Incumbent Advantage, Barriers to Entry, and Latecomer Catch-up in the Global Automotive Industry

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CBDS WORKING PAPER 2024/3

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September 2024

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CBDS WORKING PAPER 2024/3
CBDS: Centre for Business and Development Studies
Dalgas Have 15, 2200 Frederiksberg, Denmark
E-mail: cbds@cbs.dk
www.cbds.center
ISBN 978-87-85271-04-4
CBDS publications can be downloaded free of charge from www.cbds.center

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ABSTRACT

Incumbent advantages have prevented most latecomer firms from being successful in the automotive industry. The industry to this day is dominated by the first mover firms from North America and the fast followers from Western Europe and Japan. Many developing and emerging countries have significant automotive industries, but they are dominated by these incumbent foreign firms. Some of them have tried to prop up indigenous carmakers, but largely failed. In those few cases where firms managed to pursue some degree of catch-up with the US first mover automotive firms, government industrial policy played an important role, but this paper argues that the developmental state framework, emphasizing industrial policy, is insufficient in explaining catch-up by automotive firms. It presents what we call the Barriers to Entry approach, which focuses on the barriers to entry that latecomer firms face when trying to catch up in a given industry. These barriers to entry are constituted by the advantages of incumbent firms with accumulated knowledge, capabilities and a supporting nexus. The paper demonstrates these advantages but also how some firms successfully overcame them through firm cases in Japan, South Korea and China. It highlights the striking parallels between these cases and summarizes them in terms of our barriers to entry categories: closing the knowledge gap, closing the capabilities gap, building a supporting nexus, and commercializing new technologies. The evolutionary economics literature on latecomer catch-up has emphasized the importance of firm-level efforts in technological capability building as opposed to passively expecting technology transfer through foreign direct investment. Our Barriers to Entry approach builds on but extends this literature by specifying the nature of capabilities that latecomer firms needed to build in the automotive industry as well as the origins of their absorptive capacity (prior knowledge and intensity of effort) that drove them to indigenize automotive technology (scientific and tacit knowledge). In this context, we stress the importance of migratory knowledge through transnational networks as well as of role models for both industrial policymaking and firm strategies. The opportunities afforded to latecomer firms depend on the situation in a global industry at a certain moment in time, which is conditioned by foreign firms' business strategies and incumbent countries' government policies.

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1. INTRODUCTION

In 2023, eight of the ten largest global carmakers by revenue and eight of the ten largest automotive supplier companies by revenue were still headquartered in North America, Western Europe and Japan. Despite all the clamour around the current disruption of the automotive industry by the shift to electromobility, the persistence of incumbent firms in the automotive industry is remarkable. Volkswagen's revenue in 2023 was still more than four times BYD's revenue. The two firms that started the modern automotive industry in the early 20th century, Ford and General Motors, are still among the top ten largest automakers by revenue in 2023. Western European and Japanese automakers emerged during the 1930s and took global markets shares from the 1960s. However, in the second half of the 20th century, only South Korea succeeded in technological catch-up in the automotive industry, and Korea's success is about Hyundai. In short, only one latecomer firm managed to challenge the first movers and fast followers in the automotive industry. Other firms and countries have tried but failed to break through the significant incumbent advantage in the automotive industry. Since the turn of the 21st century, China tried to do so, but also with limited success until independent Chinese firms sought to leapfrog over incumbent automakers in internal combustion engine technology by being first movers in commercializing battery technologies for new energy vehicles.

How do we explain both the failure of most latecomers to compete with incumbent automakers, and then independent Chinese firms' ability to outcompete incumbents by leapfrogging into new energy vehicles? The dominant approach in the comparative political economy literature regarding the more general question of why some countries had successful economic catch-up, but most did not, is the developmental state conceptual approach and its emphasis on state-led industrial policies that create competitive industries. However, we find that the developmental state concept has many limitations in general and specifically in answering the question posed above. Therefore, we aim to move the debate beyond the developmental state approach and present an alternative conceptual approach that we call the Barriers to Entry approach, which emphasizes factors other than industrial policy and shows both the importance but also limitations of industrial policy if the other factors are not present.

The seminal works constituting the developmental state approach by Johnson (1982) on Japan, Amsden (1989) on South Korea, and Wade (1990) on Taiwan made important contributions, but also over-emphasized the role of the state and downplayed the role of firm strategies and other factors in their overall arguments. It is worth noting that Johnson himself was urged by his editor to more clearly emphasize the role of the Ministry of International Trade and Industry, i.e. the developmental state, although he thought this led to an oversimplification of the story of Japan and a de-emphasis of important contextual factors (Johnson 1999). Later work on the developmental state has integrated the role of business more firmly in its analytical work (Weiss 1995; Weiss and Thurbon 2021).

Nonetheless, we argue that the general critique made already by Hobday (1995: 33) that the developmental state literature does not tell us much about *how* latecomer firms in East Asian countries acquired capabilities to become internationally competitive in industries new to their countries remains fair. This is because that literature focuses less on the contributions of firms, their origins, strategies, structures and methods for acquiring technology (for review, see Whitfield 2023).

Furthermore, these works notably have little to say about catch-up in the automotive industry. Johnson (1982) does not mention the automotive industry in his seminal book on industrial policy in Japan. This is because Japan's Ministry of International Trade and Industry did not play a strong role in this industry, and in fact, many of its policies had little effect on the development of Japan's automotive industry (Cusumano 1985: 20-21). Regarding South Korea, Amsden's work emphasizes the importance of non-market forces (i.e. government interventions to shape markets), but this cannot be understood only as getting the prices wrong and through a strong role for the state. The role of firms and their business strategies are important, as well as the national context in which they operated. Wade's seminal book on Taiwan also does not say much about the automotive industry, and from the work of other scholars, we know that Taiwan's industrial policy in the automobile industry was ambivalent and unsuccessful.

More recent literature has pointed to other variables in an attempt to nuance the developmental state approach. Yeung (2017) points to the geopolitical context that made the developmental state in South Korea and Taiwan in the 1960s and 1970s possible, especially state financing. But then why did Korea succeed and Taiwan not in the auto industry? Kohli (1999) emphasized the legacies of Japanese colonialism in South Korea, which were much less pronounced in Taiwan, and the role of path dependence. However, there was significant variation in the performance of South Korean automakers, with Hyundai the only real success among them.

The weakness of the developmental state approach is not only that it lacks explanatory power from the 1990s onwards, as Yeung (2016) argues, but that it never offered complete explanatory power, even for the core period of the 1960s and 1970s. This is because it does not emphasize the strategies of firms to leverage foreign technology and indigenize it, much less explain it. It also does not conceptualize industrial policies within the broader global industries in which latecomer firms have to compete, but rather focuses mostly at the national level, and thus underestimates the barriers to entry posed by incumbent firms' advantages.

Other strains of social science literature focusing on the automotive industry do emphasize the persistence of incumbent automakers and the struggles of latecomer firms trying to catch up. This literature comes from various conceptual framings including innovation studies, management studies, and the global value chain approach.

Authors writing in innovation studies and management studies emphasize that incumbent advantages result from barriers to entry in the automobile industry, and the key barrier to entry is the large tacit knowledge component in automobile production. The dominant design of the automobile centred around the internal combustion engine has remained the same for more than 100 years. As a result, incumbent firms have amassed capabilities and knowledge around this dominant design, which latecomers have usually failed to match because of the cumulative nature of the capabilities and the tacit nature of the knowledge involved (Abernathy 1978; Bergek et al. 2013; Winter 1984). Further contributions highlight that latecomer firms have struggled to emulate the highly complex 'system integrator' role of automakers: purchasing components from a long list of suppliers and integrating them together with additional components made in-house into an automobile that lives up to regulatory (safety, emissions, noise) and customer demands (incl. brand recognition) (Doner et al. 2021:11; Jacobides and MacDuffie 2013; MacDuffie and Fujimoto 2010; Schulze et al. 2015). Automobiles are also developed in an 'iterative process of co-design' based on close design collaboration and intimate exchange between carmakers and their various major component suppliers (Sabel and Zeitlin 2004: 397-398). The system integrator knowledge of the automaker and the tacit knowledge and cumulative capabilities embedded in the various automaker-supplier design and production collaborations are difficult to replicate for latecomer firms and countries. The innovation and business studies literature on the automotive industry points out crucial factors behind incumbent advantage and latecomer struggles, but it has much less to say on why and especially *how* some latecomers have managed to catch up nonetheless.

The global value chain literature on the automobile industry emphasizes that incumbent automakers and their tier-1 mega suppliers have transplanted the production of the vehicle models designed in their home R&D clusters across the globe (Sturgeon and Lester 2004). Their production in emerging economies usually has very limited participation by domestic firms in those countries (Doner et al. 2021; Pavlínek and Ženka 2011; Wuttke 2023). If latecomer automakers and component firms are to compete with incumbent automakers, they need to match their production volumes to achieve similar unit costs (economies of scale). This requires taking market share from incumbent firms, which usually proves insurmountable. In their study of the automobile global industry, Doner et al. (2021) focus their explanation of why some countries have been successful on the role of institutions such as universities, testing centers and research institutes. Similarly to the developmental state framework, their study does not explain firms and their business strategies to leverage foreign technology and indigenize it.

Our Barriers to Entry approach builds on all the above work, by nuancing the role of the state and further developing the concept of incumbent advantage through barriers to entry and the importance of economies of scale. However, our framework goes beyond identifying the obstacles to also understanding how they have been overcome in certain countries by certain firms, not just in the past but also today. We do this by conceptualizing and examining the role of firm strategies to access foreign knowledge (both patents and designs as well as tacit knowledge), master it, and build competitive firms that can perform the systems integrator role.

In that way, our framework builds on the valuable work of Keun Lee and collaborators (Lee 2019; Lee 2024; Lee and Malerba 2017). The common argument is that learning and the resulting building of firm-level capabilities are the key factors driving technological catch-up by latecomer firms; that firms have to leverage foreign knowledge as opposed to passively expecting technology transfer from transnational corporations as a result of foreign direct investments; and that leveraging foreign knowledge requires firm level effort and strategies.[1] Similar to the developmental state approach, governments have a key role, but not in leading but rather supporting firms by reducing the costs and risks for firms to actually invest in technological catch-up, but also disciplining firms by enforcing competition through exporting. What is less clear in this evolutionary economics literature is exactly *how* latecomer firms do this, in the context of incumbent advantages. Lee and Lim (2001) and Lee and Malerba (2017) aim to provide a framework for explaining how latecomers catch up with incumbents and acquire industrial leadership, measured as significant global market share. They emphasize a firm's absorptive capacity and access to external knowledge as well as extra-firm factors that constitute the national innovation system or sectoral innovation systems, including public policy, university and public research system, availability of finance, collaboration among firms.

We build on these insights from evolutionary economics but put forth a different framework for explaining how latecomer firms build capabilities, in a way that allows them to eventually challenge incumbent firms in existing technologies or leap over incumbents by commercializing new technologies. Our Barriers to Entry approach is more specific about the nature of the capabilities that latecomer firms need to build and the contexts in which they do so, by prioritizing as well as being more precise on the causal mechanisms. Our approach highlights the factors that give rise to latecomer firms' initial 'absorptive capacity' and 'technological effort', rather than taking these concepts as the starting point. Indeed, the remaining puzzle is why some latecomer firms have greater absorptive capacity and put in more effort than latecomer firms in other countries. Our approach also argues that the flip side of firm level effort to leverage foreign technology is foreign firms' business strategies and the global economic conditions that shape them (Whitfield 2023). It explains how latecomer firms leverage foreign knowledge and build firm-level capabilities in the context of, and interact with, state actions (industrial policies), foreign firms' business strategies, and global economic conditions. It highlights the importance of 'migratory knowledge' in building absorptive capacity and accessing external knowledge bases, as well as role models, for both industrial policy making and firm strategies, as a key motivational factor behind the

[1] This point builds on a longer lineage of studies in Schumpeterian evolutionary economics applied to economic catch-up by emerging economies. See Bell and Pavitt (1993); Hobday (1995); Lall (1996); and Kim (1997).

developmental mindset of political elites and the technological effort of firms. These factors are present in rich empirical studies of industries and firms, but not in existing conceptual frameworks on economic catch-up, yet they are central to it.

This paper lays out our Barriers to Entry approach through an iterative theory building process. Section 2 presents the general theoretical arguments regarding incumbent advantages and types of barriers to entry, building on existing literature. We then focus on one industry—the automotive industry—through detailed country and firm level studies with a long historical perspective. This process allows us to pinpoint the precise causal mechanisms behind incumbent advantages, the specific nature of barriers to entry, and how latecomer firms overcame them to become industrial leaders. In particular, Section 3 explains the incumbent advantages of the US pioneers (first movers) of mass-produced cars and how European and Japanese firms were able to catch-up quickly (as fast followers). Section 4 explains the Korean case, the only case of successful latecomer catch-up in the twentieth century, and Section 5 contrasts the Korean case to Taiwan and other latecomer carmaker failures. Section 6 discusses the absence of radical innovations in the technological trajectory of the automotive industry, until the China challenge in electric vehicles, which is explained in Section 7. Section 8 returns to the Barriers to Entry approach, conceptualizing the specific barriers to entry in the automotive industry and how latecomers overcame them, based on the cases.

2. BARRIERS TO ENTRY APPROACH PART 1: INCUMBENT ADVANTAGE & TYPES OF BARRIERS

In this paper, we focus on technological catch-up, in the tradition of evolutionary economics starting with Joseph Schumpeter (1954) and following a long line of scholarship from the early 1990s that have examined technological catch-up by latecomer firms in emerging economies since the mid-20th century. As Hobday (1995) expressed it, the 'latecomer firm' in emerging economies is defined by two characteristics that set it apart from firms in advanced (industrial) economies. First, it is not only behind technologically, and its surrounding industrial and technological infrastructure (in its country) is poorly developed; it is also disconnected from the main international sources of technology and R&D in the relevant industry, which are located in the advanced economies. In other words, a national or even sectoral innovation system does not yet exist. Second, the latecomer firm is disconnected from markets with demanding users/consumers of the product, which are mostly in advanced economies, and such producer-user linkages are important for stimulating technological advances.

Thus, technological catch-up requires overcoming these technological and market disadvantages. Typically, catch-up is measured in terms of latecomer firms closing the gap in global market shares with incumbent firms in leading countries (Lee and Lim 2001; Lee and

Malerba 2017). It is also considered (by evolutionary economists) to be at the heart of the more general process of economic development. As Perez and Soete (1988: 459) pointed out in the edited volume *Technical Change and Economic Theory*, economic development, understood as a catching-up process, can only be achieved through participating in the generation and improvement of technologies, either as an innovator or early imitator. This is because, as Schumpeter (1954) emphasized, innovation (or the commercializing of new technologies) is the driver of wealth accumulation because of imperfect competition and thus the oligopoly profits that accrue to first movers through proprietary knowledge and other first mover advantages. However, as Schumpeter's later work recognized and Alfred Chandler's work demonstrated, global industries tended more towards creative accumulation than towards creative destruction, where the first movers in one industry continued to be the first movers in new industries due to the cumulative nature of technological capabilities, at the firm but also the country level (Chandler 2004, 2005). The automotive industry is a good example of an industry where industrial leadership shifts have been limited. While a few Japanese firms and one Korean firm caught up with US and European leaders, they did not displace them, and the challenge of Chinese firms in global markets remains to be seen.

2.1 Existing arguments on how latecomers catch-up

Evolutionary economics scholars focused then on the cases where latecomer firms did catch up technologically with leading firms (incumbents) in advanced economies to understand how catching-up happens in the context of creative accumulation. Since most of the catching-up firms have been in East Asia, the literature examines firms in these countries. Hobday's (1995) book on *Innovation in East Asia* posed a series of questions that are still relevant, in that he started the conversation but did not finish it:

- What is the origin of the latecomer firm?
- How did latecomer firms initially enter international markets?
- Once the firm entered, how did it build up and strengthen its technological capabilities, and in particular, what strategies did it employ for learning?

Hobday (1995), focusing on the electronics industry, pioneered the idea (of upgrading) that latecomer firms could move through a process of being a contract manufacturer for transnational corporations in advanced economies to selling their own brands in advanced economy markets. However, his empirical work showed that by the early 1990s, East Asian electronics firms generally had not (yet) moved beyond being contract manufacturers. Thus, his book both underestimates the difficulties of upgrading and does not discuss the causal mechanisms behind latecomer firm learning beyond the market entry stage. Furthermore, Hobday emphasizes that latecomers have a cost advantage over incumbents, and this typically forms part of their initial market entry strategy, but he does not discuss how the costs to overcoming the technological and market barriers to entry initially outweigh the cost advantages due to lower cost labor. He focuses on the mechanisms for accessing foreign knowledge, but not the costs of accessing and mastering this foreign technology and building firm-level capabilities. We argue that upgrading is more difficult due to incumbent advantages and market saturation, and we assume that the contextual details of how East Asian firms caught up are important, as this process occurred in specific countries and not others.

Lee and Lim (2001), examining only Korean firms but across several industries, propose a model of technological catch-up. In their model, the technological capability of latecomer firms is determined by the interaction of the available resources, including internal resources and accessible external knowledge base and financial resources, and the amount of technological effort, which depends on the probability of success of the effort. This is an extension of Cohen and Levinthal's argument that absorptive capacity drives firm-level learning, and prior knowledge and intensity of effort determine absorptive capacity (Cohen and Levinthal 1990). Lee and Lim's framework recognizes incumbent advantages and the sector-specificity of catching-up through the concept of technology regime. However, as with Hobday, their framework (as opposed to their specific industry cases) underestimates incumbent advantages and does not explain how latecomer firms overcome them. This goes back to Hobday's questions regarding the origin of latecomer firms, and thus their internal resources (or absorptive capacity), how they access external knowledge, and what accounts for their technological effort (or thinking that they 'can do it', which cannot be entirely explained as a technical process). We are still lacking an understanding of the *how*.

The most advanced contribution to understanding the 'how' of latecomer catch-up is the work by Linsu Kim (1998), based on studies of Korean industries. While also starting from Cohen and Levinthal's absorptive capacity approach, Kim makes a unique contribution to the literature by highlighting two factors that affect prior knowledge and the intensity of effort. First, he argues that migratory knowledge significantly affects the building of the prior knowledge base: 'the migration of individuals from one organization or country to another transfers tacit knowledge, elevating the level of the prior knowledge base' (Kim 1998: 508). Second, he highlights the role of crisis construction in Korean chaebol to explain their intensity of effort: 'the shared sense of the internally constructed crisis among organizational members intensifies their efforts to expedite learning' (ibid: 161).

To understand how latecomer firms enter new industries, build capabilities, move to the technological frontier, and then challenge incumbents in terms of market shares, we first need to understand the incumbent advantages. This is because incumbent advantages are the barriers to entry. The second step is to then understand how latecomer firms have overcome these barriers to entry. This section provides the first step. We then use the empirical cases of successful latecomer catch-up in the automotive industry as material for iterative theory building, seeking to build on but also advance the arguments of Linsu Kim, Keun Lee and others, which is presented in section 8.

2.2 Incumbent advantages are the barriers to entry

Chandler (2004, 2005) demonstrates that a relatively small number of firms concentrated in the US and Europe accounted for the commercialization of new technical knowledge in the twentieth century in chemical, automotive, electrical, and electronic industries, becoming the industry's core companies globally. These firms not only had the technical capabilities to apply new scientific and engineering knowledge to create new products and processes, but also the organizational capabilities required to transform an innovation into a commercial product, build and operate production facilities, carry out consumer research and build distribution systems. Based on these scientific knowledge and organizational capabilities, first movers generated proprietary knowledge embodied in firm-level processes and in intellectual property protected by patents. These capabilities became their learning base for improving existing products and processes and for developing new ones, but also made economies of scale and scope possible (Chandler 1990). Economies of scale arise from fixed costs spread over larger volumes as well as learning by doing that leads to productivity gains, both of which are made possible by gaining a large market share and keeping it through marketing and brand loyalty by consumers. Incumbent firms' declining production costs, brand loyalty, and significant market share constituted high entry barriers that were not quickly diminished through emulation, providing high profit margins in oligopolistic markets.

First movers used this continuous flow of capital for further research and development to explore new technologies, create patents, and set de jure and de facto industry standards, reproducing entry barriers (Chandler 2005). As competition increases, first movers can lower prices and remain profitable; whereas new entrants that have not yet achieved the incumbents' level of productivity cannot be profitable with lower prices. Entrepreneurial start-ups were rarely able to enter; rather challengers came from other countries or from domestic firms that were core companies in other industries with comparable technical knowledge or processes of production, distribution, or product development. Thus, incumbent firms became more entrenched, creating path dependence among technologically leading countries globally.

Chandler refers collectively to these features of first movers—proprietary knowledge (tacit knowledge and IPRs), economies of scale and scope, and the strong inflow of income for reinvestment—as their *integrated learning base*. But first movers must develop a nexus of firms that supply them with parts, materials, capital equipment and services: a *supporting nexus* of interconnected and complementary firms. This nexus constitutes the external economies of scale that lead to productivity gains and thus the strength of national industries.

These incumbent advantages are the barriers to entry for latecomers. Thus, we can conceptualize barriers to entry at an abstract level, before specifying them for a specific industry where the specific technology regime and technological trajectory play an important role. When flipping incumbent advantages to be perceived as the barriers to entry for latecomer firms, we conceive of the barriers as gaps between incumbents and latecomers, and then consider the costs of bridging those gaps, following the conceptualization of Perez and Soete (1988). In taking this approach, the relational aspect of barriers to entry becomes apparent, as the size of the gap differs depending on the starting point of latecomer firms: their existing scientific knowledge and relevant experience. Thus, the 'threshold for entry' leads to different costs of entry for latecomer firms depending on their characteristics and the environment in which they operate. There is a threshold below which the costs are simply too high, if existing knowledge and experience is too low, as Perez and Soete point out. This is why, we argue, the origins of latecomer firms matter, and why 'absorptive capacity' must be explained rather than being an explanatory variable.

Perez and Soete (1988) identify four barriers to entry, or costs to entry as they say, for latecomer firms to enter an industry and become internationally competitive, which resonate with Chandler's analysis of incumbent advantages:

1. Fixed investment cost relevant for the product that the latecomer is entering.
2. Accessing the (foreign) scientific and technical knowledge required to produce the product.
3. Acquiring the experience required to handle the scientific knowledge and successfully bring it to market—which means building production processes at the firm-level that can achieve the unit cost and quality combined with the distribution and marketing capabilities required to gain market share from incumbents.
4. Overcoming any 'locational disadvantages' related to the general infrastructure and other economic and institutional conditions surrounding the latecomer firm.

Each of these factors have costs, but the costs of the factors 2, 3 and 4 are relational. The closer the latecomer firm is to the required technological frontier, in terms of the required scientific knowledge, tacit knowledge in organizational capabilities (management, production, distribution, marketing) required for economies of scale, and supporting nexus (external economies of scale), the less costly it is to acquire more knowledge and capabilities. Perez and Soete (1988) also recognized that new entrants affect both the market share and profits of incumbents. This fact can, and does, lead incumbent firms' governments to restrict market access from latecomers, as we show in the automobile case. Market access is thus not only about latecomer firms achieving the required cost/quality ratio for specific products (product segments) but also political, and the restricting of market access for some latecomers can also open opportunities for other latecomers, as in the case of Korean automotive firms. Table 1 summarizes our conceptualization of barriers to entry into distinct categories.

Table 1: Abstract conceptualization of barriers to entry

Categories	General barriers to entry
Fixed capital investment	Establishing initial factories as well as expanding to reach economies of scale and new production locations.
Closing the knowledge gap	Accessing and mastering the scientific and technical knowledge for entering the industry. This knowledge is proprietary and must be bought from incumbent firms. As latecomer firms move closer to the existing technological frontier, it becomes harder to purchase proprietary knowledge, as incumbents are unwilling to sell. Thus, latecomers must shift from buying in knowledge, to creating it through R&D.
Closing the organizational capabilities gap	Developing the relevant organizational capabilities to produce and bring to market profitably, given incumbents' initial unit cost advantage and higher quality. Achieving the unit cost/quality ratio for a given product or product segment requires economies of scale, which in turn requires sufficient market access (incl. foreign markets) It also involves the ability to absorb losses while lowering unit costs and achieving the necessary quality.
Creating a supporting nexus	Creating a local supply chain in components and services, as well as the supporting public infrastructure and standards.
Forging ahead by commercializing new technologies	Choosing one technology among competing alternatives, given the high level of uncertainty around patterns of technological change.

Source: Created by the authors.

2.3 Windows of opportunity and forging ahead

Thus far we have discussed technological catch-up by latecomer firms, meaning that latecomers reach the existing technological frontier. There is no linear process of reaching the technological frontier, and latecomers may not master all the technologies that incumbents have but rather skip some stages (Lee and Lim 2001; Lee 2013). There is also the possibility of overtaking incumbent firms by commercializing new technologies, creating proprietary knowledge that sets industry standards, and thus becoming first movers. Windows of opportunity for overtaking incumbents can emerge in several ways, as discussed below, but we argue that overtaking, or 'leapfrogging' by start-up firms, still requires a large amount of catching-up first, in order to take advantage of a window of opportunity. Even start-up firms commercializing radical, discontinuous technological innovations must build organizational capabilities, reach economies of scale, and access markets as well as have the necessary support infrastructure.

Windows of opportunity for overtaking incumbent firms emerge because, as Perez and Soete (1988) noted, incumbent advantages can also become disadvantages when it comes to commercializing radical, discontinuous technological innovations. Incumbents can choose not to commercialize new technologies because they are profitable in the old technologies, and because it requires investments in new scientific knowledge and production processes in the context of uncertain market demand (Leonard-Barton 1992; Lee 2019). Thus, the technological trajectory of an industry is shaped not only by technological progress (new scientific learning), but also by incumbent firms' business strategies and their perception of the 'demand pull': the extent to which consumer preferences and habits create a demand for products based on the new technologies (Dosi 1984: 11). This situation can lead to a window of opportunity for start-up firms, producing Schumpeter's creative destruction.

This creative destruction process can also be catalyzed or augmented by government actions to finance scientific learning, create an initial market (demand pull) through government contracts and/or regulations, or end the monopolized knowledge of incumbent firms through forced licensing of intellectual property. For example, the US government financed scientific learning for military purposes on digital computing during World War II, and IBM commercialized this digital technology created under a government project, and AT&T's Bell Laboratories and IBM played an outsized roll in R&D in the 1960s and 1970s, inventing the transistor (Bell Labs), which allowed the US to take the lead over Europe in electronics. However, the transistor only led to the invention and commercialization of the integrated circuit by Texas Instruments and Fairchild, and then the microprocessor by Intel (a spinoff of Fairchild), because of the US military's interest in the application of transistors as substitutes for vacuum tubes in military equipment and weapons. Thus, the US government opened the new electronic-based industries to competition by making the patents of Bell Labs and IBM available, not just to US firms but also globally, because they were slow to commercialize new technologies, through anti-trust actions (Dosi 1984; Chandler 2005: 83). Thus, governments have had an important role in driving the technological trajectory and spurring innovation.

In the automobile industry, creative accumulation of first mover and fast follower firms mass producing internal combustion engine vehicles was retained due to the continuity in the dominant design, and thus the absence of radical innovation. These incumbent automakers engaged in incremental innovation in competition with each other, but actively resisted government efforts to shift to electric vehicles, as shown in section 6, and government regulations were not strong enough to force the switch. The switch did not happen until latecomer firms in China recognized the window of opportunity, and with government support, invested in battery technology R&D in the 2000s and the mass production of electric vehicles in the 2010s.

When Perez and Soete (1988) referred to windows of opportunity, they were referring to the kind generated by new technology systems, that are at the heart of new techno-economic paradigms such as automobiles when they emerged and the integrated circuit that led to the microprocessor. They note that the knowledge required to enter a new technology system in its early phase is public knowledge available at universities, and the window is created by incumbent firms' risk aversion to commercialize it. This creates the incumbent trap (Lee and Malerba 2017). We can debate whether this knowledge is in fact ever public, as it was held in patents in relation to electronics. Thus, there is a role for governments (as noted above) but also latecomer firm strategies in brokering access to the scientific knowledge. While the kind of opportunities Perez and Soete referred to do not occur often, the contribution of Lee and Malerba (2017) is to outline other, 'smaller', windows of opportunity for latecomer firms to catch-up and move ahead, including incremental technological changes that change part of the scientific knowledge and production process but not all, changes in market demand and the emergence of new demands, and government policies that make scientific knowledge available, create market demand and generally intervene in markets.

The general importance of windows of opportunity is that they reduce incumbent advantages, as incumbents and latecomers both must learn new scientific knowledge, create new organizational capabilities, and build a new supporting nexus. Perez and Soete (1988: 477) referred to this as 'lowering the threshold of entry where it matters most'. Lee (2013, 2019) built on this insight when he argues that frequent changes in technology, short cycle time of technologies, provide more opportunities for latecomers to catch-up and overtake incumbents, even in the absence of new technology systems.

What we observe in the automobile sector with the emergence of new energy vehicles does not fit completely any of these descriptions of windows of opportunity, because it was about the application of existing technology from one industry (battery technology from consumer electronics) to another (automobiles). But it does fit the general observation of Perez and Soete (1988: 476) that, 'Development is not about individual product successes but about the capacity to establish interrelated technology systems in evolution, which generate synergies for self-sustaining growth processes'. In this respect, the loss of manufacturing capabilities around consumer electronics in the US and Europe to Japan and then South Korea, Taiwan and China, put the West at a disadvantage, as electric vehicles are the overlapping of two technology systems, even though neither is radically new. Being close to consumer electronics manufacturing drove innovation in battery technologies, and gave Chinese pure EV firms an advantage with scientific knowledge, which was initially accessed from Japan; organizational capabilities in large-scale battery production; and the supporting nexus of firms and infrastructure. But the independent Chinese firms at the forefront of EVs needed both the automobile industry and the electronics industry in China with which to do this, explaining why it was China in which the most competitive EV firms emerged.

While industrial leadership changes have occurred in several industries, there is a pattern through which firms/countries do this: except for jets, Japan and South Korea feature strongly in the leadership change in the industries in the Lee and Malerba (2017) study. Therefore, there must be more to the explanation of how latecomers forge ahead than the factors emphasized by Lee and Malerba (2017), including high levels of learning, absorptive capacity, marketing capabilities, and supporting public policy, public research institutions, advanced human capital, finance, and a network of suppliers. As we discuss in section 8, not all of these factors are equally important and there are other important factors that are not mentioned, and furthermore we need to go beyond just listing factors to understanding how they emerged.

3. INCUMBENT ADVANTAGES IN THE GLOBAL AUTOMOTIVE INDUSTRY

Of the top 10 branded automakers in 2023 by revenue, eight were incumbent firms, including the pioneers Ford and General Motors that were established in the 1900s (see Table 2). All the European firms were established between the late 1800s and the 1930s, and Toyota and Honda were established in the 1930s and 1940s, respectively. Korea's Hyundai is the only latecomer firm founded after World War II to become a major competitor globally in internal combustion engine cars. The top ten firms remained relatively stable in the 2000s and accounted for about 70 percent of the global market, although market share changed among them, except for Chinese state-owned SAIC joining the top ten recently. Below the top ten automakers, there has been significant change due to the growth of local automakers in China, India, and Iran, but they all sell predominantly in their domestic markets, including SAIC (Sturgeon 2022). China's domestic market surpassed the US as the largest auto market in 2012 (Chu et al. 2019), and six Chinese firms were in the top 20 global automakers by revenue in 2023 (according to data from Yahoo Finance).

Data on automotive supplier firms similarly shows the remarkable persistence of incumbent firms in the global automotive industry. Table 3 displays the top ten automotive supplier companies in 2023 by revenue. Eight of the ten firms were from traditional car making countries. The Japanese suppliers Denso and Aisin used to be subsidiaries of Toyota (Cusumano 1985). Similarly, Hyundai Mobis is a spin-off from Hyundai Motor Company, which remains strongly connected to the latter. CATL from China is the clear outlier in the list. It the biggest lithium-ion battery producing company in the world (see Section 7). Among the top 100 automotive suppliers, only ten firms were not headquartered in North America, Western Europe, Japan, or South Korea, of which nine were Chinese (Berylls Strategy Advisors). These Chinese suppliers emerged based on a large domestic market for automobiles in which foreign and local automakers operate, as well as international acquisitions and the growth of electric vehicle production (as discussed in Section 7). There is only one firm in the top 100 list that is not headquartered in Western Europe, Northern America, Japan, South Korea or China: Motherson (India) grew based on acquisitions after the global financial crisis in 2008/09 (Sturgeon 2022).

Table 2. Top 10 Automotive Carmakers by Revenue*, 2023

Company	Home country	Revenue in $bn, 2023
Volkswagen	Germany	318.3
Toyota	Japan	286.2
Stellantis	Netherlands**	200.9
Ford	USA	169.8
General Motors	USA	169.7
Mercedes-Benz	Germany	161.2
BMW	Germany	158.0
Honda	Japan	129.2
Hyundai	**South Korea**	118.4
SAIC	**China**	103.2

Source: Yahoo Finance, accessed via finance.yahoo.com.
Notes: *Revenue data was used for the ranking because production data by company is only available up until 2017. Based on the number of vehicles produced per year in 2017, the ranking is Toyota, Volkswagen, Hyundai, General Motors, Ford, Nissan, Honda, Fiat, Renault, and Groupe PSA (OICA).
**Fiat Chrysler merged with Groupe PSA to become Stellantis in 2021 with The Netherlands as the headquarter.

Table 3. Top 10 Automotive Suppliers by Revenue, 2023

Company	Home country	Revenue in €bn, 2023
Bosch	Germany	56.2
Denso	Japan	45.7
ZF Friedrichshafen	Germany	42.9
Hyundai Mobis	**South Korea**	41.9
Continental	Germany	41.4
Magna	Canada	39.6
CATL	**China**	37.2
Aisin	Japan	31.5
Michelin	France	28.3
FORVIA	France	27.2

Source: Berylls Strategy Advisors, accessed via https://www.berylls.com/en/category/top-100/.

US firms pioneered the commercialization of the automobile in the mass market. The car was invented in Europe in the late 1880s, followed by several radical innovations in the engine choice and chassis design by European and US firms. For example, in 1909, there were 69 firms in the US, each producing an automobile with its own design. However, it was Ford that innovated a new mass production system in 1910 and as a result set the dominant design with the Ford Model T (Abernathy 1978).[2] Only a few other US firms were able to catch-up with Ford: GM and Chrysler. These three firms dominated global markets until after World World II when the US technology diffused to European firms as part of post-war reconstruction and investment, and Japanese automakers that had been building capabilities

[2] Chassis refers to the whole car except for the body; in other words, the frame, engine, transmission, brakes, wheels, and other mechanical components except the passenger body enclosure and its components.

were able to enter the US market. These fast-followers in Europe and Japan in addition to the first movers from the US became the incumbent firms, as shown in Table 2.

This section summarizes the US firm first movers, pioneers of mass-produced cars, and the entry barriers they created. It then explains how European and Japanese firms overcame these barriers to become fast-followers and key competitors. It shows that the market position of these incumbent firms was secured by high entry barriers that stemmed from the production process of mass-producing cars, rather than scientific knowledge and intellectual property rights. It also provides the global economic context in which these firms competed, and how their competition in turn shaped the global context which latecomers faced. Thus, it highlights the opportunities and constraints of the global market.

3.1 US firms: the pioneers of mass-produced cars

Ford achieved the dominant design because of the company's innovations in the *production process* which led to a low-price car that created a mass market in rural areas and small towns (Abernathy 1978). Ford produced one unchanged model for the low-priced market segment. The productivity gains came not just from the assembly line, but from having different productive units with specialized equipment for extensive mechanization to manufacture standardized components for a standardized product as well as innovations in work force organization. These innovations were made possible by innovations in steel making and machine tools, which Ford leveraged. The production system, across productive units, was capital intensive and tailored for one design, but with high demand and large volumes, the costs per unit fell.

As a result, Ford dropped retail prices to follow the learning curve, outcompeting all other firms and taking 50 percent of the US auto market until 1924 (Abernathy 1978). General Motors could not compete with Ford on price, so it pursued a strategy of offering consumers multiple models and frequent changes in models. GM gained in market share with *product development*, and Chrysler followed this strategy, complementing it with outsourcing components (rather than producing in-house), which allowed for more innovation in components. By 1923, these three firms had 80% of the US market, which increased to 90% by the mid-1960s. Small firms were forced out in the 1930s depression, but they never had a large market share.

The dominant design of automobiles only changed incrementally between 1908 and 1950 (Abernathy 1978). The dominant design in the engine, the low-cost v-8 engine, was introduced in 1937. Thus, patents in product design tailored off in the 1930s, with more patents in production processes, and innovations were achieved by working with the machine tool industry. The major innovations in engine and assembly plants diffused rapidly in the US.

This common production system was an engineering feat, but very capital intensive, which locked US firms into producing large car models. Most of the cost of production was fixed, so the unit cost depended on the number of units produced. There was little incentive to produce smaller cars sold at a lower retail price when the cost of production was the same. Abernathy (1978: 41-47) shows that the net value capture from changing models fell in the post-war period and that competition hinged on price and dealership services. Furthermore, 'when all firms have the same process capabilities, then any one firm can replicate the product innovations of any other', weakening the incentive for product innovation (ibid: 62).

3.2 European fast-followers, through diffusion of US knowledge

Ford and GM established automotive assembly plants in other countries in the second half of the 1920s. European countries had tariffs on finished cars and parts. Many European countries even prohibited foreign direct investment, but Germany and the UK did not, so Ford opened full manufacturing plants in these countries, and GM followed suit but instead bought existing companies. The result was that US automotive tacit knowledge diffused in Europe, especially Germany and the UK, which spurred investment by indigenous European manufacturers during the 1930s to catch-up (Altshuler et al. 1985: chapter 2). With well-trained and experienced US managers moving to European firms, as well as local suppliers becoming more efficient in order to supply to the US firms, knowledge and technological capabilities diffused through the industry, benefiting local producers and helping to close the knowledge and capabilities gap (Schwartz 2010: 231).

European automotive firms were constrained by their small domestic markets, which was resolved with the creation of the Common European Market and the reduction of tariffs among European countries in the 1950s and 1960s. European automakers produced different types of cars based on local market conditions and had different technical solutions to design requirements, with six automakers emerging as dominant. Their cars were small in design, compared to the US. Local automakers used advances in design as well as their engineering capabilities and better knowledge of local markets to compete with US firms, who had less experience operating in such fragmented markets (Schwartz 2010: 231). Between 1950 and 1973, vehicle production in Europe increased from 1.1 million to more than 11 million units equaling the size of the US market, which allowed European producers to also benefit from economies of scale (ibid: 232).

Tariffs between Europe and the US fell after World War II under GATT negotiations, but it was only in the 1970s that European cars became successful in the US market. US government regulations and oil price hikes made smaller more fuel-efficient cars necessary. European (and Japanese) automakers were better able to provide such cars because US firms did not sell small cars. US automakers responded by introducing a 'compact' car, and then European firms responded by producing 'larger' versions of their small cars aimed at the luxury market.

Thus, a key strategy for entry into the US market was to create new market segments: first the small car, and then a luxury small car. This is a strategy that Japanese firms would also use, rather than competing directly with US auto firms. European automakers were smaller in size than US firms and more specialized, relying on independent suppliers as well as design and engineering companies to play a role in R&D and new product technologies (Altshuler et al. 1984: 164). European automakers also used a different design for the body in their small cars, a unit construction, which led to material, weight and labor savings. US firms applied this design, but Abernathy (1978: 58) notes that this product design led to a production process that was even more expensive to change with each model change. Toyota and other Japanese firms were able to enter the US market in the 1970s on the basis of low cost but high-quality small cars at a time when US consumers were turning to small cars, capturing a significant US market share.

3.3 Japanese fast-followers, through leveraging US & European technology

The Japanese auto industry is almost as old as the European one, with Japanese firms emerging after World War I to make trucks for the military (Cusumano 1985). This market demand provided the first opportunity for leveraging foreign designs and experimenting with mass production systems. In 1925, Ford established a plant to assembly knock-down sets in Japan, due to the high demand in Japan for its Model T, and GM followed in 1927. The Japanese military's interest in the auto industry grew in the 1930s because of the invasion of Manchuria in 1931 and imperial expansion, which made trucks necessary.

GM and Ford trucks were superior to the ones produced by local firms, so the Japanese government adopted an automotive industrial policy in 1936 to promote the domestic industry. It banned imports, eventually squeezed out Ford and GM. The government gave Toyota, Nissan, and Isuzu a temporary monopoly in the domestic market. Market protection did not prompt Toyota and Nissan to enter the auto industry; they had entered the auto industry already in the late 1920s and early 1930s, even though the large, older trading and financial conglomerates (*zaibatsu*) hesitated due to the dominance of Ford and GM cars in the domestic market.

Nissan was set up by an industrial group (a new *zaibatsu*) that had many companies prior to World War II, including in metals, machinery and chemicals (Cusumano 1985). This industrial group had a metal parts company producing automotive parts, and bought a small local automaker with designs, engineers and manufacturing facilities. It produced parts for Ford and GM through subcontracting, and when those US firms left Japan after the 1936 law, Nissan hired many of the Japan Ford's employees and confiscated most of the assembly machinery, with permission of the government. Nissan also leveraged significant technology from the US through importing US machinery as well as vehicle and engine designs from small US firms for little or no royalty fees. It hired American engineers to set up production facilities and run operations, who recreated the Ford production system. US engineers were essential to learning how to operate the specialized American machine tools and to implementing vehicle and engine designs. Nissan pioneered the transfer of truck technology from the US to Japan, and it was the first Japanese firm to mass produce vehicles competitive with US models. However, learning truck production was expensive and required operating at a loss, financed through the industrial group.

When Nissan wanted to move into passenger car manufacturing, it entered a licensing agreement with Austin (British Motor Corporation) in 1952. The Japanese government had encouraged Japanese automakers to form alliances with European firms as a way to close the technology gap. Isuzu had an agreement with Rootes, Hino with Renault, and Mitsubishi with Willys-Overland (Cusumano 1985: 90). Nissan's contract, similar to other Japanese-European firm alliances, was to first assemble knock-down kits, gradually shift to locally made parts and make the entire Austin in Japan within three years, by mid-1956. Austin was chosen because at the time no other company exported more cars to the US market. Austin provided patents, designs and technical assistance, and Nissan paid royalties. The production technologies acquired by Nissan as a result of this technical cooperation contributed to the later development of Nissan's Cedric in 1960.[3] However, the technical cooperation agreement with Austin restricted Nissan to learning with the Austin design and parts. In contrast, Cusumano (1985) argues, Toyota moved to its own models faster, copying parts from foreign cars but changing slightly to avoid patent violations (Cusumano 1985: 100).

Toyota has its origins in textile spinning and weaving and textile machinery firms, which invented the world's first automatic loom. The owner of Toyoda Automatic Loom sold the patent rights to a UK firm and used the money to capitalize his new automobile manufacturing firm, along with private bank loans and funds from Mitsui (an old *zaibatsu*, with which he had family relations). In the prewar period, Toyota leveraged foreign technology through reverse engineering and copying components from US trucks. Toyota sent its engineers to the US to study US firms' production methods, then adapted them to lower output volumes and made as much of the production machinery in-house. It was able to do this because Toyota had accumulated capabilities in precision-machinery design and manufacturing, metals casting, and other skills from Toyoda Automative Loom that were needed in automobile production. By 1930, automobile design and manufacturing had diffused enough for Japanese engineers to copy foreign vehicles without violating patent laws. Toyota imported machine tools and then reverse engineered and produced them; it also opened its own steel manufacturing company due to a shortage in Japan. Toyota's Japanese engineers built an engine by copying a design, again buying foreign components and then having local firms reproduce them. Thus, Toyota reproduced American technology, which Nissan had purchased, without relying on US engineers and invested more in in-house R&D. Cusumano (1985) argues that this strategy placed Toyota in a better position later to

[3] https://www.nissan-global.com/EN/HERITAGE_COLLECTION/short_story/en_p13-01.html.

innovate a unique production system based on Japanese market conditions.

The protected domestic market was important for Japanese firms to have the space to learn how to produce without competition from incumbent foreign firms. However, other industrial policies were not as significant in the emergence of globally competitive Japanese automakers. Cusumano (1985: 20-21) shows that many of MITI's policies had little effect on auto industry development.

Rather, Japanese firm initiatives drove foreign technology acquisition, application and adaptation. They acquired and mastered US truck technology using finance from other industries and leveraging national capabilities in metal parts and machine tools, and produced trucks mainly for the Japanese military, with expansion in Manchuria and war with China in the 1930s. They benefited from government loans and private bank loans in the 1940s to keep them operating, before demand increased in the 1950s through procurement by the US military during the Korean war and then economic growth in the Japanese economy, which allowed the Japanese automakers to start making cars. The restructured *zaibatsu* with experience in aircraft, tank and ship manufacturing for the military moved into making automobiles in the 1950s, and brought their parts suppliers with them, and two precision machinery manufacturers also began producing automobiles, including Toyo Kogyo (Mazda). Of the eleven Japanese firms that made automobiles in the 1980s, all except Honda existed prior to World War II and had experience as manufacturers of cast-iron components, textile machinery, multi-purpose engines, motorcycles, tanks, aircraft and other precision machinery products.

When Japanese automakers moved into making passenger cars, they emulated European automakers because small cars were more suitable to Japanese conditions than large US cars (Cusumano 1985). On their part, European automakers were interested in having Japanese firms produce their cars in Japan because importation was prohibited. Japanese firms except Toyota entered arrangements with European carmakers to gain knowledge of car design and production technology.

By the 1970s, Japanese automakers had moved from catching-up to taking such large shares of the market in the US and European countries that governments responded with quota restrictions. This part of the Japanese auto story is well-known, popularized by Womack et al. (1990), who described the 'lean manufacturing' or 'just-in-time' production system of Japanese firms. However, Cusumano (1985) and Altshuler et al. (1984) provide more nuanced accounts, emphasizing the contextual factors that motivated it and made it work. The competitiveness of Japanese automakers was a combination of higher labor productivity, higher manufacturing accuracy, lower inventories in progress, greater flexibility to switch model mix and develop new products, and lower wage levels. These factors combined to give Japanese automakers lower production costs with high quality products and to respond quickly to changing market demands. These factors were the product of

Japanese latecomers introducing radical changes to the US production system and supply chain management because the smaller domestic demand meant that they could not achieve US levels of efficiency (unit cost) with the same production system. The innovations began in Toyota and were not implemented equally in all other Japanese firms, which pursued other business strategies such as Honda competing on product development (Boyer and Freyssenet 2002).

Cusumano (1985) shows how the productivity increases of the Toyota Production System came partly with ingenuity with machinery and workflow processes and partly from squeezing labor. Toyota reduced the number of workers required (and thus workers it took to build a car) by eliminating idle time (read: increased line speeds), making workers do multiple tasks, requiring overtime and unscheduled shifts as well as through producing sub-assemblies in small lots to check for errors and produce just what was needed according to projected sales. Efficiency gains at lower cost also came from spinning off its auto parts department into subsidiaries in order to increase production without raising capital investment equally and having suppliers geographically close to deliver parts in small lots just when needed for assembly and which allowed errors to be correct. Toyota also transferred value from suppliers to itself by taking advantage of lower wage scales in suppliers and price cuts following productivity gains from those suppliers. Other Japanese automakers had similar supply chain management, which resulted from the industrial group structure and specific Japanese laws on financial reporting, which recognized subsidiaries of separate firms. The Japanese automaker would be a 'core' firm, with affiliated supplier firms (equity, or JV) providing mostly single sourcing to the core firm and a further layer of suppliers in a supplier association for the core firm (Altshuler et al. 1984).

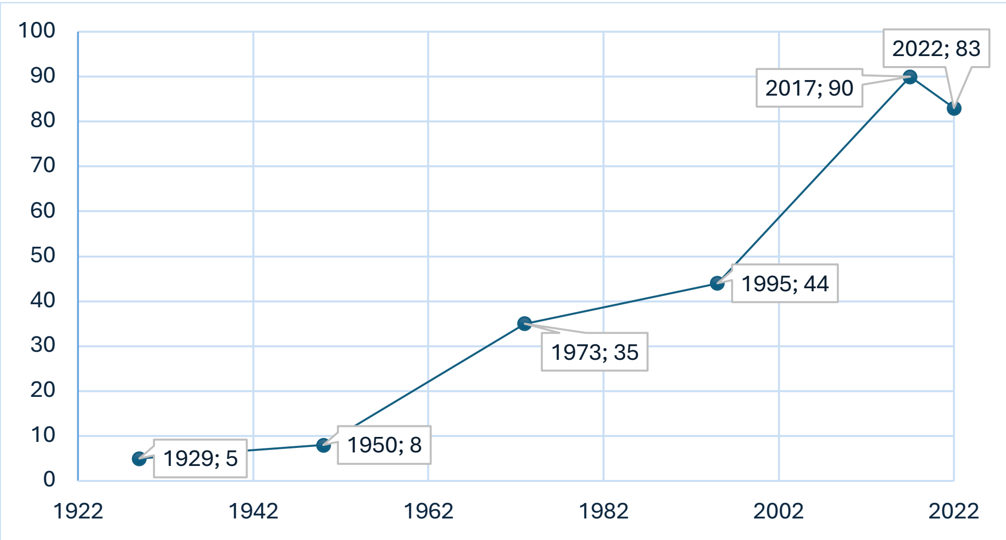
Japanese automakers' first exports to the US in the 1960s were too low quality and not successful (Altshuler et al. 1984: 31). It took them two decades to develop a production system that could produce low cost but high-quality cars that could compete with US incumbents, but there was one last important factor. Japanese automakers' ability to enter the US market with small cars owed much to oil price hikes in 1973 and again in 1979, which led US consumers to shift their preference to small cars. Altshuler et al. (1984: 162) note that Japanese automakers' market share in the US increased around these periods, emphasizing that market demand and production availability have to be synchronized in order for a particular national industry to expand its global market share.

3.4 Opportunities and constraints of the global market

The situation in the global market and access to the largest national markets are very important for the success of latecomer firms, in terms of shaping the opportunities to access demand and reach economies of scale. *There is a total world demand at any point in time*. Figure 1 indicates global car sales, which is a proxy for the trends in global demand, from 1922 to 2022. When national and global demand are growing, as in the boom period in the

1950s and 1960s, it would be easier for latecomers to access major end markets without necessarily taking existing share from incumbent firms. In contrast, when global demand is stagnating, as in the 1970s and 1980s, latecomers necessarily take market share from incumbents, prompting protectionist measures by incumbent firms' governments, as we saw with the US negotiating voluntary export restraints with Japan in 1981 on autos (and other manufactured goods), and European governments putting pressure on the Japanese government to cap auto exports (Altshuler et al. 1984). Thus, there is a fallacy of composition: with a stagnant global demand, there will be overcapacity and a zero-sum game in market share.

Figure 1: Global car sales, 1922-2022 (units, millions)



Source: BCG analysis, provided in Hagenmaier et al. (2023).
Notes: Light vehicles sales (incl. passenger cars and light commercial vehicles like pick-up trucks, but excluding heavy commercial vehicles). The lines between the data points are not reflecting actual data in those years in between. They are just connecting the available data points (1929, 1950, 1973, 1995, 2017, 2022).

Notably, the second oil price hike in 1979 led to a convergence in the type of automobiles demanded by consumers across advanced industrial countries, creating a more integrated global market; as a result, competition increased (Altshuler et al. 1984). Further convergences among national auto industries and firms occurred after the introduction of the microprocessor into auto production systems, creating more flexible manufacturing and lowering the costs of switching car models on production lines. This period also saw Japanese firms set up plants in the US and enter collaborative agreements with Western automakers in order to gain market access. For example, Ford gained approximately 25 percent in Mazda in the mid-1970s, which increased to 33 percent. One result was that Japanese innovations diffused among US auto firms, restoring the competitive balance. Japanese automakers also began using European design and engineering firms, and thus could develop capabilities similar to the specialist European automakers.

Given the global economic context in the 1970s and the barriers to entry to compete with incumbent firms with over half a century of cumulated knowledge, **the question is not why most latecomer attempts to create internationally competitive auto industries in the late 20th century failed, but rather how any succeeded**. Therefore, the next section explains in detail how the auto industry in South Korea (hereafter, Korea) emerged and its qualified success, as Hyundai was the only domestic firm that survived, in comparison to attempts by other latecomer countries.

4. SOUTH KOREA: LATECOMER AUTOMOTIVE CATCH UP IN SECOND HALF OF THE 20TH CENTURY

South Korea's first automotive assembly line was set up by Saenara Auto Company in 1962, with technical assistance from Nissan, but it shut down because it lacked the funds to import semi-knocked down kits for assembly (Kirk 1994: 125). Then the government supported a company to take over this firm, formulating a policy on import-substitution for the domestic automotive industry that promoted one company in order to achieve economies of scale (Kim 1997: 107). The selected company made financial contributions to the political party that the military government had just established, which was a general practice linked to industrial policy, especially state financing, in the 1960s (Ravenhill 2003: 117; see Woo 1991). Shinjin Motors assembled knock-down kits from Japanese automakers and then entered a joint venture with General Motors. However, Korean chaebol complained about this 'unitarization' policy, and the Korean government allowed Hyundai, Asia Motors and Kia to produce automobiles as well.

This first attempt at industrial policy is characteristic of successive Korean government policies to promote the automotive industry. As this section shows, the Park regime's policies often followed, rather than led, the initiatives of Korean chaebol—and especially Hyundai, whose founding chairman Chung Ju Yung was very close with President Park (see Kirk 1994). Unquestionably, government industrial policies supported Korean automotive firms and helped them access the necessary finance for investing, but they were only necessary and not sufficient. Without the initiatives of the chaebol, and mostly Hyundai, these policies would not have succeeded.

There were a few local firms making buses and trucks after the end of the Korean war, such as Ssangyong and Asia Motors. Kia started out in bicycles and then moved into producing Honda-licensed motorcycles and then three-wheeled trucks. Kia entered a partnership with Honda in 1967 to assemble cars. Hyundai Group was the only Korean firm that entered the automotive industry with relevant experience. It already had experience in the construction industry, including construction projects in Southeast Asia and the Middle East, and in shipbuilding (Kirk 1994; Amsden 1989). Daewoo, which would buy Shinjin in 1978 and take over the partnership with GM, had experience in machinery, including diesel engines. Hyundai and Daewoo also both entered electronics, which became important for the auto industry in the 1990s (Hobday 1995; Kirk 1994).

However, it was only Hyundai that had the kind of 'project execution' capabilities that Amsden (1989: 128) emphasizes as necessary in heavy industries and a kind of general knowledge that could be applied from one industry to the next. As Kirk (1994) shows in his detailed account of the rise of Hyundai Group, Hyundai generated these project execution capabilities through learning-by-doing in the construction industry, relying heavily on US military contracts. It then leveraged these capabilities into shipbuilding, and then into autos.

Hyundai Motors was established in late 1967 and by early 1968 had entered a partnership with the US firm Ford to assemble completely knocked down sets with equipment and technical assistance from Ford. At that time, Ford had been looking for a Korean partner, but Hyundai had resisted management participation by Ford in Hyundai Motors (Kirk 1994: 126). This is important, as the joint ventures between Asia Motors and Renault and between Kia and Mazda involved more control by the foreign partners. Hyundai and Ford eventually clashed and the partnership fell apart, as the leadership of Hyundai Motors wanted to create their own brand and not just produce Ford's cars. The partnership with Ford, however, was very critical for Hyundai Motor's ability to build capabilities in auto manufacturing, as Hyundai Motors started from scratch.

The Korean government approved plans by Hyundai, Kia and General Motors Korea (GMK) to manufacture cars (Ravenhill 2003). Asia Motors was excluded, which was bought by Kia. Shinjin, the Korean owner of GMK, was bought by Daewoo in 1978, as Shinjin did not perform well (Amsden 1989: 15). Wholly owned foreign subsidiaries were prohibited, so US and Japanese incumbent automakers took stakes in these Korean automakers in return for technology transfer. The nature of international competition in the global automotive market in the late 1970s and early 1980s is important for explaining the partnerships between Korean automakers and the incumbents. Kim and Lee (1994: 285) emphasize that in addition to taking stakes in Japanese automakers, US automakers initiated a strategy of 'captive imports' in response to their competitiveness problems with Japanese firms, which involved importing cars from their affiliates abroad first in Japan and then other Asian countries including Korea. Similarly, Japanese automakers responded by setting up plants in the US to bypass the voluntary export restrictions as well as establishing production in Taiwan and South Korea through joint ventures with local firms. Kim and Lee (1994: 286) also note that Korea had low-cost but high productivity labor, with wages much lower than Brazil and Mexico.

The government tried to limit entry to a few chaebol, but it was not entirely successful. It left the task of technology acquisition and development to the chaebol, which varied across the companies (Ravenhill 2003; Kim 1997; Kim and Lee 1994). Kia established agreements with Mazda for auto design, and Ford for marketing and sales in the US under Ford brand names, with Ford owning 10% and Mazda 8% in Kia. Notably, Ford purchased a significant share of

Mazda by the late 1970s, which explains the combined Mazda/Ford partnership agreement with Kia. Daewoo Motors had a 50% partnership with General Motors, which had management control until 1982 and provided the technology. After 1982, it was run by Daewoo but still produced GM products with older technology and was sold in the US under GM brand names. Ssangyong bought an existing local company making buses and trucks and entered a partnership with US firm AMC to make Jeep. Hyundai was the only Korean firm that rejected foreign partners that wanted participation in its management and which leveraged technologies from several foreign firms and integrated them itself into its own brand vehicle. In the early 1990s, Daewoo and Kia ended their dependence on foreign incumbent firms and tried to follow the Hyundai strategy, but it was too late, and both firms failed to survive, as shown below.

It was Hyundai Motors that spearheaded the idea of a Korean brand (Kirk 1994). The government then adopted and supported this idea in its 1973 policy for the automobile industry supporting the creation of a 'Korean car' that was locally manufactured, with the government giving very specific parameters for the car (Kim 1998).

Capabilities accumulated in assembling knocked-down and semi-knocked-down kits in the earlier period were insufficient to manufacture cars, as it required creating an entire production system that could generate cars of certain quality and at low enough cost as well as producing some parts in-house and managing the sourcing of parts from suppliers. Hyundai had to acquire body design, machine tools, engine design, and components production technologies as well as learn how to integrate them and produce efficiently.

The founder of Hyundai and his brothers sought a foreign automaker with which to partner to make its own brand car (Kirk 1994). Without much success in the US, they turned to Japan, and formed a partnership with Mitsubishi, which was seeking a Korean partner for its own reasons, as it was struggling to compete with the bigger Japanese automakers. Mitsubishi agreed to provide engine, transmission, accelerator and rear-axle designs to Hyundai for a fee. Hyundai's engineers spent years reading the literature on auto design and manufacturing and then being trained at the firms from which Hyundai acquired technologies.

But all of this was still not enough to develop knowledge of and production capabilities in systems integration. Crucial to its strategy was recruiting the ex-Vice President of the automaker British Leyland (notably, the successor to British Motor Company that Nissan had used), who had retired. On a three-year contract, this British auto expert hired a team of six foreign engineers who built the first engineering centre within Hyundai Motors. They licensed technology from 26 firms in 5 countries for various technologies (Kim 1997; Hyun 1995). The team was central to knowing which equipment, components and designs were needed, and it was central to arguing hard with Mitsubishi in terms of the engine design that was transferred. Hyundai's Korean engineers were sent to the foreign firms providing the parts and equipment for training, including a one and half year stint by five engineers at the Italian design-house Italdesign so that the Korean engineers would be able to undertake subsequent designs on their own. The British technical team made it possible for Hyundai to bring together the scientific knowledge and licenses into workable system by providing the tacit knowledge, working at Hyundai for three years. After the British engineers left, Hyundai hired Japanese engineers moonlighting from Japanese firms, for troubleshooting problems (Kim 1997).

Producing the Pony thus required Hyundai to invest in internal R&D in the 1970s and in tripling production capacity from 150,000 units to 450,000 units in the early 1980s in hope of (highly uncertain) sales on American and European markets (Kim 1997). The founder of Hyundai Group raised the financing to build the factory on land guaranteed from the government, with President Park's support, through banks loans from Britain, France and Japan as well as from local banks, totaling 172 million USD (Kirk 1994). Undoubtedly, Hyundai's track record of success in other industries such as construction and more recently shipbuilding helped to convince lenders of its ability to enter automotive. However, the foreign loans came with the condition that the money had to be spent buying capital equipment from the country form which the loan came. With this team, Hyundai Motors produced its first branded car, the Pony. The Pony was very successful in the protected domestic market, capturing 44% of market share in 1976, and was exported to the European Economic Community, but it did not meet US safety standards (Amsden 1989: 175; Lee 2024: 162). The Pony had serious quality issues but amounted to a serious jump in capabilities for Hyundai Motors (Kirk 1994).

The center piece of the government's automotive policy that supported the chaebol to produce cars included domestic market protection, through prohibiting car imports, as well as government financing through subsidized loans for investments and export subsidies, in addition to the restrictions on foreign direct investment that led to the technology transfer agreements with incumbent firms.

Through the government-controlled domestic financial system and export credits, the Korean government recycled petrodollars to the chaebol in the 1970s as 'policy loans' that had very low rates and long maturity. The government also backed the chaebol's efforts to take foreign bank loans. The chaebol and the Park's government needed each other. President Park channeled government financing primarily to the chaebol, as it argued that economies of scale were deemed necessary to survive in international competition; but the chaebol also kicked back funds from these 'policy loans' to political elites for personal and political financing (Woo 1991: 170). President Park and Chung Jung Yu, the founder of Hyundai Group, also had a particularly close relationship, with Chung often driving industrial policy by taking the first action and showing what was possible and then Park supporting him financially (see Kirk 1994).

The government automotive policy was part of its broader 1973 Heavy Industrialization Strategy that marked a shift in focus to heavy and chemical industries (HCI) including steel, machinery, shipbuilding and petrochemicals. Woo (1991) argues that the HCI strategy was the Korean government's response to several global economic and geo-strategic changes. The first was the changing position of the US in Korea, especially the winding down of US military aid to Korea under the Nixon administration. From 1950 to 1972, South Korea was one of the world's largest recipients of American military and economic assistance. In addition, US trade protectionism in the textile and apparel industry led to voluntary export restraints on Korean textiles, the country's leading economic and export industry at that time, still constituting one third of manufacturing and 38% of exports. The quota reduced exports by 15% (Woo 1991: 125). These changes made the government's previous economic growth strategy untenable. Its response was to focus on greater self-reliance, through building basic industries for industrialization and to find new exports. Basic industries such as steel, chemicals, and machine building made local production of automobile components possible.

Steel production was essential to the shipbuilding and automobile efforts. The government invested in a steel factory, financed through reparations from Japan (Woo 1991). The state-owned Pohang Steel Corporation (POSCO) started production in 1973. Government investment in the petrochemical industry started in late 1960s, making plastics production possible as well as synthetic textile production (see Kim 1997). The government also supported the machinery industry, which the largest chaebols such as Hyundai, Lucky-Gold Star (LG), Daewoo and Samsung entered, which allowed these firms to build their own tools used in other industries such as automotive.

The result of these government policies was to help create a <u>supporting nexus</u> for the auto industry. Automobile manufacturing is not an integrated process industry but a discrete parts industry, which needs steel, plastic, rubber, glass, mechanical materials, textile and later electronics (Kim and Lee 1994: 288). Steel and machine tool industries was arguably the most important backward-linkage sectors for automobile production. When Korean firms started manufacturing automobiles, steel contributed almost 81 percent of the total raw materials of Korean automobile manufacturing, slightly higher than the international standard of 76 percent (ibid). The Korean government also emphasized localization, with the Domestic Content Program, and provided financial support to local parts suppliers. Notably, some knowledge for manufacturing parts existed in Korea as a legacy from the colonial period when Japanese produced automobile parts (piston rings, bearings, and so on) for sending to Manchuria (Woo 1991: 143). This supporting nexus made it possible to build 'Korean cars' that had 80-90 percent local content by the end of the 1970s (Woo 1991; Kim and Lee 1994).

Japanese government policies and Japanese business strategies served as <u>role models</u> for both the Korean government and the chaebol. The Korean government's automotive industrial policy to create a 'Korean car', also referred to as a 'people's car' in some academic works, sounds like and the content strongly mirrors the automotive policy that Japan's MITI launched in 1955 for a 'people's car' (see Cusumano 1985: 20). Furthermore, the nationalization of the banking sector in the 1960s had been accompanied by what Woo (1991) explains was the revival of the Japanese colonial period banking structure where development banks channeled finance to *zaibatsu* to drive industrial development. The Industrial Bank of Chosen was formed in 1918 by the Japanese colonial government and modelled on the system they had at home. By the end of World War II, over half of the personnel at the Industrial Bank of Chosen were Koreans, many of which went on to occupy economic and financial decision-making positions in independent Korea. Finally, the *zaibatsu* dominated the Korean economy in the 1930s, providing a model for Korean entrepreneurs that became founders of the *chaebol*, which is the Korean transliteration of zaibatsu and was in circulation since 1932 (Woo 1991: 29-35). Thus, the Japanese colonial state-zaibatsu relationship in the industrialization drive in colonial Chosen/Korea in the 1930s and 1940s created a model for post-independence South Korean political elites and capitalists. Furthermore, the general trading companies created in 1975 to handle exports were modelled on the Japanese *shogo shosha*, which had previously handled Korean exports but left in the 1970s in response to US protectionism (ibid: 164-5).The Korean trading companies received export credits (subsidies) that were passed on to the exporting chaebol and provided a general source of finance but also an ability to export at prices that gave the chaebol low or no profits just to gain global market shares.

The second oil hike in 1979 led to a recession in the Korean and global economy, and Hyundai could not compete in export markets when Japanese firms lowered their export prices to maintain market share (Ravenhill 2003). Kia launched a new model with Mazda, while Hyundai pursued further technological indigenization to improve the quality of its cars in order to sell in the US market. Despite a decade of investment, Korea's automotive firms were not profitable. There was actually disagreement within the government, as some key political elite wanted to stop supporting the automotive industry (see Kirk 1994).

In 1982, Hyundai entered an agreement with Mitsubishi to provide expertise and capital investment. Mitsubishi agreed to license the newest generation engine (front wheel drive), which Hyundai needed for tougher markets, without management participation, only a 10% equity share, and no restrictions on exports. Hyundai continued to license technologies for body design and other aspects of car design from Italian, British and Japanese firms with which to create its new model, the Excel. However, it faced the new challenge of overhauling its production system to incorporate the new computerization technologies (electronic controlled machines) as well as meet new safety and environmental requirements. It took about six years to do this, exporting the Excel to the US in 1986.

A critical component of Hyundai's strategy, and arguably its success, was the creation of Hyundai Motors America with a group of US veterans in the automotive industry, many of which had worked in Japanese auto firms (Kirk 1994). They were in charge of sales and marketing, and created a distribution system through dealerships in the US. The Hyundai-only dealership system was important to controlling marketing and profits. In contrast, GM and Ford dominated the sales margin of Daewoo and Kia, giving them lower profit margins, although Kia was trying to market through independent dealers (see Kim and Lee 1994).

Hyundai also benefited from there being a market for small cars and from Japanese brands already being well-known to US consumers, creating a space for Asian cars. The Excel was priced very low, and dealers could make good margins. Furthermore, the appreciation of the Yen in 1985 and the import quotas on Japanese cars created room in the US market for Hyundai's Excel, which was similar to the Honda Civic but cheaper (Kim and Lee 1994). The price of the Excel in Korea was about 4500 USD but exported to the US at a price of 1850 USD, while comparable German and Japanese cars sold for 2300 USD (Lee 2024: 162).

While the Excel was initially successful, it fell in sales due to inferior quality and Japanese automakers circumvented trade protectionism in the late 1980s by producing in the US (Kim and Lee 1994; Kim 1998). In general, Korean automakers could not change models as frequently as the incumbents and had lower productivity than Japanese firms. As a result, Hyundai sought the latest generation of engine technology, as competing internationally required matching the quality of incumbents (Kim 1998). However, no incumbent firm would license this technology, not even Mitsubishi, and there was no car in Korea that had an electronically controlled engine that it could reverse engineer.

Therefore, Hyundai decided to produce its own engine and started investing in 1984. It established a R&D network with centers in the US, Korea and Japan and invested heavily in training is engineers abroad, but of utmost importance in developing engine design capabilities were two strategies. First, it hired Korean-American engineers that had worked in GM and Chrysler after getting their PhDs in the US, and through an agreement with British firm Ricardo Engineering in 1984 received training in engine design as well as engineers from Ricardo stayed in Hyundai from 1985 to 1988 (Hyun 1995). Overall, it took eight years and 140 million USD to produce its first engine by 1992 (Kirk 1994: 167). While this R&D took massive investments and time, the indigenized engine technology contained in the Accent, which Hyundai exported to the US in 1994, reduced its royalty payments to Mitsubishi from 17 million USD to zero (ibid). In other words, it strengthened its longer-term profitability, while also narrowing the competitive gap with incumbents.

Hyundai organized its sourcing based on the Toyota model, using suppliers that mostly produced just for Hyundai and to which they provided technical assistance and often credit for financing improvements (Amsden 1989: 179-188). Hyundai also sourced 40% from 'independent' suppliers within their groups, which had been divested to conform with government laws, as the government prohibited sourcing from own subsidiaries in order to support small firms. As with Toyota, subcontracting was cheaper than vertical integration, as suppliers could be squeezed and made to produce just-in-time, while close relations ensured quality and provided information on their costing. In contrast, Daewoo subcontracted less to local firms but rather imported parts or sourced from joint ventures in Korea with GM's US suppliers, as a result of its JV with GM.

It seems that licensing arrangements between Korean automakers and incumbent automakers in the 1970s and 1980s were more constraining for latecomers than they had been 30 years ago between Japanese automakers and US or European automakers. In the more competitive environment, incumbent automakers would only share technology, and old technology, if they could have management control and benefit by sourcing their brand name cars more cheaply; royalty payments were not sufficient. Even though Mitsubishi was more willing to transfer technology to Hyundai without management participation, it also held back from sharing its latest technology. Working with incumbent US and Japanese automakers which brought their technology was also an easier and cheaper option for Korean chaebol, but in the long run it created less profitability and left those firms with less knowledge and production capabilities than Hyundai, making them unsuited to survive in the competitive environment of the 1990s (which was discussed in section 3.4).

Global overcapacity put downward pressure on prices, which prompted consolidation in the global automotive industry as GM, Ford and VW took over many companies (Ravenhill 2003). Chrysler merged with Daimler Benz and took a stake in Mitsubishi, and Renault took a stake in Nissan. This consolidation among auto assemblers also led to rationalization in component sourcing through global supply chains and mega-suppliers, sharing production platforms, and engaging in joint R&D ventures. As a result, the economies of scale and capabilities required in the global automotive industry increased. Incumbent firms sought new markets after the end of the Cold War and to create a global presence. Korean firms contributed to overcapacity, as they opened new plants in Korea and other countries, increasing their debt, but at the same time they operated with low profit margins, selling low cost cars and competing on price. Ravenhill (2003) reports that Ssangyong, Kia and Daewoo did not make profits in the 1990s, although it is hard to confirm given the lack of financial transparency in the chaebol. Daewoo and Kia tried to change technology strategies and follow Hyundai, but it was too late. Kia, the second largest automaker in Korea, declared bankruptcy in 1997 before the Asian financial crisis started, as well as Ssangyong. Daewoo bought Ssangyong, but then also went bankrupt in 1999 because of the financial crisis.

Thus, there were five Korean automakers, part of conglomerates (chaebol), at the start of the 1990s, but by the close of it, there was just one national automaker with Korean control. Renault bought 70% of Samsung Motors, GM and its alliance partners took over control of Daewoo Motors. Ssangyong was sold to the Chinese SOE SAIC in 2004, and then on to the Indian automaker Mahindra in 2011. Hyundai bought Kia and turned it around, taking 72% of the domestic market. Hyundai had foreign shareholders, as DaimlerChrysler took 10% in 2000, but retained control, and DaimlerChrysler had its own problems and divested in 2004.

In the 1990s, the Korean economy was also liberalized, allowing foreign direct investment and reducing tariffs on imports. The denationalization also ocurred in components, where foreign suppliers bought out many local suppliers (Ravenhill 2003: 133).

The story of the Korean automobile industry is not one of success, but rather the success story is Hyundai. While government industrial policies and supporting nexus matters, there was variation across latecomer firms because it is firms that have to engage in acquiring, mastering and improving imported technology. Hyundai started with assembly for the Ford Cortina (1968-1976) but then broke with Ford's plans and pursued a Korean brand car with the Pony (1973-1985), while other Korean firms remained in partnerships with incumbent firms and used their technology. Hyundai then invested in improving quality with the Excel (1980-1994), and finally invested in producing its own engine in the Accent (1984-1995) in order to improve quality further, as it could not license state of the art engine technology from any incumbent. The technology that Hyundai bought from Mitsubishi would not have made it successful without the tacit knowledge of foreigners in the automotive industry (accumulated from years of experience in British and Japanese firms) that knew how to use it, and Hyundai's active technology leverage over many years of learning by doing and learning by research (Kim 1998). Thus, the case of Hyundai shows how important 'migratory knowledge' was to its process of building in-house capabilities.

5. TAIWAN AND OTHER LATECOMER AUTOMAKER FAILURES

Hyundai was the only comprehensive success case of a latecomer carmaker between 1970 and 2020. In other countries, latecomer carmakers failed to emerge, even in countries such as Taiwan with economic development success comparable to South Korea. An automotive industry started to emerge in Taiwan in the 1960s, similar to South Korea, through joint ventures between local private firms and Japanese automakers, especially after the Taiwanese government protected the domestic market with high tariffs in 1964 (Wade 1990: 92-93). However, none of these local firms developed independently as Hyundai did, and Taiwan's auto industry came to be dominated by Japanese auto and parts firms. Given the strong similarities between Korea and Taiwan historically and that both are seen as developmental states during this time period, why did a locally owned automotive industry not emerge? The Korean case shows just how high the barriers to entry were for latecomer firms to enter and become competitive auto exporters from the 1970s, but a comparison with the Taiwanese case helps to emphasize this point further.

In Taiwan, there was disagreement within the government over the direction of automobile industrial policy (Arnold 1989). Many doubted the ability of Taiwan to follow Korea's lead given the much smaller size of Taiwan's domestic market and thus inability to serve as a base for achieving economies of scale. Others in the government pushed for exporting, but through a joint venture between the SOE China Steel and a Japanese automaker, sidelining the local private automakers. The Taiwanese government did not want to support the development of large private business groups, along the lines of Korea or Japan, for political reasons (Noble 1996). Furthermore, Taiwan did not have the financial sector structure that Korea did, which was a product of Korea's colonial experience that Taiwan did not share. Thus, local firms did not have access to massive financing to support a long period of learning, nor did they have the strong production capability base that the Korean chaebol had, because state-owned enterprises dominated all heavy industries including construction and shipbuilding (see Wade 1990). In Korea, the state only dominated in steel because local firms did not want to enter (see Kim 1997). Notably, private Taiwanese firms caught-up with the Japanese in motorcycles instead, which had lower economies of scale and financing requirements (see Noble 1996).

Taiwan's experience is not the exception, but the norm. Several countries developed national automakers under protected markets and had export ambitions, such as Malaysia (from 1983) and Yugoslavia (from 1980). However, instead of developing their own technology, national firms in Malaysia (Proton and later Perodua) and Yugoslavia (Zastava's Yugo) continued to license technology from incumbent automakers, which restricted the markets to which they could export, and thus undermined their economies of scale (see Jomo 1994; Vuic 2010). The Indian government regulated foreign direct investment, requiring foreign automakers to form joint ventures with state-owned firms (the first SOE-foreign JV Maruti-Suzuki was founded in 1982). These joint ventures relied on foreign technology, and their foreign partners wanted to produce only for the domestic market. Indian private automakers emerged but remained marginal (Athukorola and Veeramani 2019). The Brazilian and Thai governments allowed foreign direct investment but pursued local content requirements as a strategy to build domestic suppliers, but these policies were not sufficient. Brazil's auto industry was dominated by foreign automakers producing for the domestic market, and local content requirements created local suppliers but then the foreign automakers switched to their transnational suppliers from the 1990s (Sturgeon 2022).

A review of latecomer country experiences highlights a knock-on effect of the failure to develop national carmakers with indigenous technology: the development of national tier-1 suppliers is also constrained. Vehicle production in developing and emerging economy locations increased massively from the mid-1990s onwards, as advanced country markets became saturated and large developing country markets experienced strong income growth (see Figure 1 in section 3.4). Since most developing countries had failed to develop national carmakers before this, automotive production in most emerging economies was driven by US, European and Japanese incumbent automakers. Facing increasing competition in growing emerging economy markets, carmakers switched from making inferior models for local markets (pre-1990s) to making centrally designed global cars with slight adjustments for local markets (post-1990s). In this context, domestic component suppliers became largely sidelined. Automakers from core countries and their most important suppliers collaborated to design new car models in their home design location, which required intensive and iterative design collaboration. In addition to product design, initial production ramp up also occurs in the home regions, in 'lead plants' of both assemblers and suppliers (Herrigel and Zeitlin 2010). After initial ramp-up and iterative process engineering between the assembler and the key suppliers in the lead plant, production is transplanted to the other production plants globally. Wherever foreign incumbent automakers assemble vehicles, they tend to require their tier-1 suppliers, with which they have co-designed the vehicle, to open a factory near their vehicle assembly plant. This process is called 'follow-sourcing' and explains why both vehicle production and tier-1 component production in developing countries are usually dominated by foreign incumbent automakers (Sturgeon and Lester 2004). Locally owned suppliers tend to come in as build-to-print suppliers in plastic moulding and metal fabrication at the tier-2 or tier-3 level (Wuttke 2023).

Foreign incumbent automakers are unlikely to collaborate with domestic suppliers as their tier-1 design partners even if they conduct some local design and product development. They already have their established tier-1 supplier partners and their proven strategy of follow sourcing (Sturgeon and Lester 2004). The presence of national automakers is thus crucial to also pull along national suppliers. A study of the South Korean tire industry by Kim and Mudambi (2020) documents how the domestic vehicle assemblers Hyundai and Kia have operated as 'keystone organizations' in South Korea's industry ecosystem and have induced domestic tire companies like Hankook to transition from imitation to innovation in product design. The Korean assemblers chose domestic tire manufacturers as their global tier-1 suppliers, which opened the door for these tire firms to enter large scale production for demanding global markets. This made the investment in design capabilities viable and attractive. The authors also point out that very similar dynamics in Japan in the late 1960s made Bridgestone and Yokohama invest in innovation and they became globally successful tire manufacturers (Kim and Mudambi 2020).

6. ABSENCE OF DISRUPTIVE RADICAL INNOVATIONS IN THE AUTOMOTIVE INDUSTRY

The dominant design of the automobile, centered around the internal combustion engine (ICE), has remained the same for roughly 100 years (Abernathy 1978; Bergek et al. 2013). Until the emergence of Tesla and competitive battery electric vehicles (BEVs) in the late 2010s, the dominant design remained steadfast and the pace of technological change in the automotive industry was incremental rather than radical. In an assessment of technological change in the automotive industry since the late 1980s until before the rise of BEVs, Smitka and Warrian (2017) find that 'new vehicle technologies are [mainly] responses to regulatory pressure to improve safety, limit emissions, and improve fuel efficiency' (p. 67), rather than revolutionary changes in technology and/or product architecture. This pattern of technological change has strengthened incumbent lead firms in the industry, rather than undermined them – aptly called ‘creative accumulation’ by Bergek et al. (2013).

The continuity in the dominant design has allowed existing technologies, capital investments, and business practices around production, distribution and sales to be retained. On top of that, the cumulative nature of capabilities and tacit knowledge of the incumbent firms under such conditions meant that the barriers to entry for latecomers increased over time. When a few firms control the market, their competitive strategies determine the course of technological progress, unless governments intervene, or other external stimuli occur. One key constraint for incumbents themselves to expedite radical technological change has been the need to keep the retail price of automobiles within consumer reach, even while cars became more complex, which required high efficiency in production systems. Such capital intensity and assets created an incentive to keep changes incremental: not change too many aspects of productive units at the same time, which would be costly (Abernathy 1978). Eventually, it was technological progress in lithium-ion batteries in the late 2000s and early 2010s that made BEVs commercially viable, initially in the premium segment, and incumbent firms started to face competition from newcomers like Tesla and BYD. Instead of embracing this technological shift, incumbent carmakers tried to slow it down and as of today, are falling behind the newcomers: they have fallen into the ‘incumbent trap’.

Alternative technologies to the internal combustion engine have been around for some time. The most prominent examples are fuel-cell based electric vehicles (FCVs) and battery electric vehicles (BEV). While FCVs have not reached commercial viability even today, BEVs are currently disrupting the automotive industry. BEVs, however, have been around for decades. Policy has occasionally tried to push BEVs as an alternative technology to internal combustion engine vehicles. In the early 1990s, two federal legislations in the US, the Clean Air Act Amendments of 1990 and the 1992 National Energy Policy Act, as well as even tougher regulation in California spurred carmakers to seriously look into alternative technologies to the internal combustion engine (Dyerson and Pilkington 2005). In 1990, the California Air Resource Board declared that 10% of new vehicles in 2003 should be Zero Emission Vehicles for every carmaker selling more than 35,000 cars in California per year. The policy was officially technology neutral, but unofficially the Board made it clear that it was expecting battery-powered vehicles, sparking efforts by GM, Ford, Chrysler, Toyota, Nissan and Honda to commercialize BEVs throughout the 1990s. At the time, however, battery technology was simply not far enough, and none of the carmakers dedicated significant resources to their EV projects, as it was clear that these would not be commercially viable. The EV projects were compliance and marketing projects to appease emissions regulators (Dyerson and Pilkington 2005; Tillemann 2015). Eventually, carmakers successfully lobbied the California Air Resource Board to reduce the Zero Emission Vehicle mandate to 4% by 2003 instead of 10% (Dyerson and Pilkington 2005).

Nevertheless, it was clear that emission requirements would continue to tighten going forward. Given the infeasibility of BEVs because of the insufficient battery technology with regards to weight and limited power storage capacity, carmakers aimed to reduced emissions in different ways. Throughout the 1990s, two Japanese carmakers made remarkable progress in this regard. Toyota developed its Prius model. The Prius was a hybrid electric vehicle (HEV), running both on a gasoline engine and a battery. It was not a plug-in hybrid (PHEV), as it did not feature the option to plug into an electrical outlet to recharge the battery. Simply put, HEVs are more similar in design to internal combustion engine (ICE) vehicles, while PHEVs are more similar to full BEVs. Honda invested significant R&D into building very-low emissions combustion engines (Tillemann 2015). European carmakers also responded similarly, with further refinement of ICE powertrains making them global leaders in low-emission diesel engines, and hybrid offerings for the premium segment (Magnusson and Berggren 2011). A convenient side-effect of going for HEVs and low-emission ICE vehicles was that the overall technological trajectory remained centred around ICE, keeping the dominant design and thereby the entry barriers in place.

In the late 1990s and early 2000s, EVs were simply not competitive because of lack of range due to limited technological progress in lithium-ion batteries. But after the global financial crisis 2008, the situation was different, as lithium-ion batteries had improved a lot and had become much cheaper, driven by their mass application in mobile phones and laptops (Magnusson and Berggren 2011). BEVs had another thing going for them, as oil prices continued to rise throughout the 2000s and early 2010s. However, given the resistance of incumbents to change towards a different technological trajectory, regulation was required to incentivize the transition to BEVs. This transition was basically suppressed in Europe, especially in and by Germany, and largely also in Japan.

The German carmakers (VW, Daimler, BMW) resisted a stronger regulatory focus on EVs. They did not want to see BEVs cannibalize demand for conventional cars and successfully lobbied the German government to slow down EV incentives in Germany, and to oppose and postpone stricter emission regulations at EU level (Meckling and Nahm 2018). In Japan, Toyota had established its strength in gasoline-electric HEVs, and Honda had focused on low-emission engine technology. They successfully lobbied the Japanese government to not push BEVs, and to instead support hybrids and efficient ICEVs for the time being, and to opt for FCVs as the long-term solution (Tillemann 2015). Nevertheless, other Japanese OEMs, namely Mistubishi, Subaru and Nissan went for EVs, which they saw as a niche to potentially leapfrog Toyota and Honda. Building convincing prototypes with much improved batteries, based on lithium-ion chemistries, they convinced the Japanese government by 2010 to provide significant subsidies to buyers of EVs (50% of the cost differential of the EV compared to the gasoline car). By 2013, Nissan sold 90,000 units of its EV model LEAF globally (ibid.). This initial success, however, never caught on. The 2012-2020 Shinzo Abe government emphasized the ‘hydrogen economy’ and not BEVs. By 2021, only 22,000 BEVs and 23,000 PHEVs were sold in Japan, in contrast to 2.96 million ICEVs and 1.44 million

HEVs.[4]

In the US, in contrast to Europe and Japan, the government tightened fuel and emissions standards more significantly, and also subsidized R&D and commercialization of electric vehicles earlier and more consistently. It doubled down on this strategy under the Obama presidency when the US carmakers were in financial trouble after the global financial crisis. Eventually, California's strict emission reduction requirements became federal law. The automakers opposed this, but failed to prevent it (Meckling and Nahm 2018). Incumbents, including GM, undertook serious efforts to develop EVs. The Chery Volt and especially the Nissan LEAF had decent sales in the US in the early 2010s. But the real breakthrough came from Tesla, a newcomer to the industry which exclusively built BEVs. It was supported by the US government, for example via a $465m loan by the Department of Energy for the Model S (Tillemann 2015: 176). Tesla was one of the few pure BEV carmakers globally in the mid-2000s and the first (in 2008) to commercialize lithium-ion batteries into a robust EV powertrain and battery pack (Perkins and Murmann 2018). Tesla took the risk on lithium-ion technology but also created a car based around information and communication technologies in which its owners had expertise. To create cars, Tesla hired experts to solve the battery problem and had various types of partnerships with Daimler, Toyota and Panasonic (Stringham et al. 2015). The key entry barriers were the network externalities related to charging infrastructure and finding finance for capital-intensive manufacturing. The latter was overcome through the massive federal government loan, tax breaks and incentives from local government, and then a public offering, and the former by Tesla investing in charging infrastructure and encouraging other firms to do so.

Overall, the only real breakthrough in BEVs in the 2000s and 2010s came from a newcomer to the industry: Tesla. Incumbents dragged their feet. Initially this was justified because EV and especially battery technology was simply not good enough to compete with ICE. But once lithium-ion batteries improved significantly in the late 2000s and early 2010s, that became less of a problem. However, incumbents did not embrace this new technology and instead tried to quell it. They lobbied against tougher regulation where they could. And wherever they entered into battery-powered vehicles, their strategy was to make the EV car and its role in society as much like a traditional car as possible. They preferred HEVs over PHEVs. They offered electric versions of their mainstream vehicles whose design was not optimized around a battery-electric powertrain, but reducing cost and risk by retaining existing body-chassis technologies that are optimized for ICE rather than battery electric solutions (Wells and Nieuwenhuis 2012). They also responded to threats posed by radical new technologies and associated companies by internalizing those technologies and companies (Wells and Nieuwenhuis 2012: 1685-6). It required an outsider start-up like Tesla and the technological improvements in lithium-ion batteries to break this deadlock. While Tesla was making headlines in the West, Chinese firms similarly identified BEVs and the

[4] Data from the Automobile Business Association of Japan, accessed via https://www.aba-j.or.jp/info/industry/16684/.

obvious incumbent trap as their opportunity to catch up in the automotive industry.

7. THE CHINA CHALLENGE: LEAPFROGGING OVER INCUMBENTS INTO EVS IN THE 2010s

China's automobile production was negligible until 1988 when the government decided to identify six state-owned enterprises (SOEs) – 'three majors' (FAW, SAW/Dongfeng and SAIC) and 'three minors' (Beijing, Tianjin and Guangzhou) – that from then on were allowed to exclusively produce and sell vehicles in China. These firms were supposed to achieve economies of scale in the domestic market, which was insulated by high tariffs (Chu 2011). They were allowed and encouraged to form joint ventures (JVs) with foreign carmakers to access technology. The strategy was understood as 'trading market for technology' (Feng 2020). In the late 1990s, the entry restrictions were loosened because of the imminent entry into the WTO, and more foreign investors were allowed in. The foreign investors nevertheless always had to form JVs with local SOEs. Chang'an and Yunque were two other SOEs that were allowed to form JVs, in addition to the above six (Feng 2020).

Under the 'trading market for technology' regime, vehicle production increased from 650,000 units in 1988 to two million units in 2000. Between 2000 and 2006, it increased to more than seven million units (Chu 2011). The problem with that regime was that the SOEs did not indigenize technology. They did not develop their own designs. They continued to rely on their foreign JV partners for technologies and platforms to introduce vehicles into the Chinese market (Brandt and Thun 2016; Feng 2016; Thun 2018). Their JV partners also actively prevented technology transfer to their local Chinese partners, as it was not in their interest (Feng 2016: 143-145; Nam 2011). Until the early 2000s specifically, the foreign partners often introduced outdated vehicle models, which they were no longer producing in their home markets.

Some contributions in the literature still claim that the trading market for technology policy was successful (see e.g. Bai et al. 2022).[5] Our analysis in this paper of the Chinese case, but also of previous cases of automotive catch-up, highlights the centrality of firms' own

[5] Bai et al. (2022) paint a positive picture of the policy which they call 'quid pro quo', based on an econometric analysis of the quality of vehicle models in the Chinese market. They point out that SOEs' own models' quality has improved significantly over time because of learning through foreign-SOEs JVs. The fact that SOEs' own models' quality improved should not surprise anyone though. The SOEs tend to license design and technology from foreign firms, even for their own vehicle models outside of the JVs (Feng 2020). This means that their models are of decent quality, but they are largely dependent on foreign technology. Bai et al. (2022: 19) claim that they address this issue by controlling for patent transfers in their econometric analysis. They find little evidence of patent transfers and therefore conclude that "the observed patterns of spillover are unlikely to be driven by market transactions of technologies" (p. 20). This conclusion is unjustified, since the SOEs might have (and based on Feng's detailed studies, are likely to have) engaged in licensing agreements over design, blueprints and other forms of proprietary knowledge, which would not have been captured by Bai et al.'s control variable of patent transfers.

technology leverage and learning efforts. The trading market for technology policy in China was helpful in terms of indirect spillovers, i.e. capability-building of engineers in SOE-foreign JVs and establishment of local automotive supply chains, but was at best irrelevant and in some ways counter-productive with regards to technology indigenization. The latter was driven by independent carmakers like Geely, Chery and later BYD.

In 2001, the three major's car models Jetta (FAW), Santana (SAIC) and Fukang (Dongfeng) captured 50% of the domestic market. This figure dropped to 18% by 2004 (Feng 2016). Independent Chinese automakers without foreign technology partners, often supported by local governments with funding, were making significant inroads into the market. In contrast to the SOE-foreign JVs, the independent automakers did not form JVs with foreign firms. They developed in-house capabilities for vehicle development and design from the beginning, unlike the JVs which relied on foreign technology (Li 2009; Feng 2016, 2020).[6] The way the independent Chinese automakers developed their capabilities is in many ways similar to how Hyundai did it. In contrast to Hyundai, however, they had the advantage of being able to almost fully rely on the large domestic market, without having to convince in export markets.

There were over 100 independent Chinese automakers that emerged in the late 1990s and early 2000s (Feng 2010: 81). Importantly, they emerged against the central government's will and operated illegally without licenses. The two most successful ones were Geely and Chery. Geely was founded in 1997, coming out of a company that existed since 1986 and had previously produced refrigerators and motorcycles. Chery was also founded in 1997, and was owned and supported by the Wuhu municipal government in Anhui province (Chu 2011; Feng 2010). Despite being "state"-owned, Chery did not enter into a JV, because it was owned by the local government and not by the central government. Geely was privately owned, but also supported by the local government, e.g. with funding for its first automobile factory. Both Geely and Chery were uninteresting for foreign investors and thus had to develop their own capabilities to develop and introduce car models. They did not have a license to operate, as the central government strictly restricted entry into automotive production until 2001. So, they initially operated without license, and then started to pick up licenses by making deals with existing SOEs, which is what Chery did with SAIC, or by buying bankrupt SOEs with licenses, as Geely and BYD did (Feng 2016: 151-52).[7]

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[6] Once Chinese policymakers noted the success of these private carmakers, they embarked on a significant policy transition: Rather than relying on 'trading market for technology', they started to focus on 'indigenous innovation'. The term was introduced in 2006 via the *National Programming 2006-2020 for the Development of Science and Technology in the Medium and Long Term*, and indigenous innovation has been the core focus of Chinese innovation and industrial policy ever since (Feng 2020). The SOEs had to react to both the policy shift and the success of local private carmakers. They introduced more modern models based on foreign platforms, and also started to set up indigenous brands. However, they did not really manage to shed the old 'trading market for technology' mindset. SAIC performed the best out of the three majors and has managed to develop cars and engines independently, while FAW and Dongfeng still depend heavily on foreign technologies and platforms to develop new products (Jiang and Lu 2018).

[7] Chery ensured managerial independence in its contract with SAIC (Luo 2005: 16).

For their initial models, which were low-cost entry-level vehicles, both Chery and Geely relied on hiring (retired) senior engineers from SOEs – Chery from FAW and Dongfeng, and Geely from FAW; and on reverse-engineering and mimicking SOE-JV models. Both managed to attract these SOE engineers by giving them important posts and because the engineers were intrigued by the prospect of developing independent car models, having become frustrated by the absence of local development work within the SOEs (Chu 2011; Feng 2016; Luo 2005). Geely built its first model in 1998, the HQ, after Tianjin-VW's XiaLi model, adopting the engine and chassis assemblies from the XiaLi's domestic supply chain (Feng 2010: 197). Chery's first model, the Fulwin (1997), was based on the SEAT Toledo, which had the same chassis as the Jetta that FAW-VW built in China (Chu 2011; Feng 2010). The former FAW engineers understood the car well and had contacts to Jetta suppliers in the country that Chery could use. SEAT did not provide the molds for the body and Chery used a Taiwanese supplier for that (ibid.). In 1999/2000, Chery and Geely started to sell the Fulwin and the HQ. They rapidly gained market share in the low-cost entry market segment, based on low prices. Geely's HQ, for example, was sold at RMB40,000 in 2000, 40% of the price of comparable SOE-foreign JV models (Li 2009: 29).

In addition to skilled personnel from the SOE-foreign JVs, the independent automakers could also use the established local supply chains of the JVs. This illustrates how the policy for trading market for technology via SOE-foreign JVs was a failure with regards to the technological capabilities of the SOE automakers, but nevertheless had important spillover effects, which other automaker firms could build on, especially the human capital and the supply chains. But Geely and Chery also aimed to become less dependent on the SOEs' supply chains and encouraged smaller local suppliers to upgrade and take more responsibilities by moving into the first tier and supply full modules (Brandt and Thun 2010: 1569). They encouraged talented engineers to set up their own companies to supply them (Feng and Li 2019). In that way they built up their own supply networks. The more successful they became, foreign tier-1 suppliers, which had originally come to China to supply the SOE-foreign JV carmakers, became also more willing to supply them (ibid.), and the independent automakers themselves spun off internal divisions into tier-1 suppliers as they grew (Feng 2010: 131).

The knowledge and capabilities acquired through reverse engineering and imitation and by hiring domestic experts from the SOEs for the first models built the absorptive capacity to acquire and adopt foreign technology and knowledge in the next step (Feng 2016: 157). For their second and further models, the independent automakers wanted to rely more on genuine model development rather than mimicking and reverse-engineering existing models, mainly to overcome the reputation that they were cheap and technologically backward copycats (Feng 2016). Just like in the case of Hyundai in Korea, significantly more intense technology leverage efforts were needed for this second step. They set up large R&D centers. By 2005, Chery had 2,000 R&D staff, and by 2012, it had more than 6,000 (Feng and

Li 2019). The independent automakers started to access and integrate foreign knowledge. Notably, the downturn of the Western auto industry in the 1990s led several automotive technology provider companies like Pininfarina, a specialized Italian car body design company, to look to China as a potentially interesting market. It entered into a collaboration with HaFei, an early private Chinese automaker (founded as a subsidiary of an aviation company in 1980), in 1993 in order to enter the Chinese domestic market. Both Chery and Geely relied on numerous similar external collaborations, in the same way as Hyundai had done in the 1970s and 1980s. Chery collaborated with AVL from Austria (engine); Bertone, Pininfarina and Torino Design from Italy (overall design); MIRA (chassis) and Ricardo (transmission) from the UK; Lotus (testing) from Malaysia; and Dürr (paint) and MAG Müller Hille (engine cylinder production line) from Germany (Feng 2016: 156).

Like Hyundai before them, both Chery and Geely ensured that they would actually benefit from these collaborations by absorbing knowledge: Engineers that were sent to the overseas partners were required to regularly report back which new technologies they had learnt; and they were endowed with funds to search for new collaboration opportunities when sent abroad (Feng 2010: 226; Li 2009: 35). The external partners often tried to shut Chery's and Geely's personnel out from development activities, and thus the independent automakers had to force their external partners to be allowed to learn. To achieve this, they let engineers with in-depth knowledge on the bottleneck technologies draft the collaboration contracts to ensure learning would happen. They sometimes terminated the collaborations if they felt they were not getting enough out of them. They ensured to get more and more activities located inside China, which increased their control (Feng 2010: 128). In addition to these external collaborations, another mechanism of integrating external knowledge was hiring overseas returnees (Chu 2011: 1257; Feng 2010: 219-222; Li 2009: 33). In 2007, Chery had almost 100 returnees with experience from working in leading automotive MNCs. Chery and Geely actively headhunted Chinese in overseas carmakers and suppliers (Li 2009: 34). Certain high-skilled individuals received RMB1 million by the central government to return to China to help domestic firms (Helveston 2016: 93-94).

Table 4: Share and units of indigenous brands in the Chinese domestic car market, 2001-2017

	2001	**2002-3**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Share	<5%	n/a	21%	25%	26%	26%	26%	44.3%
Unit		n/a	463,000	692,000	983,000	1,242,000	1,308,000	4,577,000
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Share	45.6%	42.2%	41.9%	40.3%	38.4%	41.3%	43.2%	43.9%
Unit	6,273,000	6,112,200	6,485,000	7,222,000	7,573,300	8,737,600	10,529,000	10,847,000

Source: Feng (2020: 49), based on Chinese government data.

By 2007, local Chinese brands had reached 26% market share in China (see Table 4). Chery was the largest with 381,000 units (as well as 120,000 units exported to overseas market), and Geely was second with 221,000 units in 2007 (and exports of roughly 20,000 units) (Li 2009: 36). The independent local automakers had had tremendous success: They disrupted the local automotive industry, developed indigenously designed vehicle models, and reached production volumes in the 100,000s. The share of indigenous Chinese brands in overall vehicle sales continued to increase to 45% in 2010. At that point, however, it stalled and even slightly decreased (Table 4).[8] Until the late 2000s, foreign firms, i.e. the incumbent automakers from the core, had mainly introduced vastly outdated models at highly inflated prices into the Chinese market. Once they saw their market share being eroded, they started to launch newer and better models in China, and lowered their prices, as they upgraded their local production facilities and supply chains. Especially in the middle- and high-end segment of the market, from 2010 onwards they outcompeted independent Chinese automakers like Chery and Geely (Brandt and Thun 2016; Feng 2016).[9]

Once the foreign firms started to take the Chinese competition seriously and entered with frontier models, the local Chinese automakers were faced with the full force of incumbent firm dominance. Their capabilities were not at the same level as those of the incumbent automakers from the West and Japan and Korea, which had built cumulative tacit knowledge and capabilities over many decades and in some cases more than a century. It was only in a new technology where the incumbent advantages were significantly eroded that local firms managed to truly outcompete foreign incumbent firms: **electric vehicles (EVs)**.

In the field of EVs, the core independent local companies were not Chery and Geely, but the two private firms BYD (cars and batteries) and CATL (batteries). Central government support for EV technology in China goes back to 1992, but until 2009 focused exclusively on R&D funding and administration of R&D projects (Chen et al. 2024; Feng and Li 2019; Gong and Hansen 2023; Wang and Kimble 2011). Battery EVs were supported as one type of new energy vehicles (NEVs), in addition to HEVs, PHEVs and FCVs. The Ministry of Science and Technology did not support one technology over another. In 2001, Chery, for example, joined the Ministry's high-tech program, the 863 program, as 'its most enthusiastic participant', but chose to focus on non-plug-in hybrids (HEVs) instead of PHEVs or BEVs. In HEVs, Toyota had clear incumbent advantages, including patents that Chery could not circumvent, and to this day, Chery has not recovered from this wrong initial technology choice (Feng and Li 2019: 429). Wan Gang, a former Audi engineer with a PhD in automotive engineering from Germany, oversaw the 863 EV program since 2001 and became Minister of Science and Technology in 2007. He was always convinced that China needed to use an alternative technology to leapfrog the incumbent automakers from Europe, Japan, the US, and South Korea, but he left the technology choice open to companies (Tillemann 2015). He himself was an expert on FCVs. Until 2009, the Chinese government's support for BEVs was

[8] The data in Table 4 also includes indigenous brands of SOE-foreign JVs, which started to proliferate after the 2006 policy shift and which were often based on foreign technologies and platforms.
[9] Geely acknowledged this ceiling and changed strategy to entering the middle- and high-end segment via acquisitions, including the Australian transmission company DSI in 2009 and Swedish Volvo Cars in 2010 (Balcet et al. 2012).

purely in terms of R&D funding. It did not provide incentives for BEV purchases and/or mass production, and it did not create a charging infrastructure for BEVs.

Table 5: BEVs and PHEVs sold in China in '000, 2013-2022

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BEVs	15	45	248	409	652	984	972	1,115	2,916	5,364
PHEVs	3	30	84	98	125	271	232	251	603	1,519
Total	18	75	332	507	777	1,255	1,204	1,366	3,519	6,883

Source: Statista, based on China Association of Automobile Manufacturers (CAAM), accessed via https://www.statista.com/statistics/425466/china-annual-new-energy-vehicle-sales-by-type/.

Consequently, progress in BEVs and PHEVs was slow in China. In 2013, only 15,000 BEVs and 3,000 PHEVs were sold in the country (Table 5). The SOE-foreign JVs did not want to enter the 'risky field of electric vehicles' (Altenburg et al. 2017).[10] The real shift was driven by a private company. BYD Company was established in 1995 and became one of the world's largest battery suppliers for laptops and cell phones by the early 2000s. In 2003, it decided to also venture into the automotive industry by purchasing a bankrupt SOE automaker and its license. BYD's founder Wang Chuanfu entered the automotive industry in 2003, with the clear vision of eventually making and selling battery-driven vehicles, based on the company's expertise in batteries (Yu 2008). It started an internal EV R&D project in 2003 (ibid.). But in terms of production, BYD initially focused on ICE vehicles, as BEVs were not yet competitive. It went through a similar trajectory as Chery and Geely in internal combustion engine vehicles, but remained slightly smaller than Chery and Geely: In 2008, BYD sold roughly 190,000 ICE vehicles in China (Wang and Kimble 2010: 79).

BYD was a first mover in lithium-ion batteries and BEVs. It had acquired strong capabilities in lithium-ion and nickel-metal hydride battery development for laptops and cell phones. In 2006, it launched an industrialization program for lithium-iron phosphate (LFP) as the cathode material for batteries, based on findings from a 2005 study by MIT researchers. It did so explicitly against the government's recommendation, which urged local producers to adopt existing mature battery technologies rather than aiming for new technologies. Until 2007, BYD had never been included in the central government's NEV research activities (Shen et al. 2016: 7). By 2009, BYD was producing large volumes of LFP batteries for EVs. Based on these batteries (Wang and Kimble 2010: 81), it launched the F3DM plug-in hybrid EV (PHEV) model in December 2008, which was replaced by the Qin model, also a PHEV, in 2012. In 2010, it launched its first non-hybrid pure BEV model, the e6, which was followed by the more sophisticated model Denza in 2014 (based on a technical collaboration with

[10] The SOE-foreign JVs only truly moved into EVs in the late 2010s when they were incentivized by the large EV subsidies. Initially, "they relied on retrofitting the internal combustion car models rather than developing models optimised for electric vehicle technology" (Altenburg et al. 2017: 191). And still today, independent automakers' models sell much better in the Chinese market than SOE-foreign JV's EV models, see Table 6 below.

Daimler). It took BYD some time to ramp up both EV and LFP battery production: By the mid-2010s, it was mass-producing both (Zhao and Lüthje 2024: 17). After BYD's success with PHEVs and BEVs, based on LFP batteries, other Chinese carmakers also abandoned HEVs and focused on PHEVs and BEVs (Feng and Li 2019).

At the time when BYD brought its first PHEV and BEV models to market, government industrial policy support also become more active, driven by concerns over air pollution and dependence on oil imports. Since 2008, various local government initiatives spurred initial production and the public acceptance of BEVs. These included programmes for the 2008 Olympics, 2011 Summer Universiade in Shenzhen, and the G20 Summit in Hangzhou in 2016, as well as the 'thousand EVs in 10 cities' programme started in 2009 (Feng and Li 2019: 428). At central government level, the major responsibility for NEV policy was moved from the Ministry of Science and Technology to the National Development and Reform Commission and to the Ministry of Industry and Innovation Technology. Now, instead of R&D support only, in 2009, subsidies for private 'new energy vehicle' (NEV) purchases were introduced (Feng and Li 2019; Gong and Hansen 2023). The subsidies were given to consumers as discounts on the vehicle price at the point of purchase, and via exemptions from the purchasing tax. In addition, in large cities, where license plates are rationed, NEVs were prioritized. Support for BEV charging infrastructure was initially lacklustre, which explains the slow uptake of PHEVs and BEVs (Table 5), but accelerated from 2015 onwards (Chen et al. 2024: 17).

Nevertheless, the central government did not make clear technology choices for a long time. It supported both EV charging infrastructure, as well as hydrogen infrastructure for FCVs, and the 'NEV' definition included FCVs, HEVs, PHEVs, and pure BEVs (Chen et al. 2024: 18). It was only in 2017 that the central government excluded non-plug-in hybrid vehicles (HEVs) from the 'NEV' definition to circumvent Toyota's advantage. In response, local carmakers focused more on pure BEVs and PHEVs, following BYD's lead (Feng and Li 2019: 427-28). In October 2019, the Chinese government announced a ban on the sale of all-gasoline vehicles by 2035 (Li and Lazonick 2022). Lastly, under the so-called dual credit policy (enforced since 2019), carmakers that overachieve with regards to the share of NEVs in their overall sales can sell credits to underachievers on the market. Both BYD and Tesla, for example, generate in excess of $1bn that way per year – a significant indirect subsidy (Shou and Li 2024).

What has emerged since BYD's entry into PHEVs and BEVs in 2008 is a Chinese EV industry with constantly increasing sales figures, with BYD as the clear leader. In 2023, BYD sold 2.7 million BEVs and PHEVs (with a distribution of roughly 50-50). The second-largest carmaker in this regard had sales of roughly 600,000 units, not even one quarter of BYD's volume (Table 6).

Table 6: NEV sales volumes in China by carmaker, 2023

Carmaker	Units
BYD	2,706,075
Tesla China	603,664
GAC Aion	483,632
Geely	469,427
SAIC-GM-Wuling	457,848
Chang'an	384,915
Li Auto	376,030
Great Wall	236,856
Nio	160,038
Leapmotor	144,155

Source: CnEVPost with data from CPCA, accessed via https://cnevpost.com/2024/01/10/automakers-nev-market-share-in-china-in-2023/.
Notes: NEVs include BEVs and PHEVs.

BYD's rise is based on its inhouse battery capabilities, as well as strong government support. Via the so-called Battery Whitelist, which was in place from 2015 to 2019, the Ministry of Industry and Innovation Technology practically made the receipt of subsidies dependent on using batteries made by Chinese producers (Gong and Hansen 2023: 11). This supported BYD, but also other battery producers like CATL. The Battery Whitelist effectively pushed foreign producers, and especially the world leaders from South Korea and Japan, out of the Chinese market (Lüthje et al. 2022). Jointly with their already ongoing internal technological development efforts, the Chinese battery firms caught up with the global technological frontier, at least in LFP lithium-ion batteries, and to some extent even leapfrogged. The largest Chinese battery producers, both specializing on LFP lithium-ion batteries for EVs, are CATL and BYD. They are also the largest two producers of EV batteries globally by market share in 2023, with 37.8% (CATL) and 15.8% (BYD) respectively, followed by LG Chem (12.9%), SK On (4.8%) and Samsung SDI (4.5%) from South Korea and Panasonic (4.4%) from Japan.[11]

CATL is a 2011 spin-off from Amperex Technology (ATL). ATL was founded in 1999 and made lithium batteries for all sorts of mobile electronics, e.g. MP3 players and DVD players, based on a lithium polymer patent acquired from Bell Labs in the US. After its initial success, ATL was acquired by TDK from Japan in 2005 and subsequently became a large battery supplier for Apple and Samsung smartphones. ATL's founder Robin Zeng had worked for a TDK subsidiary (making magnetic recording heads for computer hard drives) in Hong Kong until 1999, and was convinced by his CEO to set up ATL in 1999. The link with TDK helped with access to technology and knowledge. In 2006, ATL established an internal EV battery development department, and in 2008, ATL batteries were used in electric buses during the Beijing Olympics. In 2011, the founder decided to spin off the EV battery business into the separate company CATL (Contemporary Amperex Technology Co., Limited). CATL was an

[11] Source: Statista, based on a survey by SNE Research, accessed via https://www.statista.com/statistics/235323/lithium-batteries-top-manufacturers/.

independent company, with 15% ownership by ATL (until it was bought out in 2015) but zero ownership by TDK. It thereby became a fully Chinese battery champion with full local management control. Crucial events in CATL's early development included hiring the automotive battery expert Bob Gaylen as CTO (2012-2019), who had previously worked as automotive supplier Magna's President of battery development; and a supply contract for the foreign-SOE JV BMW Brilliance in 2012. The initial partnerships with automakers like BMW Brilliance involved significant co-design and collaboration, as, unlike in ICEVs, automakers did not yet have established tier-1 suppliers and were looking for capable cost-efficient battery suppliers (Sanderson 2022).

Both CATL and BYD have their initial capabilities from producing lithium-ion batteries for consumer electronics. They both specialized in LFP lithium-ion batteries for EVs early on. Through their success, they made the technology choice for China's automotive industry towards battery-driven electric vehicles (PHEVs and BEVs). Today, BYD is the in-house battery producer for its own automobile division, and CATL is the by far dominant battery provider for all non-BYD EV makers in China, and even globally. In 2019, CATL established a large battery factory in Germany. Both CATL's and BYD's competitive advantage is based on scale economies and associated learning effects and accumulated tacit knowledge in production (Zhao and Lüthje 2024). Large volumes (75% of global EV battery production capacity is in China) allow for low costs and reliability in production. Both CATL and BYD rely mainly on imported equipment, but have become experts in organizing and adjusting this equipment for their production processes. External partnerships and learning, e.g. from Panasonic in the case of BYD, helped with accumulating knowledge. Chinese battery producers also benefit from important advantages related to the supporting nexus of interconnected and complementary firms in mineral processing, waste management, chemicals and other components, which are both a legacy of long-standing battery production for consumer electronics and today's large scale in production for EVs (ibid).

The large production volumes and scale economies provide powerful barriers to entry against new entrants into the industry, including carmakers from the West who want to become less dependent on Chinese battery producers. Around their LFP-specific capabilities, BYD and CATL have even developed indigenous patented technologies: BYD's LFP blade battery, and CATL's cell-to-pack technology (Lüthje et al. 2022). BYD's blade battery is 'an improvement of product form design and product structure re-engineering, without changing the fundamental battery materials and electrochemical system' (Lüthje et al. 2022: 25). CATL's cell-to-pack technology is also a process innovation, rather than a fundamentally new technology: 'Cell To Pack (CPT) is a new process eliminating the modules in order to increase utilization of pack space. CATL is now able to produce bigger cells and link them to make the whole battery pack directly' (ibid.).

On the back of PHEV and BEV sales, domestic carmakers have achieved more than 50% market share in all vehicles (incl. internal combustion engine vehicles) for the first time in China in late 2022 (Zhang 2023). While Chery and Geely hit a ceiling in ICE vehicles in around 2010, now the ceiling seems to have been shattered with Chinese firms' leapfrogging into

EVs. BYD is the by far largest brand on the domestic market for NEVs, with sales more than four times higher than the number two (Table 6).

The number two is Tesla, which the Chinese government allowed to enter as the first-ever wholly-owned subsidiary of a foreign carmaker (i.e. without local JV partner) in 2019. The idea was to spur competition to improve the capabilities of local new energy vehicle makers, so that the latter do not become complacent in a heavily subsidized domestic market (Yang 2023). This seems to have worked: While Tesla has become a significant brand on the domestic market, BYD is still far ahead and several other local brands sell volumes roughly equal to Tesla, including private automakers like Li Auto and Geely as well as SOEs like GAC Aion, SAIC-GM-Wuling and Chang'an (Table 6). The central government made it part of the deal that Tesla had to source from local battery producers (Li and Lazonick 2022: 34).[12] And thus, while Tesla exclusively sourced batteries from Japan's Panasonic and Korea's LG Chem before, it now switched to CATL for its Chinese-made vehicles, giving access to further market share for the Chinese battery champion. In addition to the insertion of Tesla competition into the local EV market, subsidies have also been gradually reduced and the Battery Whitelist has been dropped in mid-2019, indicating that local EV makers have become sufficiently competitive (Gong and Hansen 2023).

While the noise is loud, Chinese EV makers have not yet started exporting in large volumes. The US market is effectively closed off for Chinese EVs because of the 100% tariff on Chinese-made EVs. There are also tariffs for exports into the EU, but at much lower levels, and significantly lower than the cost gap between Chinese EV producers and European EV producers (Sebastian et al. 2024). In 2023, total Chinese new energy vehicle exports were 1.1 million units, around one third of which went to Europe. Chinese firms made up one half, while the other half were exports by foreign firms, dominated by Tesla (31%) and European JVs (11%). Among the Chinese-owned new energy vehicle exporters, only SAIC-MG (306,000), BYD (243,000) and Geely (28,000) had relevant volumes (Luk 2024).[13] In sum, Chinese firms focused predominantly on the domestic market. BYD's exports were less than 10% of its domestic sales. While exports were a clear indicator of catch-up success in Japan and Korea, the low Chinese numbers do not mean that the Chinese new energy vehicles brands are lagging. Rather, they indicate that the Chinese domestic market is so large that local carmakers do not have to look so much towards exports to achieve high production volumes and economies of scale.

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[12] A different version of the story is that Tesla did not have to be forced to source from CATL, as 'it met both its cost and technology requirements' (Sanderson 2022: 44). Either way, CATL became the major battery supplier to Tesla Shanghai.

[13] The Chinese SOE SAIC sells vehicles under the brand MG Motor, which is a formerly British car brand that SAIC acquired in 2007. The MG4 by SAIC-MG is the most successful Chinese-made EV in export markets. In the first half of 2024, it was the fifth-best selling EV model in Europe at 37,049 units (European Commission 2024). The MG4 and the Nebula platform, on which it is based, were developed from the beginning as a 'global car' with the European market in mind. It was co-developed by SAIC's Chinese and British development teams (Rahman 2022).

BYD's higher profitability than Tesla is arguably because of its proprietary control over batteries, which in turn are low cost because of high economies of scale in production.[14] BYD is predicted to sell roughly four million cars in 2024 with a revenue of $90 billion, thus exceeding Tesla's predicted revenue of $84 billion. BYD's gross profit margin for 2024 will be approximately 24.5%, outpacing Tesla's predicted 15%. CATL is as profitable as BYD because its scale in production also lowers unit costs. In addition, BYD and CATL have pricing power in global markets for their low-cost high-performance LFP batteries, because of their high production volumes and a limited number of competitors, which means that customers are dependent on these two firms. Although Geely, Chang'an and GAC are investing in in-house battery production capacity to be less dependent on CATL, their sales volumes are around 500,000 cars per year, which means that they will struggle to compete with CATL on battery cost for a long time because of much lower scale in battery production (unless they capture outside customer demand). Other battery producers than CATL and BYD face the same problem: they have much lower production volumes than the two giants, and therefore much higher unit costs.

The rise of BYD and CATL as global leaders in new energy vehicles and batteries shows that these Chinese firms have forged ahead in the global automotive industry by commercializing new technologies, and other local firms are following in their footsteps. They currently set the dominant design in low-cost high-performance LFP lithium-ion batteries: BYD with blade battery, and CATL with cell-to-pack. This allowed them to not only close the gap with incumbent automakers in the US and Europe, as Toyota and Hyundai did before, but also forge ahead, potentially become the leading incumbent firms in the global automotive industry going forward, around the new dominant design of BEVs. However, this remains to be seen.

8. BARRIERS TO ENTRY APPROACH PART 2: OVERCOMING BARRIERS TO ENTRY

Table 1 presented an abstract conceptualization of barriers to entry that latecomer firms face. The detailed empirical cases of Japanese, Korean and Chinese automakers catching-up in the global automative industry as well as the many cases of latecomer failure allow us to specify the barriers to entry in the global automotive industry, which have done in Table 7. We also summarize the strategies that Japanese, Korean and Chinese automakers employed to overcome them successfully, and the government industrial policies that enabled and supported these strategies.

[14] The data in this paragraph is based on analysis posted by Glenn Luk on X on 3rd and 4th September 2024, accessed via https://x.com/GlennLuk.

Table 7. How latecomer firms overcame barriers to entry in the automobile industry

Types of barriers to entry	Specific barriers to entry in the global automotive industry	Latecomer firm strategies	Latecomer government industrial policies
Fixed capital investments	Establish initial factories and expand to reach economies of scale; R&D for indigenous technology development	Automobile firms as part of diversified business groups: can raise foreign loans—showing assets and relevant experience; have equity for investment.	Low-cost finance from national/local financial institutions; Land at cheap rates; Protected domestic market to secure initial demand and higher prices than in export markets; Public procurement; Export subsidies.
Closing the knowledge gap	Acquire existing proprietary knowledge: --Designs for various parts of the automobile: body, engine, etc. --Designs for factory set up and machine tools. Develop indigenous proprietary knowledge: --Develop own designs, machine tools, factory set up, etc.	Licensing; Reverse engineering without licenses; Foreign partnership that does not give foreign management control; Hiring experts with the scientific knowledge: locals poached from foreign firms; locals overseas with experience working in foreign firms; foreigners with experience in foreign firms; Overseas outposts	Prohibit pure FDI: foreign automakers must enter partnerships with local firms; Financial incentives for returnees.
Closing the organizational capabilities gap	Creating a production system: --system integration knowledge (how to turn licenses into a product) --production process (how to build a factory floor and manage production) --market access --branding, marketing and developing distribution channels	Leverage relevant experience from other industries; Foreign partnership that brings tacit knowledge, without foreign management control; Foreign consultants; Locals hired from foreign firms; Locals sent abroad for training; Overseas outposts and foreign consultants for consumer market intelligence and distribution plans.	Negotiate market access through trade agreements; Financial incentives for returnees.
Creating a supporting nexus	Local parts suppliers with high capabilities, and machine tool providers. Necessary supporting public infrastructure.	Leverage existing foundational industries steel, machine tools, plastics, textiles.	Support to heavy industry sectors; Encourage FDI in components, but have local content requirements; Finance for specialist component suppliers; Create necessary infrastructure.
Commercializing new technologies: EV case	Market uncertainty; High unit costs until reach scale; Creating a new supply chain.	Combine capabilities from consumer electronics and automobile production; acquire relevant patents; R&D in battery production	Indirect producer subsidies; Providing the supporting infrastructure; Creating the market through public procurement & subsidizing consumer purchases; Temporary protected market for local battery suppliers.

Source: Created by the authors.

As Table 7 shows, government industrial policy was necessary, but not sufficient. Government policies were most important in providing financing or reducing the costs of fixed capital investments in the early phases: government provides a ‘cost of entry rebate’ (Perez and Soete 1988: 470). Industrial policies were also important in catalyzing the creation of a supporting nexus, especially since the localization of automobile production requires many supporting heavy industries for component production. Both Japan and Korea automotive industries benefited from the heavy industrialization drive of their governments. In China, independent Chinese firms benefited from the existing component supply chain from the first automotive push around joint ventures between state-owned enterprises and foreign incumbent automakers, as well as a heavy industrialization drive in steel, petrochemicals, and textiles that included reforms of state-owned enterprises. Government policy is also very important in commercializing new technologies, as illustrated in the case of EVs in China, which required government support in the creation of industrial clusters and local supply chains, charging infrastructure, initial market demand through public procurement and consumer subsidies as well as an eventual ban on gasoline vehicles and producer subsidies for meeting EV targets.

However, in the actual processes of closing the knowledge and capabilities gaps, government policy is of little value because ‘technology transfer’ cannot be mandated; technology, understood as both scientific knowledge and tacit knowledge, must be leveraged by local firms, which involves firm-level learning (Matthews and Cho 2000). Prohibiting pure foreign direct investment, as the Japanese, Korean and Chinese governments did, is important for protecting the local market from being overrun by capable foreign firms. However, market protection alone is wholly insufficient (and is probably why in many countries it led to less than desirable outcomes for technology transfer and local firm competitiveness).

Furthermore, government officials formulating industrial policy must understand the global industry and be able to forge foreign connections. These capabilities within government agencies are not available in the early phases and thus also require translocal linkages and role models to emulate. In Korea, the government often mimicked the policies that were successful in Japan, such as with the ‘people’s car’, and inherited a financial system created in the image of Japan that was geared to financing industrialization driven by large firms. Furthermore, government industrial policy tended to follow rather than lead firm initiatives. This was true in Korea, where Hyundai’s founder was in the driving seat and had close relations with Park Chung-hee (see Kirk 1994), as well as in China, where the government changed its initial industrial policy approach of trading market for technology via SOE-foreign JVs to allowing and supporting the initiatives of independent Chinese firms. In China’s rise in EVs, the core ingredient were BYD’s and CATL’s advances in battery technology, which were driven by the firms themselves rather than by government policies. The latter reacted to and facilitated the process, but the initial direction came from the firms (Shen et al. 2016).

It has become a common argument that government support to local firms (the 'carrots') without compulsions to invest in learning (the 'sticks') usually fails to achieve its objectives, popularized by Amsden's persuasive argument regarding reciprocal control mechanisms in the case of South Korea. However, it was not government policy that drove Korean automakers to export, which was quite lax in terms of how policy loans were given out. Rather, it was firm level initiatives, which were driven by the need to access larger markets combined with limited but fierce competition between Korean firms and the drive to catch up with Japanese automakers that drove local firms to generally use government financing and other subsidies for investing in learning (see Woo 1991; Kirk 1994). Thus, we have to look beyond government industrial policies to understand how latecomer firms closed the knowledge and organizational capabilities gaps.

Closing the knowledge gap requires that latecomer firms acquire foreign scientific and technical knowledge. When far from the technological frontier in the industry, and just entering, latecomer firms can license technology from incumbent firms, who are willing to provide it for the fees and royalty payments, as it generates little wealth for them. However, latecomer firms still must master foreign technology, as engineers with no experience in the automotive industry cannot understand the designs. Mastery can come through reverse engineering, but has always involved some degree of migratory knowledge, as the cases show. Migratory knowledge comes from a flow of nationals with work experience in incumbent firms located in the country (even as joint ventures) or abroad, through returnees.

Acquiring and mastering scientific and technical knowledge is insufficient on its own, as latecomer firms need to build the capabilities to use it and achieve the unit costs of incumbent firms to compete internationally. In the automotive industry, tacit knowledge is the more significant barrier, and thus migratory knowledge plays an even greater role not only in generating systems integration capabilities and production process capabilities, but also in distribution, marketing, and sales services in main markets (including foreign markets).

Moving to the technological frontier required investing in indigenous knowledge creation rather than licensing foreign technology. This is because as global competition among automakers increased, incumbent automakers (and their governments) became more aggressive and less willing to engage in technology transfer agreements with latecomer firms. Increased competition among automakers created a fight for market share, driving down prices, and incremental innovation was not enough to create greater demand. Market growth required automakers accessing new markets or a big change in consumer preferences in existing markets that could be filled with a new car.

Mastery of technological learning at one stage provides a foundation for the subsequent technological learning, but making a big leap in capability building cannot be done through learning-by-doing in the existing technologies. Fully indigenizing automotive technologies, including own engine design, requires more than joint ventures and passive technology licensing. It requires firm-level effort and massive resources in research and development, including straddling the countries with firms at the technology frontier, through research outposts and other means such as hiring foreigners or diaspora nationals that have worked in firms at the technology frontier.

With regards to the window of opportunity in electric vehicles in China, we observed that the forging ahead of certain Chinese firms in EVs and EV batteries was based on long previous periods of building up knowledge, capabilities and a supporting nexus. Rather than emerging as start-ups, the most successful firms BYD and CATL produced batteries for the electronics industry in China since the 1990s. BYD also had experience in making cars with internal combustion engines since the 2000s. In contrast, Chinese startups in EVs such as NIO that emerged to make use of the EV window of opportunity struggled.

The emergence of EVs and their policy support in key automotive end markets, including in China, provided a window of opportunity for Chinese automotive firms. This is due to the incumbent trap, meaning that incumbent automakers dragged their feet with regards to venturing into this new vehicle type as long as they could (see Section 6), but also because of the erosion of incumbent advantages. In EVs, the incumbent advantage is eroded to the extent that the internal combustion engine is replaced by a battery, a technology where Chinese firms are successful fast followers and currently the largest global producers. The incumbent advantage in system integration (i.e. producing an automobile consisting of countless components from numerous suppliers that meets customer and safety expectations) somewhat remains. While EVs are less complex than internal combustion engine vehicles in this regard, it is still difficult to catch up with incumbent automakers' system integration knowledge and organizational capabilities. This also explains why Chinese EV makers with a longer history of automotive production are doing better than complete newcomers.

Eventually the question that remains is what motivated latecomer firm strategies and made them possible? Why did a few firms in East Asia undertake these efforts, while others did not? The literature tells us that a firm's absorptive capacity (its ability to master foreign technology) comes from prior knowledge and intensity of effort, but where do they come from? Amsden (2001) shows that the absorptive capacity of local firms comes from firms' previous manufacturing experience, or in the language of Perez and Soete (1988): relevant experience. Relevant experience is very important, and explains Hyundai's choices in relation to producing cars, as it drew on organizational capabilities developed in its global construction and shipbuilding industries. It had the confidence to take the risks because of its existing capabilities and its support from the Korean government.

Two other important factors, either not mentioned in the literature or not well-known, emerge from the study of the global automobile industry. One is transnational networks, and the other is foreign firms' business strategies. Whitfield (2023) first argued for the importance of transnational networks and foreign firms' business strategies in explaining firm-specific initiatives to leverage foreign technology. Transnational networks involve diaspora who have experience in foreign firms that return to their home country, or become 'straddling nationals', and bring important tacit knowledge and contacts to foreign firms (see Saxenian 2002). But transnational networks also involve, as the global automotive industry shows, foreign experts migrating from one automotive company to another, spreading tacit knowledge. The second factor is foreign firms' business strategies, which shape their willingness to share knowledge and work with local firms, which in turn are shaped by national industrial policies but equally by global market competitive dynamics at given points in time. These two factors are contextually dependent, which means that the opportunities are not the same for all latecomer countries at a given point in time in the global economy.

In sum, latecomer firms develop individual business strategies for leveraging technology, which are in turn shaped by the resources that they can draw upon and their individual histories. Governments can only direct capital to the sector, limit foreign competition in the domestic market, and encourage localization; they do not engage in the difficult task of acquiring and indigenizing knowledge and capabilities. That is why role models and transnational linkages matter as well as the differential resources upon which individual companies can draw.

9. CONCLUSION

Incumbent advantages have prevented most latecomer firms from being successful in the automotive industry. The industry to this day is dominated by the first mover firms from North America and the fast followers from Western Europe and Japan. Many developing and emerging countries have significant automotive industries, but they are dominated by these incumbent foreign firms. Some of them have tried to prop up indigenous carmakers, but largely failed (e.g. Proton or Yugo).

It is true that in those few cases where firms managed to pursue some degree of catch-up, defined as global market share, with the US first mover automotive firms, government industrial policy played an important role. The success cases of Toyota, Hyundai and BYD would probably not have happened without industrial policy support in protecting domestic markets, and creating new markets for EVs in the case of BYD. But we have argued that looking at industrial policy as the key factor in explaining catch-up by automotive firms is insufficient.

Our Barriers to Entry approach puts the focus on firms, and therein on the barriers to entry that latecomer firms face when trying to catch up in a given industry. These barriers to entry are constituted by the advantages of incumbent firms with accumulated knowledge, capabilities and a supporting nexus. We demonstrated these advantages and how firms successfully overcame them through the cases of Toyota, Nissan, Hyundai, Chery, Geely and BYD. We highlighted the striking parallels between these cases, and summarized them in terms of our barriers to entry categories: closing the knowledge gap, closing the capabilities gap, building a supporting nexus, and commercializing new technologies. The existing literature on latecomer catch-up has emphasized the importance of firm-level efforts in technological capability building as opposed to passively expecting technology transfer through foreign direct investment. Our approach is more specific about the nature of capabilities that latecomer firms needed to build in the automotive industry as well as the origins of their absorptive capacity (prior knowledge and intensity of effort) that drove them to engage in indigenizing automotive technology (scientific and tacit knowledge). In this context, we highlighted the importance of migratory knowledge through transnational networks as well as role models for both industrial policymaking and firm strategies, and the opportunities afforded to latecomer firms by the situation in a global industry at a certain moment in time, which is conditioned by foreign firms' business strategies and incumbent countries' government policies. This is just a first step and can be done with other industries to further substantiate and revise the Barriers to Entry approach.

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