to a more advanced stage, which they labelled as 'stage skipping'. This is illustrated in Figure 3.

Figure 3 A stage skipping leapfrog

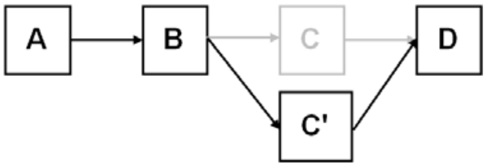


This pattern is the one most commonly associated with leapfrogging and can be found in a number of articles (Fan, 2006; Mu and Lee, 2005; Wei et al., 2005); however, some caution is required in its interpretation. While this pattern may be seen as significant and unusual in some circumstances, in others it simply becomes part of the normal cycle of industrial development, as Soete (1985, p.416) observes,

> "Few economic development experts would at present formulate an industrial development strategy based on the development of steam power, steam engines or steam locomotives."

The third pattern identified by Lee and Lim was termed 'path creating'. This involves not so much skipping over a stage, but finding an alternative route to the notional normal development path to that followed by its predecessors. This is illustrated in Figure 4.

Figure 4 A path creating leapfrog



This pattern differs from the previous one as it assumes a much higher level of technological capability. It is not a case of missing out an obsolete developmental step, but creating an alternative stage that differs from the developmental path taken by others.

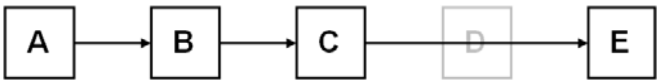
This form of leapfrogging also differs in as much as it has significant implications for the competitive position of those that can execute it successfully. The crux of the argument is that, by successfully following a path that others either did not recognise or saw as being less valuable, the creator of the new path gives itself an opportunity of seizing the initiative and becoming the leader in that particular field of technology.

Finally, in addition to the work of Lee and Lim, Gallagher (2006, p.384) also identifies two forms of technological development that she describes as leapfrogging,

> "... (1) leapfrogging by skipping over generations of technologies; and (2) not only skipping over generations, but also leaping further ahead to become the technological leader."

The first is clearly of the same form as that illustrated in Figure 3; the second could simply be an example of the pattern identified in Figure 4. However, we would also like to consider the possibility of another form of leapfrogging. If a nation can, clearly and unambiguously, leap ahead of the existing technology as opposed to simply sidestepping a stage in the normal development, then in doing so it will, in effect, create a new technological paradigm. Such a change might be illustrated as Figure 5.

Figure 5 A paradigm changing leapfrog



The differences between these different forms of leapfrogging are subtle but important. The leapfrogging shown in Figure 2 and Figure 3 essentially maintains the status quo and offers no particular competitive advantage to those following it.

The form of leapfrogging shown in Figure 4 however, if successful, does offer a competitive advantage based on the level of difficulty that potential competitors have in copying the new path. Borrowing a term from strategic management literature, this is similar to a disruptive strategy where some form of new innovation 'disrupts' the way a market operates giving the innovator a significant advantage until their competitors learn how to deal with the disruption (Charitou and Markides, 2003). The final type of leapfrogging shown in Figure 5 however, is where a player succeeds in not only disrupting the existing strategic game but re-writes the rules altogether. This form of leapfrogging is closer to a breakthrough strategy, which is harder to emulate and offers those who can execute it a more longstanding advantage (Charitou and Markides, 2003).

Having identified four general patterns that might legitimately be termed 'leapfrogging' – path following, stage skipping, path creating and paradigm changing leapfrogs – we will now consider some specific factors that might influence the likelihood of China's automobile industry being able to leapfrog to a dominant position in the production of EVs.

3 The prospects of China 'leapfrogging' to leadership in EVs

There is no doubt that China would like to leapfrog into a position of leadership in EVs (Zhao, 2006). China now has the highest level of automobile production and sales in the world, overtaking the USA in 2009. Having achieved this position the Chinese government must now consider the future prospects for the industry, which is seen as one of the pillars of China's continuing industrialisation. Two issues have been identified as critical for the sustainable growth of the automobile industry in China: dependency on imported fossil fuels and the reduction of pollution caused by automobiles (Fang and Zeng, 2007; Nordqvist, 2007). EVs seem to offer a solution to both.

Although China began its research and development of EVs in the 1990s, it is only recently that a national strategy has begun to emerge. Current plans are that 'New Energy Vehicles' (a classification that includes pure electric, electric hybrid and other alternative energy vehicles) should account for around 5% of annual new car sales. If this objective were reached, China would become one of the top five countries producing alternative energy vehicles. All of this begs just one question: can China's automobile industry leapfrog to new vehicle technologies and compete internationally? In the following sections, we will examine whether China has all of the pieces of the puzzle it needs to achieve this ambition: in terms of the technology for EVs, for batteries and for charging stations. First, however, we will look at some broader social factors: the role played by national and regional government and some features of the indigenous Chinese market that might influence the development of EVs.

3.1 The role of central and local governments

Central government has given increasing importance to the development of EVs since the early 1990s. In the eighth period of five-year planning (1991–1995), technology and research work on EVs started as part of the national development project. During the period of the tenth five-year plan (2000–2005), the EV became one of the '*863 Projects*', a status given to high-tech development projects by the state that signals that they are national priorities.

The changes in industrial policy towards the automobile industry over the last two decades reveal a shift in national strategy. The first *Industrial Policy for the Automobile*

Industry was published in 1994: EVs were not mentioned. The objective of industrial policy in that period was to develop and consolidate China's indigenous gasoline automobile industry. The second version of the policy published in 2004 stated that the automobile industry should begin to research and develop both EVs and batteries. More recently, *Planning for Restructuring and Revitalization of the Auto Industry* was published in January 2009, which set targets for new energy vehicles to account for 5% of annual new car sales between 2009 and 2011. If this target were reached, China would become one of the top five countries producing alternative energy vehicles.

There are also a number of new policy directives in the pipeline that deal with the development of new energy vehicles. By the end of 2010, a specific policy, named *Development Planning of New Energy Vehicles* is expected to be published together with the third version of *Industrial Policy for the Automobile Industry*. The *12th 5-Year Planning and Objective of Automobile Industry* (2011–2015) is now also under discussion and should be published in late in 2010.

The standardisation of batteries and recharging equipment is a critical issue for the future development of EVs where central government has a role to play. Two options for recharging EVs exist: the 'plug-in' and the 'battery-remove' system. For the 'plug-in' system, the length of time the vehicle needs to be connected to the charging station is critical in determining its commercial viability. For the 'battery remove' model, the removal and replacement of the battery is quick and easy but necessitates a large stock of batteries that need to be recharged.

The top ten Chinese carmakers favour the 'plug-in' system and have established an *Electric Vehicle Industry Alliance*, whose main objective is standardisation of components for pure, hybrid and fuel cell EVs. Another alliance, named *Alliance on the Stimulation of Industrialization of China Pure Electric Vehicle*, was established by smaller carmakers and the electricity companies that favour the 'battery remove' system. Its aims are to bring together key stakeholders in fields of vehicles and batteries and the provision of recharging stations.

The Chinese government has already established some standards for the development of EVs. For example, in June 2009, it published the *Access Regulations for New Energy Vehicle Manufacturers and Products* which contained a roadmap for the development of the battery industry. Additional roadmaps and standards are expected to be published in 2010; these include *National Standard for Electric Vehicles*, *Technical Conditions for Pure Electric Passenger Cars* and *Specification and Dimension of Traction Batteries for Electric Vehicles*.

Both central and local government has a further role in overcoming the 'Catch 22' problem of costs and production volume: while production volumes are small, costs remain high, and while costs are high, the market remains small. The absence of a plan to encourage consumers to acquire EVs in China has been a long-standing criticism of government policy. After making significant efforts on the production side, the government has finally outlined a stimulation plan for consumption in 2009.

To stimulate the usage of clean mass-transport vehicles in the public transport system, the Ministry of Finance announced *Energy-Saving and New Energy Vehicle Demonstration and Extension of Financial Assistance Fund Management Interim Measures* in February 2009. These will be applied in pilot cities that belong to the first batch of the *1,000 New Energy Vehicles in 10 Cities* project. One-off fixed grants of between 4,000¥ (400€, 584$) and 600,000¥ (60,000€, 88,000$) will be made available, linked to the different types of battery technology and vehicle. In addition to the larger vehicles used for public transport, smaller new energy vehicles, such as cars, will also be integrated into the government vehicle-purchase system.

Finally, as well as the actions taken by central government, regional governments have also taken initiatives to stimulate consumption, with at least seven provinces announcing the establishment of regional *Alliances of New Energy Vehicles*. Most of those alliances have strong regional visions of industrial development and key carmakers, component producers, universities and research institutes are gathered under the jurisdiction of regional governments.

Regional governments have strong financial motivation to participate in the commercialisation of EVs. Under the project *1,000 New Energy Cars in 10 Cities*, ten pilot cities will be selected each year to receive funding from the Ministry of Science and Technology and Ministry of Finance to put 1,000 new energy cars on the road. In return, cities are expected to guarantee the necessary infrastructure, in particular the recharging stations.

3.2 Factors related to the dynamics of the local market

We have argued previously that a variety of factors such as the number of fast growing, low margin businesses in China and, perhaps perversely, the uncertainty and situational constraints that entrepreneurs face, can lead to a high level of innovation in terms of both business models (Wang and Kimble, 2010b) and product development (Wang and Kimble, 2010a). When looking at the specific dynamics of the local market for EVs in China, three developments merit attention. The first is the capacity for the creation of innovative new business models in China, the second is the emergence of a new market segment for so-called ‘low-speed electric vehicles’ (LSEVs) and the third is the existence of a market for bicycles that can easily adapt current products to exploit the growing demand for so-called ‘e-bikes’.

Firstly, concerning the development of new business models, two of the hurdles that need to be overcome in order for EVs to be a viable commercial proposition are their high price and the problems associated with battery recharging. Zotye, a small carmaker, has proposed two business models aimed at overcoming these.

The first is to create a car-leasing scheme. The company proposes to lease small SUVs that would cost 119.800¥ (11.980€, 17,490$) to buy, at a monthly rental of 2,500¥ (250€, 365$); similar to the cost of renting a comparable gasoline powered car. The first batch of 100 cars to rent was made available in Hangzhou city, one of the cities that receive subsidies from central government for the development of clean vehicles in public transport, in January 2010.

The second is for consumers to ‘buy the car but lease the battery’. Since the battery accounts for half of the total cost of an EV, the separation of the cost of the vehicle and the battery would cut the initial purchase price of a vehicle in half. In December 2009, Zotye signed a cooperation agreement with Potevio CNOOC New Energy Power Co, under which it would produce the EVs and Potevio CNOOC would construct the recharging network and the battery removal and replacement system.

However, while traditional carmakers are struggling to produce prototype EVs, a new market for LSEVs has already opened, created primarily by companies from the agricultural machine industry, which lies outside the mainstream automobile industry.

LSEVs are two to four seat compact vehicles, powered by lead-acid batteries that can be recharged from a domestic 220-volt electrical outlet. They have a limited range and cost between 20,000 and 40,000¥ (2,000–4,000€, 2,920–5,840$). The purchase price and running costs of LSEVs are a fraction of mainstream EVs. LSEVs are an attractive alternative to gasoline-powered vehicles for low-income consumers in rural areas. Most rural commuting distances are less than 20 km and the cost of electricity is around 6¥/100 km, compared to a cost of 36¥/100 km for a gasoline powered car. In addition, there is a growing overseas market for these vehicles in applications such urban cleaning, local community transportation, and use in golf and leisure resorts.

A further illustration of the dynamics of the local market in China is the flourishing 'e-bike' industry. The term 'e-bike' is used to cover a variety of vehicles from straightforward electric bicycles to electric mopeds and three-wheelers. Looking specifically at electric bicycles, China is already a world leader in terms of production, sales and exports. According to the statistics of China Bicycle Association (CBA), more than 1,000 companies are currently assembling electric bikes. The average growth rate of this sector was 45% between 1998 and 2008, with production expected to reach 30 million units in 2010.

However, like the market for LSEVs, the market for e-bikes is mainly a local market with 90% being sold in China. From the technological point of view, these companies are using appropriate technology without any dependency on foreign technology transfer. From the industrial point of view, China has all that is needed to produce an e-bike. From the market point of view, the number of Chinese customers is sufficient to support mass production. However, unless the customer base can be expanded outside of China this low-cost low-margins industry will not be able to continue to fund the investments of technology needed to improve quality and performance.

3.3 EVs in China

A significant number of Chinese companies have now entered the market for EVs. All the top ten automobile groups have announced EV projects and several of the smaller carmakers and component suppliers have joined them. However, carmakers in China and elsewhere are at different stages of technological and commercial development and long-term strategies have yet to emerge. Below we simply review some of the routes that Chinese companies have followed to meet their current needs in terms of the production of EVs.

The vertical integration of battery and vehicle production in a single company is one route to the production of EVs in China. For example, BYD, one of the top ten Chinese carmakers, began life as a battery manufacturer in 1995. After becoming the world's second largest producer of nickel-cadmium (NiCd) batteries and NiMH batteries, and the third largest of lithium-ion batteries, it expanded into car production. In 2008, BYD produced a prototype plug-in hybrid vehicle (PHEV) named F3DM, and followed this with the announcement of a pure EV, the E6, which is due to be released in the US in 2010.

Another route to EV production is through cooperation with local and foreign battery suppliers. Foreign carmakers are reluctant to transfer cutting-edge technology for EVs, particularly for smaller companies producing local Chinese brands (Gallagher, 2006). As a result, we see the widespread development of partnerships between Chinese carmakers and local suppliers of battery systems. Several of the larger Chinese automobile groups however, have established sino-foreign joint ventures. For example SAIC, the biggest auto group in China has established a 51:49 equity joint venture with a US lithium-ion battery maker. Similarly, Geely has entered into agreements with Danish companies for the supply of key components for its vehicles.

In addition to the above, China has also seen direct investment by foreign companies, such as Nissan, which have begun to build EV assembly plants in China. In November 2009, Nissan and the Dongfeng Motor Corporation signed an agreement with Guangzhou city – a metropolitan area in the south of China with a population of more than ten million – to set up a manufacturing site for EVs there. Nissan has signed a similar accord with Wuhan city, where the headquarters of Dongfeng Motors is located.

3.4 Battery technology in China

Currently, battery technology is a major hurdle for the commercialisation of EVs, both in terms of cost and performance. lithium-ion batteries have been identified as the medium-to-long term solution for powering EVs. However, within the lithium-ion family, there are at least five types of batteries, each with different strengths and weaknesses. Similarly, the demands of PHEVs (mostly commercial vehicles such as buses) and 'normal' EVs (mostly smaller personal vehicles such as cars) differ considerably. Currently no single technology has a clear advantage in terms of both cost and performance.

Most Chinese companies produce Ni-MH batteries. The technology of Ni-MH batteries is mature and the value chain for Ni-MH batteries is complete in China. Despite their poorer overall performance, the cost Ni-MH batteries is half that of lithium-ion batteries and the Ni-MH battery has been identified as the short term solution for the development of PHEV vehicles in China. Chunlan is the leading domestic company producing this type of battery. The production of lithium-ion batteries is still at a relatively early stage involving only around ten companies. BYD is one of the leaders, producing batteries for both PHEVs and EVs, and is focused on the development of lithium iron phosphate (LiFePO4) technology for the future.

China also has other advantages in terms of battery production. It has the largest reserves of rare earth metals used in the production of Ni-MH batteries: 89 million tons, representing 59% of the world's reserves. More importantly, China's output of rare earth ores accounted for 96.8% of world production in 2008 (CREI, 2009). Thus, Chinese companies have significant cost advantages in terms of their acquisition of rare earth metals. China is also an important producer of lithium carbonate, the raw material for the lithium-ion battery. China is the world's third largest producer of lithium carbonate and ranks third and fourth respectively in terms reserves of salt lake brine lithium and lithium ore (CLCI, 2009).

Finally, China also has a solid manufacturing base in batteries; it is, together with Japan and Korea, one of the top three producers of the various types of batteries used in PHEVs and EVs. Taking the example of lithium-ion batteries, a few companies such as BYD, BAK and Tianjin Lishen, have all reached annual production volumes of 600 million units. In addition, companies such as BYD have exhibited not only a capacity for innovation in battery technology, but also in process innovation that has enabled it to compete in terms of both performance and cost (Wang and Kimble, 2010a).

3.5 Charging stations in China

The future commercial success of EVs will be heavily dependent on the availability of a suitable recharging network. There are two key players in the development of this infrastructure: the groups that form the core of the electricity business, the State Grid Corporation of China (SGCC) and China Southern Power Grid (CSG), and those that represent the petrochemical industry, China Petrochemical Corporation (SinoPec), China National Petroleum Corporation (CNPC) and China National Offshore Oil Corporation (CNOOC). Although each is under the direct supervision of the State Council, they have different levels of commitment to EVs and different corporate strategies.

The petrochemical groups SinoPec and CNPC already have a network of gasoline stations: SinoPec has more than 28,000 and CNPC has in excess of 19,000. Although it is cheaper to add recharging facilities to existing stations than to build new ones, SinoPec and CNPC have significant concerns about the EV recharging business. Firstly, there is uncertainty on the level of profitability. Secondly, not all the existing stations are big enough to host new facilities for EVs and there is the risk of poor utilisation of existing space (a limited resource in cities) if the charging time is too long. Finally, to install recharging systems, they would need to work with a competitor in the form the electricity companies. Currently, neither SinoPec nor CNPC have made any firm commitments to provide electric recharging stations.

In contrast, CNOOC, which has the monopoly of production of offshore oil and gas but few service stations, has moved aggressively, announcing an ambitious plan to acquire existing gasoline stations and move into the EV business. In addition, they have become involved in the ‘battery lease’ business and have expanded into the production of lithium-ion batteries.

The electricity companies SGCC and CSG also have an incentive to become involved in recharging stations. Firstly, they have a natural advantage in terms of power generation, and the construction and operation of power grids. Secondly, the power companies wish to become the main suppliers of energy for transportation. Thirdly, in the long term, the power companies have the ambition to integrate EVs and charging stations as part of an intelligent power grid to optimise the electricity supply between peak and low periods. The main problem for them is that the petrol companies already have the service stations. The power companies would have to bear the cost of land acquisition and the construction of new charging stations estimated at three million ¥ (300.000€, 438.000$) per station. Consequently, the electricity companies favour a strategy of cooperation with other players in the market rather than attempting to develop a new network of charging stations themselves.

4 Analysis and conclusions

Having reviewed the ways in which the term leapfrogging is used and having looked at the factors that might contribute to China’s ability to leapfrog into a dominant position in the production of EVs, we will conclude with an analysis of its prospects of it doing so successfully. This analysis will first take the form of an evaluation of the strengths and weaknesses of China and then, based on this and the empirical data, we propose three scenarios that China’s automobile industry might follow in terms of potential leapfrogging trajectories in the production of EVs.

4.1 China's strengths and weaknesses

In terms of strengths, China's track record is impressive. When it began to open up to the outside world in the 1980s, it only produced 222,000 vehicles almost all of which were sold in China. By 2009, it produced 13.6 million vehicles and had become a world leader in terms of the production and sales of automobiles with Chinese brands taking a 31% share of the local market. It has also built a complete value chain with a high percentage of locally produced components being incorporated into foreign cars produced in China. Although the EV industry is in its early stages, thanks to its firm foundations in terms of key raw material extractions, battery production and infrastructure for vehicle manufacturing, China has the foundations to build a similar value chain of EVs. Finally, as we have seen elsewhere (Wang, 2008), Chinese companies have proved to be creative, innovative and adept at the integration of a range of different technologies into a single product.

However, China also faces some challenges if it is to overtake the West and become dominant in the manufacturing of EVs. Firstly, it is still weak at the level of basic research and development of related technologies and registers far fewer patents than Japan, the USA or other western countries. Secondly, many of the key technologies for EVs, such as certain components of lithium-ion batteries, DC/DC converters and battery management systems, are still controlled by foreign companies. Finally, within China, coordination among the different ministries and between central and regional governments is poor, and although some commercial alliances have been formed, companies are in general more adept at competition than coordination. The lack of global standards for EVs represents an opportunity for China, however it is also a gap that others could fill; without coordination and strong governance this opportunity could be lost.

4.2 Three possible scenarios

Before looking at some the possible outcomes, we must first qualify our conclusions. The technology for EVs is not a mature and its development is effectively a race between several strong competitors (Aggeri et al., 2009); without knowing the winner, it is not yet possible to talk of 'catching up' or 'stage skipping'. In addition, because this race does not have a firm favourite, and because leapfrogging is a complex phenomenon that can take place at many different levels, any conclusions we draw must be tentative. However, based on what we know of the phenomenon of leapfrogging, of the overall strengths and weaknesses of China and of the individual factors that might influence the eventual outcome, we can visualise three possible EV leapfrogging scenarios for China.

Firstly, after the technology for EVs has matured, China might become the biggest producer of EVs. Chinese companies have already shown their ability to succeed in volume production; by importing core technologies from foreign companies, Chinese companies could take the lead in volume production and technology integration. In terms of the typology of leapfrogging we discussed earlier, this would look more like stage skipping at the industrial level than path creation at the technological level.

Alternatively, China might gain global competitiveness in a particular market segment such as e-bikes of LSEVs. The market and industry dynamics for this exist, however even although this type of vehicle could be a part of the strategic positioning of China in the EV industry, no policies to encourage their development exist because they are seen as a marginal and 'low-technology' products. In terms of our typology, this outcome could be seen as a ‘path creating’ leapfrog at the industrial rather than the technological level.

In terms of the social and technological factors we reviewed earlier, both of the above scenarios represent less than ideal outcomes. In the first, neither the social nor the technological pieces of the puzzle fall into place and China ends as a follower not a leader. In the second, although the technology works, weak governance means that the potential dominance of a niche market could be lost. There is however a third scenario that could offer China a significant leapfrogging advantage.

As we noted earlier, the race for EVs is an open with no one clear favourite. Currently a number of options for EVs coexist and the conditions are right for a ‘standards war’ (IEC, 2006) where the eventual victor will, by controlling the standards, control the market. China’s recent legislation could form the basis for such a victory. For example, a draft standard for charging plugs is expected to be published by the National Standards Committee in 2010. This could have significant implications both at national and international level, particularly if China becomes the biggest market of EVs. Based on its understanding of the technological constraints of EVs and its systems of governance that allow it to implement a single standard across a globally significant market, it might be possible for China to implement a paradigm changing leapfrog that will make it a global leader.

However, until the race has been run, all of this will remain speculation. Will China successfully leapfrog to EVs? Only time will tell.

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