Green Industrial Policy, Directionality of Innovation, and Sectoral Change: Case Study on China's Early Transition to Electric Mobility

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by

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Abstract

The directionality of innovation, which bears significant developmental consequences, is under-researched. Green industrial policy, on the other hand, is perceived as important to foster green structural change. Whereas the theoretical and empirical understanding of the nexus between green industrial policy and directionality of innovation is insufficient, and systematic, in-depth empirical research in developing countries and emerging economies is scarce. The thesis attempts to fill the gap by investigating the political economy of directionality of innovation in early industrial green transformation in the emerging economy of China.

Based on an interdisciplinary framework built up in the thesis, an embedded, longitudinal case study is conducted on China's early transition to electric mobility from early 1990s to 2020. Regarding direction of innovation, the analysis shows that green industrial policy can facilitate technological substitution by intervening into the process of technological through its selectivity. However, such selectivity may also result in system gap that leads to undesirable lock-in and constrains the industry's capacity in technological substitution in the longer term. It is found that this partly counteracting result is attributed to business firms' heterogeneous responses in their innovation strategies and activities characterised as "system building". The effectuation of green industrial policy at the level of policy objective – business firms, can only be understood sufficiently by being examined as an integral part of the incentive structure firms are embedded in, and looking at the conditioning role of technological capabilities and resources at organisational level.

The thesis contributes to literature in (green) industrial policy, innovation system's approach, and understanding of firm innovation activities and processes in the context of transformational change. It also bears important policy and management implications for green transformation of industrial sectors in developing countries and emerging economies.

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List of abbreviations

Technical terms

BEV	Battery electric vehicle
BMS	Battery management system
EV	Electric vehicle
HEV	Hybrid electric vehicle (non-plug-in)
ICE	Internal combustion engine
ICEV	Internal combustion engine vehicle
LiFePO.4	Lithium iron phosphate
LNG	Liquefied natural gas
LSEV	Low speed electric vehicle
NCM	Nickel- Cobalt - Manganese
NiMH	Nickel–metal hydride
NEV	New energy vehicle
PHEV	Plug-in hybrid electric vehicle
ZEV	Zero emission vehicle

Government and political entities

CCP	The Chinese Communist Party
GO_CCCPC	The General Office of the Central Committee of the Communist Party of China
GO_SC	The General Office of the State Council
MEE	Ministry of Ecology and Environment
MIIT	Ministry of Industry and Information Technology

MNR	Ministry of Natural Resources
MOF	Ministry of Finance
MOFCOM	Ministry of Commerce
MOHRSS	Ministry of Human Resources and Social Security
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
MOT	Ministry of Transport
MPS	Ministry of Public Security
NAO	National Audit Office
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
NEA-NDRC	National Energy Administration
SAMR	State Administration for Market Regulation
SASAC	The State-owned Assets Supervision and Administration Commission of the State Council
SAT	State Administration of Taxation
SC	State Council

Non-government entities and intermediaries

CAAM	China Association of Automobile Manufacturers
China EV100	China Electric Vehicle Association
China-SAE	China Society of Automotive Engineers
ICCT	The International Council on Clean Transportation
SEM	School of Economics and Management

SPPM	School of Public Policy and Management
TAI	Tsinghua Alumni Association of Automotive Industry

Business firms

BAIC	Beijing Automotive Group Co., Ltd
CSGC	China South Industries Group Corporation
CSPG	China Southern Power Grid
FAW	China FAW Group Corp., Ltd.
JAC	Jianghuai Automobile Co Ltd
JJECN	Jing-Jin Electric Tech
GM	General Motors
GAC	Guangzhou Automobile Group Co., Ltd.
GWM	Great Wall Motor Co., Ltd.
SAIC	Shanghai Automotive Industry Corporation Motor Co., Ltd.
SGCC	State Grid Corporation of China
VW	Volkswagen Group

Other organisations

CAS	Chinese Academy of Sciences
CAST	China Association for Science and Technology
CSSAP	China Social Sciences Academic Press
UNIDO	United Nations Industrial Development Organisation

Academic terms

AT	Appropriate technology

BM	Business model
BMI	Business model innovation
CAFC	Corporate Average Fuel Consumption
CAQDAS	Computer assisted qualitative data analysis
CPS	Corporate political strategy
CSR	Corporate social responsibility
DTC	Directed technical change
FYP	Five-year-plan
GIS	Global innovation system
GHG	Greenhouse gas
GWO	Green window of opportunity
IIH	Induced innovation hypothesis
JV	Joint venture
MNE	Multinational enterprise
NIS	National innovation system
OBM	Original brand manufacturer
ODM	Original design manufacturer
OEM	Original equipment manufacturer
PH	Porter's Hypothesis
POE	Private owned enterprise
PSS	Product service system
R&D	Research and Development
RIS	Regional innovation system
SME	Small and medium enterprise
SSIP	Sectoral system of innovation and production

SOE	State owned enterprise
TIS	Technology innovation system
VoC	Varieties of capitalism
WW2	World War Two

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Chapter 1 Introduction

Humanity faces the imperative of a techno-economic paradigm shift (Freeman, 1992) towards sustainable development. In the economic and industrial realm, there is an urgent call for green growth, i.e., making it more resource efficient, cleaner and more resilient without making slowing growth (IMF, 2012). Despite controversy, there is no denying that such a strategy of "relative decoupling" (Panel, 2011) still contributes to mitigation of climate change, and is more technically, economically and politically practical compared to the absolute decoupling approach.

An essential aspect of green growth is the green transformation of industrial sectors which take up the bulk of worldwide economic activities and affect behaviours in production and consumption. It is argued that this provides "green windows of opportunity" (GWO) that latecomer countries may seize and exploit to achieve industrial catch up (Lema et al., 2021). However, green transformation does not take place automatically. Because innovation is not only a major driving force of economic growth, but also sustainable development, an important pathway to push for structural change in industrial sectors towards green growth is through unleashing the power of innovation. This is especially relevant for developing countries as their gap with developed countries in the field of green and clean technologies is generally narrower compared to those deeply entrenched industrial regimes.

While the speed and rate of innovation has been a major focus in economics, public policy and business management literature, far less is known about *the directionality of innovation*. Recent literature on "directionality" of innovation is disproportionately normative and is discussed as a rationale for transformative policy mainly in Western countries (Lindner et al., 2016;

Mazzucato, 2018). The material side of directionality of innovation, i.e., the concrete industrial structure and technological configurations adopted, and resulting trajectory of capability building and network formation, is often neglected (Dosi & Nelson, 2010; Lundvall, 2007; Nelson & Winter, 1982). This latter aspect points to the process of change and under-addressed developmental consequences of directionality of innovation. Therefore, directionality of innovation in green structural change warrants systematic and in-depth study for better an understanding of policy and management of innovation for green transformation in developing countries.

The objective of this thesis is to investigate the shaping forces of directionality of innovation, and the underlying processes wherein, in green transformation in emerging economies from a political economy perspective. The perspective is critical given that the state sector is widely acknowledged to play an important role, yet existing theoretical and empirical inquiries so far have been rather limited. To conduct the research, the thesis makes several conceptual and theoretical endeavours that build on and integrate different strands of literature, so that it develops an analytical framework capable of addressing the research topic.

In the first place, an integrated concept of directionality of innovation in green transformation is put forth. Such an attempt benefits a lot from bringing back the evolutionary economics tradition, where the process of learning and capability formation lies in the core but is not well captured in neo-classical view of economic activities and technical change. Specifically, it refers to a selection process in green transformation that consists of two co-occurrent processes: a) technological substitution, i.e., green technological regime replacing the polluting one, which is a regime shift with a normative agenda (greening the growth); b) technological variation, i.e., the co-existing of multiple technological trajectories and solutions, each having corresponding product architecture, artifacts, networks and exchange relations, which denotes the material or positive side of directionality of innovation.

The fact that directionality of innovation in essence is a selection process means that it takes shape in the co-constitutive interactions between the major forces in the selection environment. The role of state is emphasised when it comes to green transformation by both environmental and innovation policy literature and industrial catch-up studies (Hepburn et al., 2018; Lema et al., 2021; Mazzucato, 2018). Particularly, the green industrial policy literature presents a strong theoretical case as a second-best solution for developing countries to achieve sustainability and competitiveness goals through facilitating innovation-driven structural change in industrial sectors (Altenburg & Assmann, 2017; Kemp & Never, 2017). However, this literature is still nascent and "strong in theory, ambiguous in practice" (Rodrik, 2015). The majority of existing research is the rationale and design of policy instruments, whereas there is little knowledge on *how green industrial policy takes effect (*not the *effect* of green industrial policy*)*, and empirical evidence from developing countries and emerging economies is scarce (Harrison et al., 2017). One recent study by Anzolin and Lebdioui (2021) points out the multi-dimensionality of green industrial policy and the importance of a holistic and comprehensive approach, which informs the conceptual and theoretical basis of this thesis.

One of the reasons for this significant gap is the neglection of directionality of innovation, which is supposed to channel policy incentives toward certain pathways of capability building. If incentives of innovation and capability building are taken seriously (Fu, 2015; Lundvall, 2007), then the innovation strategies and processes by business firms should also be assigned analytical primacy, because they are the economic and business agents that consciously make decisions and undertake innovation activities, and as a result, modify the system of production and innovation. The behaviours of firms are even more worthy of close investigation when the selection environment is highly uncertain, complex and contested, and the incentive they face is partly shaped by intentional state intervention. However, existing literature on the role of state and public policy in general has largely failed to pay enough attention to firm innovation

strategies and processes with very few exceptions (Zylberberg, 2017), thus the understanding of the effectuation of green industrial policy can be oversimplified or even misleading.

While a neo-classical assumption tends to treat innovation process and the firm as a black box, the evolutionary perspective can add to the considerations on embeddedness, processes and dynamics of firm innovation as seen in the system of innovation perspective. Because green industrial policy approaches state intervention with a focus on industrial sectors, the sectoral system of innovation and production (SSIP) framework is especially relevant here. It is widely applied to describe and explain the process of capability building and industrial catch-up (Keun Lee & Franco Malerba, 2017), and most recently, in face of GWOs (Dai et al., 2020; Hain et al., 2020; Lema et al., 2021; Zhou et al., 2020). However, when it comes to the understanding of the transformation of innovation system itself, e.g., green transition towards sustainability in incumbent industrial sectors, the innovation system concept – including the SSIP framework – seems to encounter its limitation. Specifically, there is a lack of capacity to explain the forces and processes of why and how transformative change takes (Weber & Truffer, 2017), especially when the state sector plays a supposedly important yet insufficiently understood role in the selection environment and triggers reactive innovation activities by firms.

The thesis argues that this limitation by no means negates the relevance of innovation system concept and framework in addressing contemporary development issues but necessitates a rethinking and refinement of it. In particular, and theoretical connection between SSIP and the political economy perspective is necessary to bring the "agency" – both the state and business firms – back to the overly structural analysis and the one-directional explanation. The political economy literature that tries to make sense of institutional change in presence of path-dependency is helpful here. The varieties of capitalism (VoC) program (Hall & Soskice, 2001) provides a delicate explanation on the influence of institutions on innovation but is less capable of accounting for discontinuity (Deeg & Jackson, 2007; Hall & Thelen, 2009). Becker (2007)

puts forward an *open systemness approach* as a fruitful remedy. By emphasising the *contested reference frames* in a political economy and *(semi-) equi-functionality* to achieve a diversity of goals (interpreted as reference frames), this approach creates sufficient theoretical space for political economic dynamics and the agency of change – both the state and firms (Deeg & Jackson, 2007; Schmidt, 2007). This is exactly what is analytically insufficient in the innovation systems concept.

Therefore, the thesis bridges the two disciplines and adopts an *open systemness approach to SSIP under green transformation*. Directionality of innovation, featuring technological multiplicity, is where political economic forces unfold. Its openness not only gives green industrial policy analytical prominence, but also view firms as heterogenous agencies embedded in a loosely coupled system where any seemingly definitive relation drawn between institutions and policy incentives and firm innovation should be avoided. The interaction between different agencies in a loosely coupled system can be strong source of system change as their innovation activities endogenously change resources, assets and networks within and beyond the sectoral boundary.

With these aforementioned conceptual and theoretical efforts, this thesis provides a political economy understanding of directionality of innovation in sectoral change toward sustainability by looking at the interaction between state policies and firm innovation strategies and activities, and presents an empirical study on green industrial transition in China as a n emerging economy. The topic is addressed by answering a set of three interrelated and logically coherent sub-questions. The first sub-question examines the effectuation of green industrial policy at the sectoral level. It asks: (**Q1**) *How does green industrial policy affect the directionality of innovation in the early phase of sectoral change*? Existing economics and policy science literature largely looks at the consequences of policy intervention in a unidirectional, mechanic and static manner, and neglects the necessarily complex feedback loops and interactions in the

innovation system. Consequently, the real impact of state intervention, in terms of green industrial policy, would be oversimplified, over/understated and even misunderstood. This thesis instead focuses on the causal mechanisms from an evolutionary perspective by embedding the green industrial policy – directionality of innovation nexus in the open systemness of SSIP.

The feedback loops and interactions in the sectoral system are the aggregated result of innovation activities conducted by firms. Because heterogenous business firms are the concrete agents of change in the market, and their innovation strategies and activities in response constitute the *de facto* pathway of innovation and capability building, the second sub-question seeks to uncover how firms choose and concretize directionality of innovation in presence of state intervention. It asks: (**Q2**) *How do firms in the focal sector strategically innovate in response to policy intervention differently?* With thesis question, the thesis zooms in to the firm level and examine the interaction between organisational innovation strategies and their "environment" - here, the open systemness of SSIP with green industrial policy playing an influential role. Here, only incumbent firms are examined because they often face a more contested selection environment compared to new entrants in terms of state-business interaction; limiting the scope of the sample ensures necessarily in-depth analysis, too.

The chosen directionality of innovation by incumbent channels and mediates the influence of green industrial policy to the orchestration of innovation activities and processes to embark on the development, deployment and diffusion of green innovations. From a value chain perspective underpinning the SSIP, firm innovation inevitably modifies the system of innovation, production and consumption, hence leads to organisational and sectoral level outcome. The thesis characterises the boundary-spanning, systemic and transformative process of firm innovation as "system building". Then the third sub - question proceeds to study innovation processes and outcomes following firms' innovation strategies by uncovering and

explaining the process of "system building". It asks: **(Q3)** *Given innovation strategies on directionality of innovation, how do incumbent firms perform system building dynamically?* The thesis conducts a firm-centric analysis at the organisational level, and at the same time sheds light on how these activities and processes translate into system-level dynamics.

Because the thesis is interested in the dynamics and interactions in a sectoral system and innovation processes from an evolutionary perspective, a longitudinal case study design is an ideal choice to unpack and explain changes (Volmar & Eisenhardt, 2020; Robert K. Yin, 2013). It selects the transition towards electric mobility in China's automobile industry from the early 2000s to 2020 to conduct the case study. This presents a good case for several reasons.

First, the automobile industry is a typical multi-tech, multi-component sector and has a high degree of technological and product complexity, hence suitable for understanding an array of important innovation dynamics including technological multiplicity, design rules, value chain and complementary assets (Hobday et al., 2005).

Second, the automobile industry is an important sector for investigating structural change towards sustainability. The sector is heavily polluting in its internal combustion engine vehicle (ICEV) technological regime, and it is widely envisioned that transition towards clean, electric vehicle (EV) is an important option to decarbonize the transport sector. Although the technological details are still contested, and it is not enough to just decarbonise the end product, the production and diffusion of electric cars is an important pathway to facilitate the decarbonisation of upstream sectors as well (e.g., energy).

Third, the automobile industry itself is a highly regulated sector and a major object of green industrial policy intervention. In China, the automobile industry has only seen moderate catch-up in the ICEV regime via technology transfer from global original equipment manufacturers (OEMs). The transition towards electric mobility is hence viewed as a window of opportunity

to achieve both competitiveness and sustainability goals. Since late 1990s, Chinese government already started to support the technological exploration of EVs and has so far one of the most comprehensive policy arrangements to facilitate the deployment and diffusion of EVs. A critical characteristic of the policy intervention is the disproportionate support for battery-based solutions, manifested in the "Pure Electric Drive" strategy in the milestone 2012 national policy (see Chapter 5).

Fourth, China as both a transition economy and emerging economy provides an ideal setting for the exploration of the complex institutional environment. China has shifted from planned economy to the dual track of state intervention and market coordination. Despite state-owned enterprise (SOE) reform, it still plays an important role in strategic sectors in national economy, for example, the automotive industry. The joint venture (JV) arrangement between SOEs and global OEMs creates even more diversified institutional profiles. This is very useful to the understanding of how green industrial policy plays out in a loosely coupled system. Moreover, the co-existence of different ownership types and vast regional difference in China enables enough variation among firms in the focal sector, hence provides a very suitable setting to understand firm heterogeneity in the process of system change.

Two levels of analysis are involved in the thesis. The first sub-question is addressed at the sectoral level, or meso level. The second question dives down to examine firms' innovation strategies in response to green industrial policy intervention. It looks at both individual firms and aggregated groups of firms. The third question further zooms in to unpack firms' innovation processes and activities, and how these translate into system level dynamics. Hence both the second and third sub-questions do not solely conduct organisational level analysis, but study the interaction between the sectoral level and the firm level. Therefore, under the overarching longitudinal sector-based case study design, the thesis applies embedded, multiple case studies. This is suitable for answering research questions that seek to understand

heterogeneity and variations among different organisations and make conceptually and theoretically guided comparisons.

Correspondingly, the unit of analysis is at multiple levels as well. The first research question looks at governmental policies and different segments of the EV industrial value chain. The unit of analysis involves both the state – the notion of government and its policies and activities – and the sector, including the focal sector (EV) and its related sectors upstream (e.g., power batteries) and downstream (e.g., charging infrastructure). Of course, some individual firms are mentioned where their innovation activities and strategies are influential in the process of sectoral change and relevant to policy intervention. The second and third sub-questions take firms and their groups as the unit of analysis.

Data comes from both primary and secondary sources. In terms of primary source, the author conducted a period of field work in China's major automobile industrial clusters where there is concrete activity of EV manufacturing and deployment. The field work totals almost one year before and after the outbreak of Covid-19 pandemic. Semi-structured, face-to-face interviews were conducted with policy makers, policy consultants, senior business managers, prestigious technological professionals in the sector; this switched online to remote interviews during the Covid-19 pandemic. The author followed the methods and guidelines of "elite interviews" (Harvey, 2011; Richards, 1996). Informants were first accessed during three-month research stay at Tsinghua University, School of Economics and Management (SEM) as a visiting PhD student, a research intern at China EV 100 afterwards, and then through a snow-ball sampling process as the fieldwork unfolded. A diverse source of secondary data was collected as a supplement and for the purpose of triangulation. This includes policy documents related to the automobile industry, EV sector and its upstream and downstream sectors, as well as business reports, archives, existing publications and formal media coverage, etc. The

secondary data source, such as historical interviews, became especially important during the pandemic when interviews were not easy to conduct.

Following this introductory chapter, the reminder of this thesis is organised as the follows. Chapter 2 conducts a critical review of the literature that is particularly relevant to the thesis topic, including green industrial policy (with industrial policy in general), direction of innovation, SSIP (including a broader notion of innovation system) and innovation management. The discussion of these works with reference to thesis topic identifies important gaps in each strand of literature and points out the needs to bridge different disciplines together in order to better understand the political economic dynamics of directionality of innovation in early phase of green transformation.

Chapter 3 proceeds to build the integrated analytical framework of the entire thesis. It re-interprets the SSIP framework in its original form and bridges it with open systenmess perspective in political economy literature. This results in an open systenmess approach to SSIP under green transformation. It elaborates on the five major elements of the framework, where directionality of innovation relates to the first and most important one – technological multiplicity in transformative change with a normative agenda. This framework assigns paramount importance to the interaction between state intervention – manifested as green industrial policy in the "endogenous institution" regime – and business firms in the focal sector revolving around directionality of innovation. The consequence of firm innovation is further examined from the perspective of "system building", hence connecting actor-oriented analysis with system-level outcomes.

Chapter 4 lays out the research design of the thesis. Within the overall longitudinal case study on China's electric mobility transition is both sector-level and firm-level analysis. The rationale for the case study design and selection of firms is explained in detail. Moreover, it gives an overview of the four phases that could be divided into to characterise the development of

China's emerging EV sector. This division of time would also guide analysis in the remaining chapters. Method of data collection and analysis, along with research ethics, is discussed in this chapter. Prior to empirical analysis in the chapters that follow, it dedicates one section in Chapter 4 to provide a description of the development of China's electric vehicle sector in the global context, and the policies and ecosystem of electric mobility in the country. This offers necessary background and contextual information for readers.

Chapter 5 addresses the first sub-question at the sectoral level. It views green industrial policy not as a single policy instrument, or a mix of different policy instruments, but an evolving portfolio of multiple-level institutional, regulatory and policy specifications revolving around a specific strategic policy goal. The effectuation of green industrial policy on technological substitution and technological variation is investigated from its interaction with major building blocks in the SSIP, and the feedback loops and imbalances in the value chain are uncovered. The core argument is that underlying the successful intervention of green industrial is the mechanism put forth as "dynamic institutional complementarity" (chapter 5). However, with the intention to "endogenize" technical change for competitiveness, green industrial policy is not "an unalloyed blessing" for industrial competitiveness or sustainability. If the speed of technological substitution is achieved at the expense of narrowed scope of technological variation, this may produce system gaps that sustain the problems with industrial upgrading and capability building that already exist in the sector.

The often-neglected feedback loops and imbalances in the sectoral system are to a large extent contributed by firm heterogeneity and its consequences. The findings in Chapter 5 soon lead to the necessity to understand in depth the object of green industrial policy, i.e., firm innovation in the focal sector at a more disaggregated level. Chapter 6 to 8 hence address the second sub-question motivated by this need. Chapter 6 presents a descriptive analysis of how directionality of innovation is characterised at the firm level and its evolutionary dynamics before and after

2015. This is a preparatory chapter for explanatory empirical analysis. Chapter 7 and chapter 8 undertake the analysis dedicatedly by focusing on the period before 2015 and after respectively. They offer an explanation for firm heterogeneity in their innovation strategies responding to state intervention. Considering that the sectoral system is loosely coupled, and firms are faced with contested reference frames, it focuses on the *variegated incentive structure* firms are embedded in that mediates the influence of green industrial policy. Moreover, the chapter further looks at the moderating role of important firm-level factors in the process, namely technological capability in the incumbent technological regime, and its overall resource portfolio. The thesis argues that only by anchoring green industrial policy within the firm-centric incentive structure and studying the interplay between system-level and firm-level factors could the actual impact of state intervention be sufficiently understood.

Given chosen directionality of innovation by firms, the thesis investigates firms' innovation processes and activities that lead to both organisational and system level consequences in Chapter 9, the last empirical chapter in the thesis. Firm innovation is conceptualised as "system building". By looking at how design rules, positioning along the industrial value stream and sources of technology and resources qualitatively change over time, the thesis inductively develops a process-based model of system building, hence elucidates on the role of incumbent firms in translating organisational behaviours into system level dynamics in green transformation.

Chapter 10 concludes with major findings in the thesis and discussions in relation to literature with policy and management implications. This is accompanied with a discussion on the broader global context, especially considering both incumbents and start-ups in the Western countries, and the growing challenges brought about by geopolitical factors. Last, it points to the limitations of the thesis, and future directions of research considering these limitations and industrial-level and global-level dynamics.

This thesis seeks to advance the theory and literature on policy and management of innovation for sustainable development in several aspects. Foremost, the thesis marks an interdisciplinary attempt to address "grand challenges" that no stand-alone theory, literature or discipline could sufficiently accomplish (Buckley et al., 2017; Kuhlmann & Rip, 2014). It bridges and integrates the following strands of literature: green industrial policy, sectoral system of innovation and production, and capability building and theory of the firm. Correspondingly, it demonstrates how disciplines at different levels and focuses of analysis - political economy, evolutionary economics and innovation management - could be fruitfully bridged. The common core is an evolutionary understanding of technical change, transformation of economic systems and interrelations between heterogeneous change agencies. On such basis, the innovation systems concept (in the thesis, the focus is on sectors) at the meso-level is flexible enough that channels and mediates macro-level factors (state intervention) into meso- and micro-level outcomes, and in turn functions as a basis for feedback between structural and agency factors. This potential is unleashed by applying an open systemness approach to innovation system adapting from political economy literature. As such, the thesis is able to provide a political economy and evolutionary understanding of directionality of innovation in early phase of green transformation, where the directionality of innovation bears significant implications for development outcomes.

At the same time, the thesis advances developments in each strand of literature respectively.

(1) It deepens the understanding of the nature and impact of green industrial policy in sectoral structural change in developing countries and emerging economies in four aspects. First, instead of focusing on policy instruments, it views green industrial policy as an evolving set of institutional arrangements in the broader context of "endogenous institutions" (Geels, 2014), which is multi-dimensional (Anzolin & Lebdioui, 2021). While the thesis is informed by yet does not intend to fully engage the "policy mix" literature (Rogge & Reichardt, 2016), which

would otherwise be another study, paying attention to the interaction between green industrial policy with other policies and regulations initiates a dialogue between political economy research and sustainability transition research community (Geels, 2018; Köhler et al., 2019). Second, the study adds to the understanding of the causal mechanism of green industrial policy – directionality of innovation nexus by embedding the link in the system of innovation. Those feedback and interactions do not occur at random but originate from the openness and imbalance in the system under green transformation. Third, by considering the strategic responses from policy objects – firms in the focal sector, it contributes to a more comprehensive, less-biased understanding of the role of green industrial policy. Fourth, while green industrial policy literature is "strong in theory, ambiguous in practice" (Rodrik, 2015) and majority of the few empirical works talk about selective "best practice" (Harrison et al., 2017), this thesis provides rich empirical evidence on the nature and influence of green industrial policy in developing countries and emerging market economies through a comprehensive, systemic and in-depth case study from a longitudinal perspective.

(2) The thesis contributes to the theoretical development of the SSIP in particular and innovation systems concept in general. The idea of political economy as an open system emphasises (semi-) equi-functionality and contested reference frames concerning firms' behaviour (Becker, 2007). This also captures the nature of innovation system under change and is hence adapted to re-interpret and refine the SSIP framework. The resulted open, loosely coupled and imbalanced system loosens the overly structural-functional conceptualisation of innovation system, and gives more space to strategic interaction between political and economic actors. As such, this thesis has taken an experimental step to bridge the SSIP framework with political economy insights and shown how a better explanation of system transformation is possible through this cross-fertilisation. The thesis argues that while the notion of technological regime and industrial value chain may be distinctive to a sectoral

perspective, whereas the open systemness approach, with its theoretical roots in political economy discipline, bears implications for rethinking innovation system concept in general.

(3) The thesis provides an integrated conceptualization of "directionality of innovation" by combining the normative dimension (agenda setting, desired status of future system) and positive dimension (the material side, i.e., designs, artifacts, linkages, etc.). Between an overall agenda of regime shift on the one hand, and technological multiplicity on the other, one can use the concept as a lens to examine how political, technological and industrial dynamics unfold revolving around system change and the potential tension within. Moreover, it can be operationalised at different level of aggregate depending on the research question and level of empirical analysis.

(4) The thesis enriches the understanding of firm heterogeneity and how it plays out in innovation system under green transformation. First, it provides a topology to characterise the pattern at firm level concerning directionality of innovation considering both the normative and positive dimension. Second and more importantly, on the premise that firm heterogeneity channels the green industrial policy differently in the sector, the thesis provides a novel analytical framework to explain firms' different behavioural patterns in response to state intervention by looking at the mutually contingent interaction between system-level and organisational factors, and hence takes one step towards reconciling the classical structure-agency dichotomy. The multiple level explanation further broadens the perspective on firm heterogeneity by going beyond economics and management studies (Hottman et al., 2016; Noda & Collis, 2001) to the integration of political economy insights. The notion of "variegated incentive structure" is particularly important here. Derived from major building blocks in the SSIP, it functions as an integrated firm-centric decision-making environment where the implication of green industrial policy incentives becomes explicit only when they are examined as an integral part of the incentive structure. In this way, the study also points to the contingency

of institutional embeddedness of firms in the changing innovation system, hence enriching the neo-institutionalism perspective as well.

(5) The thesis provides a systemic and comprehensive understanding of firms' innovation process in early phase of green transformation, which has been under-conceptualised and under-researched in innovation management and system literature. The formal conceptualisation of "system building" for the first time brings fragmented concepts and elements together in a coherent way and connects firm-level innovation activities and processes to system level dynamics. It allows for the investigation of the complementary relation between technological, product and business model innovations. On such basis, the process-based model of system building more generically explains how qualitative change takes place among incumbent firms in a multi-tech, multi-component sector in early stage of green transformation. The findings also invite more theoretical discussions on interrelated concepts in the field of industrial architecture (Jacobides et al., 2006), product-service-systems (PSSs) (Mont, 2002; Tukker, 2004) and industrial platform (Gawer & Cusumano, 2014). These constructs are exactly where firms' innovation activities translate into higher-order outcomes.

Chapter 2 Literature review

This chapter conducts a critical review of four major relevant strands of literature: (green) industrial policy, innovation systems approach, evolutionary economics and innovation management studies, additionally with relevant discussions on the implications of environmental economics and environmental policy studies.

Before progressing to literature review, it is important to make clear how innovation is defined in the thesis. Many conventional indicators such as patenting activities and R&D expenditure risk failing to capture the activities and processes of innovation in developing countries, where non-technological, process-based and learning-oriented efforts are contributing to growing innovation capacity and structural change in their economies (Fu, 2020). Moreover, as developing countries are closer to technological frontier in terms of green technologies and emerging technologies, and the progress of these activities seem to be faster than the adaptation of existing IP systems, it is also worthwhile to paying attention to non-patent, non-technological dimensions of these most recent progresses. Therefore, I adopt the broad definition of innovation, according to OECD and Eurostat (2018, p. 20), as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)". Hence innovation activities include not only R&D activities, but also marketing and brand-related, innovation management, and so on (OECD & Eurostat, 2018). For developing countries, innovation does not need to be new to the world, but new to the country, the sector, or even the firm.

2.1 Industrial policy and role of state at the crossroad

The role of state and related debate over state-market relation is frequently centred on the justification and specification of industrial policy. The term industrial policy itself is still highly controversial and its meaning and the focus of debate has been constantly evolving. This section tries to trace the generational evolution of industrial policy debate relevant to our topic but is aware that "any temporal dimension will be a 'loose sequence' of emergent scholarship" (Stephenson, 2013b). The loose sequence helps to draw rough distinctions between important milestones in the scholarly history of industrial policy and glean out the core debates and their implications for green transformation.

2.1.1 Industrial policy debate before the 1970s: a tale of two worlds

The debate over the rationale and design of industrial policy has a long history. Systematic discussion on state intervention into economic activities can date back to the classical political economy period and manifests in the accounts of Germany's industrial catch-up. The point is that the state has played an important role in economic and industrial development in history. Even in times of the Great Recession and post-World War Two (WW2) period, the "visible hand" of the public sector contributed to economic recovery and employment growth significantly. The quarter of a century after the WW2 features a strong hand of the government in regulating and rejuvenating economic activities. With a growing number of countries in the Third World regained independence and sovereignty, this is also the age of "development" really sets in motion at a global scale (Rist, 2014). Under the similar umbrella of "modernisation", however, the practice of industrial policy exhibit "two worlds" in the global North and global South respectively.

Though industrial policy means different things to different people, it is widely accepted that it refers to "any type of selective government intervention or policy that attempts to *alter the*

structure of production in favour of sectors that are expected to offer better prospects for economic growth in a way that would not occur in the absence of such intervention in the market equilibrium" (Pack & Saggi, 2006, p. 268). The reasons for adopting industrial policy in the context of latecomer development are tremendous and have strong rationales, frequently found in arguments including knowledge spillovers and dynamic scale economies, the presence of coordination failures and informational externalities – a variety of externalities and "failures" under the broad "market failure"[1]. However, there are also counter arguments, especially that the government is not capable of picking winners, which not only distorts the incentive structure but also invites rent seeking (Maloney & Nayyar, 2018; Stiglitz et al., 2013).

In spite of the pitfalls, industrial policy is still widely practiced in developing countries, from Latin America, Africa and East Asia in different formats. When it comes to the evaluation of the effectiveness of industrial policy, however, available results are very ambivalent. In many cases for Latin American and African countries, the growth outcome is undoubtedly disappointing at large (Etzkowitz & Brisolla, 1999; Khan & Blankenburg, 2009). Perhaps the only ones out of few that have successfully caught up are the East Asian economies especially Japan, Korea and Taiwan that are characterised by political economists as the "developmental state" models (Johnson, 1982, 1999; Öniş, 1991; Wade, 2004). Even so, a lot of scholars argue that the casual mechanism is not rightly explained and because of the lack of counter-factual, one cannot easily claim whether industrial policy is successful, or the rise of these countries should be attributed to industrial policy and the developmental state (Wu, 2004, 2005). China, of course, took the East Asian Miracle's example, too, and applied a developmental approach to its national economic growth (Knight, 2014; Nee et al., 2007). Nevertheless, the cultivation of "national champions" has largely backfired (Nolan, 2001). The country realises that it should

[1] For a detailed review, see Pack, H., & Saggi, K. (2006). Is there a case for industrial policy? A critical survey. *The World Bank Research Observer, 21*(2), 267-297.

make greater efforts to strengthen its science and technology base and shift from factor-driven to innovation-driven growth. This underscores the relevance of political economists' institutional interpretation of the Korean industrial policy story that puts more emphasis on the role of learning and capability building (Chang & Amsden, 1994; Chang, 2002).

In the global North, strong presence of the state intervention in national economic activities in can be seen the reconstruction period after the WW2. Although governmental policies and actions are hardly labelled as "industrial policy", this experience is still relevant in the sense that it touches upon the classical state-market relation debate. The WW2 period motivated significant breakthroughs in science and technology supported by state funding, which were then actively diffused to the society through state-lead initiatives where the private sector participated in (Mazzucato, 2011). This is what characterised the United States' technological progress and economic boom following the "Endless Frontier" report (Bush, 2020). Similarly in Western Europe, countries such as France exercised strong state planning in its industrial development under The Marshall Plan (Geroski, 1989; Owen, 2012). Although this was soon taken up by the resurgence of liberalism in the 1970s after the oil crisis, stagnation and with the increasingly problematic oversized public sector, the role of state should not be underplayed from the macroeconomic perspective. In European sub-national level, industrial policy is more explicitly mentioned to boost regional economic revival through support for industrial clusters and promotion of specialization (Buigues & Sekkat, 2009).

The fading enthusiasm and growing disappoint towards industrial policy in the developing countries and the embrace of neoliberalism signalled by Regan's and Tatchell's administration eventually consolidated as the Washington consensus. As a result, both ideologically and in practices, the state retreated substantially from intervening the economic activities and market regulation, only serving a minimum role. Whether industrial policy is still relevant in such a context is once again cast into question.

2.1.2 The return of industrial policy agenda with new faces

After the turn of the century, both academic and policy-making realms are witnessing a return of industrial policy (Rodrik, 2010; Wade, 2012), which arises from various theoretical developments, shift in policy paradigms and in response to co-occurrent challenges facing both developed and developing countries. Innovation-driven knowledge economy becomes a new agenda for Western countries in face of productivity growth slow-down. In its broad term, industrial policy gradually evolves to involve the science, technology and innovation (ST&I) dimension of public policy that serves to encourage R&D input, inter-organisational collaboration and provide horizontal support for these activities (Bailey et al., 2019; Rodrik, 2009). State intervention from this perspective is justified based on the costly, risky and uncertain nature of innovation itself, as well as information and technologies as public goods that discourage private sector efforts in conducting R&Ds (Stiglitz et al., 2013). Such trend is strengthened by the outbreak of 2008 Financial Crisis and ascendance of China in global economy, which brought the issue of economic growth and competitiveness to the forefront of policy debate. Consequently, there is growing recognition that industrial policy is no longer an "existential" problem, but a "what" and "how" question (Rodrik, 2009).

It is within this turn of industrial policy's focus and rationale underpinning that some of the highly developed, industrialised OECD economies engage in actual industrial policy practice. For example, the U.S. is argued to be a "hidden developmental state" in the sense that support for technological and industrial competitiveness is conducted in a networked, decentralised manner, therefore less recognisable following the traditional definition (Block, 2008; Wade, 2014). Another example is the EU, which emphasises an integrated approach to industrial policy in order to achieve economic growth and re-establish competitiveness (Westkämper & Walter, 2014). Despite these *ad hoc* practices and nuanced variants of industrial policy, proponents of industrial policy are still wary of the consequence of "winner-picking" aspect

and base their arguments largely on a neoclassical assumption of economic activities while aware the bounded rationality of actors. The renewed rationale for industrial policy (sometimes used together, or interchangeably with innovation policy) hence rests on the horizontal dimension, and the government matters in terms of correcting "market failures" and creating benign environment for knowledge infrastructure (Chang & Andreoni, 2020).

The role of innovation-driven economic development is recognised in parallel in developing countries and emerging economies. Different from the science and technology-driven model in the West, developing countries possess inferior technological bases and capabilities. Therefore, their approach to industrial policy is to foster technological upgrading through both indigenous efforts and more importantly technology transfer via various channels (trade, FDI, and people flow) to strengthen their open national innovation system (Fu, 2015; Fu & Gong, 2011), and actively embedding themselves into the global value chain to achieve upgrading (Lebdioui, 2022; Lebdioui et al., 2021). A portfolio of policy tools and instruments are utilised, such as industrial clusters, special economic zones (SEZs) and export processing zones (EPZs), etc. (Harrison & Rodríguez-Clare, 2010; Pak & Park, 1997). Whereas their effectiveness in technological and upgrading is contested and this partly depends on the appropriateness of technologies (AT) (Eckaus, 1977). At the same time, attention is also paid domestically to innovation policy instruments such as public R&D to enrich the knowledge pool and strengthen university-industry linkages (Maloney, 2017).

While there is a wide array of means to acquire technologies, another related debate is whether the practice on industrial policy should comply to or defy a country's comparative advantage. The compliance argument raised by the so-called new structural economics (NSE) tries to rescue development economics by combining neoclassical assumption of the market and the firm and the structural change objective in developing countries. It contends that government plays a facilitating role that works in concert with efficient market according to a country's

comparative advantage expressed in factor endowment prices. The dynamic accumulation of endowment factors under such condition leads to structural changes (Lin & Monga, 2013). By contrast, institutional political economists disagree with this reasoning, arguing that industrial specific capabilities need to be developed in order to enter new sectoral domains therefore requiring industrial policy to defy or at least develop comparative advantage (Chang, 2013; Lin & Chang, 2009). Though the debate is far from being settled, the focus of industrial policy in developing countries has fundamentally shifted to entrepreneurial activities, learning and capability building, and the strengthening of linkages and coordination in economic activities.

2.1.3 "Grand challenges", green industrial policy and the role of state

Perhaps a more fundamental renewal of industrial policy agenda, together with the role of state in economic activities and social change, is the imperative to address "grand challenges" facing human society (Kuhlmann & Rip, 2014). These challenges, for example, combatting climate change, are systematic and demanding. Therefore, a group of scholars are moving beyond neoclassical fixes and trying to argue that public sector should be "entrepreneurial" in taking risks and "crowd in" private investment to create innovation that solves tricky social problems, such as renewable energies and other clean techs (Mazzucato, 2011, 2017). Such a stance is resonated by another school of quickly emerging scholarship, transition studies, which recognises the state's role in addressing "system failures" but at the same time acknowledging the importance of non-state actors in the governance of transition processes (Köhler et al., 2019; Markard et al., 2012). These two strands of literature to a large extent focus on developed countries, converge on an overall active role played by the public sector in encountering "grand challenges", but has anchored the solution in the design and implementation of "policy mix" to manage and facilitate transition (Flanagan et al., 2011; Kern et al., 2019; Lindberg et al., 2019), or transformative innovation policy (Diercks et al., 2019). To date, these scholarships have distanced themselves from industrial policy literature despite their sporadic usage of

industrial policy tools and elements to varied extent (Johnstone et al., 2021). Only recently some researchers in innovation policy studies call for a serious examination of the role of industrial policy in their research agenda (Johnstone et al., 2021), but the reception appears to be slow and reluctant.

Developing countries face a dual challenge: they have the "traditional" task to foster industrialisation and overcome "middle income trap"; at the same time, they are encountered with sustainable development imperatives while more vulnerable to climate change (Kemp & Never, 2017; Rodrik, 2015). These challenges, of course, can also be opportunities for developing countries to restructure industrial sectors and embark on green growth. Some industrial catch-up and development literature presents the idea of "green leapfrogging", a possibility that the global South could find alternative paths in developing green technologies and narrow the gap up with industrialised capitalist economies (Doig & Adow, 2011; Ho, 2005). The possibility has been concretised into innovation activities in some emerging market economies, a typical example being the rise of solar PV industry in China and India (Fu & Zhang, 2011).

Mostly recently, with the deepening trend of green transformation in the globe, industrial dynamics and development scholars further elaborate on these opportunities as "green windows of opportunity" (GWO) that developing countries could seize and exploit to narrow the technological gap with the West (Lema et al., 2021). While the GWO literature points to a wide array of factors contributing to successful catch-up by developing countries, including the opening of technological, institutional and market windows, the strategies of state and business actors and the fact that industrial forerunners are caught by "incumbent trap", etc., the role of government is only discussed as one of the factors and not in a systematic way (Dai et al., 2020; Zhou et al., 2020). The same can be said on the broader industrial catch-up and green leapfrogging literature. Moreover, so far they are more concerned with technological and

industrial catch-up objectives and outcomes, leaving the sustainability issue less discussed (Matsuo & Schmidt, 2019).

Green industrial policy literature, by contrast, focuses on the design and implementation of policies that have the ambition to combine the sustainability and competitiveness objectives (Kemp & Never, 2017). There is a strong theoretical case for the introduction of green industrial policy approach to achieve green restructuring. First, structural change does not happen automatically and there is deeply rooted path dependence associated with the previous polluting growth strategy due to technological, market and institutional lock-in (Simmie, 2012). It plays a critical role in fostering structural change in developing countries (Anzolin & Lebdioui, 2021). Therefore, public policy needs to provide enough incentive to enable system change. Second, the development and diffusion of green technologies suffer from double externalities (Oltra & Saint Jean, 2009), i.e., knowledge spillovers from innovation activities as well as both producers and consumers bearing environmental costs in the early stage. Third, what is special about green industrial policy is that it emphasises the urgency and directionality of green transformation (Altenburg & Assmann, 2017). The urgency of mitigating climate change means that there should be swift and decisive action. The directionality of green transformation means that innovation efforts should be directed towards the green growth pathway instead of serving the interests of the polluting regime. Fourth, although green industrial policy implies trade-offs, developing countries would still be better off by "greening early" than adopting a "wait-and-see" strategy because of early-mover advantage in environmental and economic benefits, as well as fewer switching costs and regime resistance compared to "greening later". Finally, the quest for domestic economic welfare and industrial competitiveness is not to be blamed, if the policy tools are properly designed and executed (Altenburg & Assmann, 2017).

While it is strongly argued as a perhaps second-best but realistic option for developing countries, the emphasis on structural change towards sustainable development and competitiveness is also relevant for developed countries, particularly those amidst degrowth and deindustrialisation debate (Lucchese & Pianta, 2020; Pegels & Lütkenhorst, 2014a). As an important, ascending part of contemporary industrial policy research agenda, green industrial policy study does not only attract attention and interests from industrial and innovation policy researchers but also development scholars; not only in the academia but also among prominent development organisations such as United Nations Industrial Development Organisation (UNIDO).

Of course, this literature is aware of the various failures potentially arising from policy making and implementation. Similar to what commonly happens to industrial policy in general, there are government failure and political economic failure associated with green industrial policy that may well be more acute than general one. On the one hand, because of the highly uncertain, complex and systemic nature of green transformation, the information and learning challenge for the public sector is tremendous. On the other hand, policy design and implementation are especially subject to the influence of interest groups and particular types of business actors because of the fuzziness of policy design itself, as well as the politically contested framing of policy goals, strategy and instruments (Altenburg & Assmann, 2017). Because of this political economic failure, the process of policy implementation may result in unintended consequences that are not desired by the original policy agenda. However, these failures do not serve to negate green industrial policy as a whole, but rather necessitate better quality by ensuring more reflexivity, accountability and continuous policy learning and experimentation (Rodrik, 2015).

2.1.4 Limitations

Research on green industrial policy is still in a very nascent stage, with a lot of important questions being unanswered or insufficiently addressed. The definition of "green industrial policy" itself is already no less debatable than "industrial policy". I will discuss this and justify the choice of definition in chapter 3. Furthermore, the design and contents of green industrial policy are ambiguous, too, and policy tools vary from case to case, often summarised in an *ad hoc* manner (Harrison et al., 2017). Substantial theoretical and empirical studies are needed to advance our understanding of the nature, analytical underpinnings and regularities about the policy approach.

More importantly, the influence and consequence of green industrial policy is surprisingly unclear. Empirical studies examining the impact of alleged green industrial policy often focus on quantitative evaluation of specific policy instruments – often in the form of environmental regulation or policy incentives - on green or environmental innovations (Ambec et al., 2013; Shao et al., 2020). This literature overlaps with environmental economics and environmental policy literature a lot, and produces contrasting empirical results. The analysis can generate cross-country and cross-sector insights, yet is overly static and uni-directional, without fully appreciating the process and activity of innovation undertaken by firms – the objects of policy intervention (Zylberberg, 2017), and their embeddedness in the innovation system. As a result, the mechanism through which green industrial policy takes effect on innovation and sectoral change outcome remains as a black box. Empirical study employing case study method has been limited, mostly seen in selective "best practices" that may be partial and not comprehensive. Empirical evidence from developing countries and emerging economics is scarce with very few exceptions (Anzolin & Lebdioui, 2021).

Another problem is with the dependent variable, i.e., directionality of innovation. Directionality of innovation bears significant developmental and sustainability consequences yet has not been examined from the perspective of state intervention, green industrial policy and related political economic dynamics. This is partly because that directionality of innovation itself is under conceptualised, and its overly normative dimension in certain Western context often neglects the positive side, the concrete pathways of capability building, which eventually lead to different outcomes of industrial competitiveness and environmental performance. The next section hence proceeds to review existing conceptual approaches to "directionality of innovation" and puts forth an integrated definition that helps to advance a political economic and evolutionary understanding of industrial green transformation.

2.2 Directionality of innovation: widely used but under conceptualised

The problem with existing approaches to "directionality of innovation", argued in this subsection, is that there is a disconnection between the "normative" and "positive" dimensions of directionality in several disconnected strands of literature – political science, evolutionary and environmental economics, and innovation systems approach. Addressing this problem would prepare the foundation for empirical examination of the role of green industrial policy and business responses in sectoral change towards sustainability.

2.2.1 The input-factor-based understanding

Technical change is not neutral but biased toward/against certain socio-economic parameters. Whether there is abundant stock of these parameters to some extent determine the competitiveness of a country, region or organisation. While there is no formal definition of directionality of innovation, the mostly known approach built on this notion is the macroeconomics focus on relative price and supply/demand conditions of these input factors. The famous Directed Technical Change (DTC) theory goes along this line. It argues that

technical change is biased towards skilled labour in the long run with input factor such as labour and capital are considered (Acemoglu, 2001). This not only has implication for competitive advantage, but also distributional outcomes in within and across countries. Some countries are better off because of richness in higher education human capital, while others, mostly developing countries, are disadvantaged because of lack of capital and skilled labour. A related framework, appropriate technology (AT) (Eckaus, 1977), fits into this input-factor-oriented understanding of direction of innovation when talking about technology transfer. It is also aware of the matching of broader institutional, economic and social conditions.

The input factor-oriented perspective means that a change in the price can create incentive for firms to alter their decisions of investment and production, and this change does not only stem from economic factors but is also affected by public policies that are targeted at externalities. This is how policies and regulations are justified in environmental policy and environmental economics literature. Two influential theories have drawn wide attention and inspires both empirical research and policy design. The first one is the induced innovation hypothesis (IIH), which is perceived to be the predecessor of the DTC theory. First put forward by Hicks (1963, p. 124), the hypothesis goes that "a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind - directed to economising the use of a factor which has become relatively expensive." It bears relevance to climate change mitigation as has been recently mobilised by environmental policy and environmental economics literature to study the impact of policy instruments that alter the relative price between "dirty" and "clean" technologies (Hepburn et al., 2018). It is expected that increase in energy prices would encourage the innovation of energy-efficient technologies and this prediction is supported by numerous empirical tests and constitute an important policy rationale (Aghion et al., 2019; Popp, 2002). The second theory is the Porter's Hypothesis (PH). It does not focus on the factor price directly but the role of environmental regulation in incentivising

firms to development environmentally friendly technologies (Ambec et al., 2013). Contrary to conventional view that the requirement of firms to internalise environmental costs reduce their profits, the strong version of PH argues that well-designed regulations can actually enhance firms' competitiveness (Shao et al., 2020).

According to the DTC theory, the direction of innovation is inherently and naturally determined by the input factors in the macro-economic process. For IIH and the Porter's hypothesis, input prices do not stay unchanged but can be affected by public policies that intend to solve the externality problem. While sharing the same assumption on the nature of firm-level economic activities, the latter point to the normative dimension of direction of innovation, that is, intentional government action should be taken to provide incentives for firms to achieve societally important, non-economic objectives (environmental protection) (Acemoglu et al., 2012; Aghion et al., 2019). However, none of these theories speak about the innovation process and activities as learning and capability building when dealing with direction of innovation.

2.2.2 Direction of innovation in evolutionary economics

Different from the neoclassical assumption of innovation and production activities in macro-economics and partly development economics, evolutionary economics sees innovation as an evolutionary process characterised by the process of selection, variation and retention of knowledge and technology. As such, it implicitly interprets the direction of innovation as the dynamics of technological paradigms and technological trajectories, a model that accounts for both continuity and discontinuity in technological change (Dosi, 1982): "Continuous changes are often related to progress along a technological trajectory defined by a technological paradigm, while discontinuities are associated with the emergence of a new paradigm" (Dosi, 1982, p. 147). Therefore, the direction of innovation involves both continuity and discontinuity, which is an open process without predefined path. Moreover, instead of assuming that market

is the prime driver of the emergence of a new paradigm, evolutionary economics attributes it to a combination and complex interplay between a diversity of factors including economic factors, scientific advance, institutional factors and unsolved problems in the established technology path (Murmann & Frenken, 2006).

This is how direction of innovation is implicitly understood in evolutionary economics literature at the macro level. Taking a closer look, technical trajectories do not exist in a vacuum but take certain configurations and have their material side, often embodied in various sectors and technological solutions to the problem of concern. At the meso-level, direction of innovation hence can be viewed as a process of technological discontinuity and re-establishment that renders the incumbent technological regime obsolete and new technological regime prospect to take the place of the existing one (Dijk, 2000; Ende & Kemp, 1999). The cyclical model of technical change exactly depicts this process using concepts of technological discontinuity, "era of ferment" and dominant design (Anderson & Tushman, 1990; Ferrigno et al., 2022; Utterback & Suirez, 1993). The notion of "era of ferment" is especially important here, for that it refers to the period of selection process of regime competition between the old and new, as well as design competition in the emerging regime, that eventually shape the path and outcome of "creative destruction".

Due to the open-endedness of this selection process, and the complexity of the selection environment, there might not be "dominant design" but instead the continuous co-existence and competition of different viable technological paths and solutions fulfilling the same functional objectives in a sector. All of them have economic, social and environmental consequences. This is amplified by the peculiarity of green transformation, because there are no prior-known paths to achieve the goal which is yet to be decomposed into science and technology-based solutions. Moreover, the selection environmental is highly contested by political factors and ambiguous and vested economic interests (Murmann & Frenken, 2006;

Yap & Truffer, 2019). However, evolutionary economics tends to understate the role of political factors and the state actor in intentionally intervening the selection process. This is why an integration of evolutionary thinking with political economy perspective could fruitfully help understand the direction of innovation and its determinants in the context of green transformation.

2.2.3 The normative turn in "directionality of innovation" -- what gets lost?

The understanding of directionality of innovation in environmental policy and economics literature already implies a normative stance, i.e., the objective of environmental sustainability. With a focus on environmental performance in the economy, this literature asks what policies work for directing innovation toward environmental benefits and reduce environment degradation. Similar logic applies to energy economics and energy policy literature in quest for climate change mitigation solutions based on energy and related sectors aside from maximising efficiency and economic benefits.

The fundamental normative turn in the understanding of direction of innovation takes place together with the normative turn in innovation policy. As the subsection 2.1.4 has mentioned, the innovation policy literature has shifted from seeking policy instruments conducive to science, technology and innovation to enhance economic and social welfare and competitiveness, to address "grand challenges". Most recently innovation policy in the European context is "mission-oriented' and innovation is critical in resolving these challenges such as the climate change (Mazzucato, 2018; Robinson & Mazzucato, 2019). A related stance from the transition studies community advocates that to encounter these "grand challenges" it is necessary to transform the entire socio-technical systems rather than focusing on technological innovation narrowly (Geels, 2018). Because system transformation has its

desired destination and outcomes, it inevitably imposes directionality to innovation as a driving force for the change.

Different but interrelated, the two strands of literature share a common strong normative assignment to the directionality of innovation. Put it simply, the normative part is the judgement of what is "good" and what is "bad" according to the problem to be solved, the mission to be achieved, or the destination to be arrived. The policy implication is that transition process should be governed purposefully, with state and non-state actors actively participating while maintaining the evolutionary potential of the system (Farla et al., 2012). If actors and their policies fail to do so, the result would be "directionality failure" (Lindner et al., 2016). For example, the transport sector largely remains locked in to burning petrol instead of using clean, renewable energies.

The normative turn is legitimate in the sense that "grand challenges" are real, pressing and systematic that calls for a substantial rethinking of the nature, role and approach of innovation. However, what is less visible is the "positive" dimension of directionality of innovation which is submerged by the overly normative call. In the context of green industrial policy, s claiming that state intervention is needed for climate change mitigation through green industrial restructuring is an important first step but far from enough. In particular, it tells little about the concrete innovation and capability building paths followed and technological configurations adopted (Andersson et al., 2021), while this "positive" dimension, or the "material" side of directionality, is critical to understand the consequences of resulting innovation processes on capability building, competitiveness and sustainable outcomes.

2.2.4 Synthesis

To this point, it has been shown that several quite distinct strands of literature have discussed the directionality of innovation implicitly or explicitly. They share some commonalities but

more differences, in terms of the input-outcome dichotomy as well as the normative-positive demarcation. On one hand, there is a positivist view on direction of innovation, partly represented by the input-factor based approach in macroeconomics literature which also inspires the DIT and AT thinking, although the theoretical focus has changed a lot in the latter frameworks. The similarly positive but more open-ended approach is found in evolutionary economics. It is positive in the sense that technological trajectories, regimes and designs are the focal object of analysis and they assume a material facet and result in concrete pathways of capability building. At the same time, it is open-ended in the sense that choices are not solely bounded by factor price and its change in the production function but subject to the selection process that is uncertain and complicated. At the normative extreme, "mission-oriented" innovation (and its policy) and transition studies assign a desired destination or prescribe a problem or challenges to be addressed, but leaves the positive dimension, the concrete technological configurations and their related development consequences, almost as a vacuum. This may be because that this literature is deeply affected by the political debate and agenda in European context – which gradually spreads to other regions yet has paid little attention to the necessarily important capability building in developing countries context.

To take directionality of innovation into the empirical understanding of the impact of green industrial policy, none of the above approach is sufficient on their own. An integration between the normative and positive dimension of directionality of innovation is essential, but these strands of literature develop isolated and hardly talk to each other. To fill the gap, in the next chapter, the task is in the first place to give a useful specification of directionality of innovation in the context of radical transformation of systems (toward sustainability), which lays the basis for further development of analytical framework and empirical analysis.

2.3 Sectoral change from the perspective of innovation systems approach

Innovation does not happen in isolation but is embedded in social, political and economic systems, co-constructing each other in the ever-changing environment. A system approach originating from the evolutionary economics and neo-institutionalism tradition has been developed and adopted to explain the process of innovation, marking a departure from the neo-classical economics perspective of innovation as a black box. It is informed by early functionalist system thinking in the mid - 20th century (Newell & Simon, 1972) and formally conceptualised and theorised by pioneering scholars such as Lundvall, Freeman and Nelson in the seminal National Innovation System (NIS) scholarship (Freeman, 1995; Lundvall, 1992; Nelson, 1993). Putting learning, knowledge and capability building at the centre of innovation process, the system approach has been applied at various levels and units, including Regional Innovation System (RIS) which is most similar to NIS in its theoretical core, Sectoral System of Innovation and Production (SSIP) and the emerging Technology Innovation System (TIS) (Edquist, 2006, 2010). Recognising the importance of international knowledge flow and learning, the framework of Global Innovation System (GIS) is also suggested to move beyond the existing territorial boundary (Binz & Truffer, 2017). As this thesis focuses on structural transformation in industrial sectors toward sustainability, here I limit the current review to the SSIP framework.

The SSIP framework highlights that knowledge and technological regime differs across sectors and this makes a difference for the particular model of innovation undertaken by firms and the type of inter-firm networks (Malerba, 2002, 2004). Two other elements are also at work. First, the market regime that describes the demand conditions in the sector, and second, the institutional regime that defines the "rule of games" that bound and regulate firms and other entities (North, 1990). For example, biotech sector is science-based, featuring a huge number small and medium enterprises (SMEs) with fast turnover and vibrant competition dynamics.

On the contrary, machinery tool sector is often dominated by limited large firms interacting closely with downstream customers in a longer cycle time (Malerba & Nelson, 2011). In developing countries, the creation or transformation of sectoral innovation systems faces greater challenges than industrialised countries, as institutions may be under-developed thus provide insufficient support for knowledge development and networks formation. Available knowledge and technology base is also limited, which may be exacerbated by a lack of human capital and limited spillover from the NIS. For developing countries, learning and capability building is the most central theme in strengthening or transforming a SSIP (Malerba & Mani, 2009).

Sectors do not always stay at the same but experience frequent changes. This either occurs exogenously or endogenously, triggered either by external shocks such as the financial crisis or pandemic, or internally by the knowledge and technology breakthroughs, change in demand conditions or institutional frameworks. Such a potential is mobilised by the industrial catch-up literature to explain change in industrial leadership as the result of a combination of several factors (Keun Lee & Franco Malerba, 2017; Keun Lee & Franco Malerba, 2017b). First, there are windows of opportunity that arise from change in three elements in the SSIP framework, namely technological, market and institutional windows of opportunity. Second, latecomers need to seize and exploit these windows of opportunity. When the literature talks about "latecomers", it is often the firm that lies at the centre of analysis. Of course, governmental policy may also play an important role, but this varies from case to case. State and business actors are both examined in the overall latecomers' context to describe their strategies in resource leverage and learning activities. Third, forerunners are supposed to fall into the so-called "incumbent trap" (Christensen & Rosenbloom, 1995) and slow in responding to these windows of opportunity and proactive actions taken by latecomers, and therefore may lose their competitive edge.

This scholarship does provide useful insights on industrial change embodied in pathways of path-following, path-skipping and path-creation. However, its relevance for discussing the role of green industrial policy is limited. This framework is mainly utilised to explain success or failure of change in industrial leadership, and the objective is to achieve industrial catch-up. Even the GWO literature so far has not substantially engaged sustainability outcomes. Moreover, in the catch-up literature governmental policy is only one of the forces contributing to change when relevant, often treated exogenous, while green transformation, as the GWO literature rightly claims, is endogenous and institutional in nature, which is regretfully not taken into more depth to shed light on system change dynamics.

This last point relates to a more fundamental conundrum the SSIP framework is faced with. Lots of literature is constantly questioning the relevance of the broad innovation system approach and critiques go that it is strong in description and structural comparison but not able to sufficiently explain change (Weber & Truffer, 2017), especially the transformation of system driven by innovation – at least in its current status quo of theoretical development. In particular, for green transformation that is affected by endogenous forces (for example, institutions), the SSIP framework falls short of accounting for how actors and agencies play a prominent role in acting on structures that are both constraints and enablers of change. Because direction of innovation towards sustainability is highly uncertain, political and contested, the political economy of government policies is a critical venue to uncover system change. However, most of the innovation systems literature stops at policy analysis, which should be not blamed as it is the original motivation and remains its advantage. But to gain strong explanatory power to understand transformative system change, however, this literature should be bridged with political economy of innovation literature, which has not been poorly undertaken so far in extant literature.

2.4 Firm innovation and strategic responses in business and management studies

Due to the disciplinary boundary, industrial policy literature does not frequently incorporate the objects of policy intervention - business firms and their behaviours - into formal analysis. Innovation systems and industrial catch-up literature does look at firm strategies, but often together with government policies at a more aggregated level of analysis. They do not go into depth of the strategic responses of firms in terms of innovation and production revolving around the directionality of innovation and their implications for policy impact and system change. This requires a closer look into the business and management literature on the strategies, activities and processes of innovation, which, as to be shown in the following paragraphs, has not been well developed to respond to transformative changes.

This has a lot to do with the neoclassical assumption of firms in mainstream micro-economics and industrial organisations research (Shapiro & Shapiro, 1976). Firm is abstracted as a rational and utility (profit) maximisation entity responding to market incentives automatically. Sometimes market incentives can be altered by policies and regulations, for example, carbon tax and feed-in-tariff in the context of green transformation, and the responses of firms are expected to be rationally automatic and identical in the same way. This is the way much of the existing environmental policies and environmental economics literature deals with policy incentive – firm innovation linkage (Ambec et al., 2013; Shao et al., 2020). Though these massive empirical studies are helpful in evaluating the policy impact at the aggregate level, such a perspective is not only single directional, but more importantly, treats firms' innovation activities and processes as a black box. The agency of business firms is also taken away, as if they merely act as a passive recipient of external incentives automatically and naturally. Thus, a related problem is that firms are viewed as the same, and their heterogeneity in terms of strategies, incentives and capabilities are neglected.

Business and management literature is not unaware of this. It recognises that firms are more active actors driven by their own interests and strategically respond and even shape their external environment. The corporate political strategy (CPS) scholarship partly delivers this objective by elaborating on various strategies firms adopt, from passive to proactive, to act on their entangled political institutions and policies (Hillman & Hitt, 1999). Its full attention to heterogeneity is firm's strategic responses and their change over time is well informed by neo-institutionalism literature in the field of organisation studies (Ozer et al., 2010). It is true that its focus is on how firms act upon their external environmental, in particular policies and regulatory institutions. However, the CPS literature does not specifically look at strategies and activities of innovation. In addition, it hardly talks about green transformation as a type of disruption in firm's environment. Another strand of literature does look at how firms react to such transformative change, that is, the corporate social responsibility (CSR) (Smith, 2003) that takes environmental friendliness as one of the responsibilities that business entities need to take on (Matten & Moon, 2004; Orlitzky et al., 2011), and most recently business firms as important player to address "grand challenges" (George et al., 2016). But similar to the CPS literature, it seldom brings innovation to the centre of in-depth unless relevant. Moreover, it bears very limited reference to the role of state and firms' interaction with industrial policies.

By contrast, innovation and technology management literature examines exactly what strategies firms adopt in order to enhance their innovation capacity and the resulting organisational performance in a turbulent environment. A large proportion of innovation management literature investigates how firms, often incumbent in a given sector, respond to technological discontinuity (Eggers & Park, 2018). This is enhanced by its evolutionary economics tradition in the sense that various incumbent responses are explicitly concerned about how learning activities are mobilised and competence and capability is preserved/modified/displaced. The heterogeneity of firm's strategic responses is accounted for.

This ranges from innovation models being incremental or radical from a slightly abstracted level (Anderson & Tushman, 2018), explorative or exploratory orientation from the organisational learning perspective (Stata, 1989; Weick & Westley, 1999), to various open innovation strategies in terms of how firms source technology and knowledge to best fulfil their innovation objectives (Chesbrough, 2004, 2017; Di Minin et al., 2010). From these rich and diverse perspectives, it can be seen that innovation strategy is underspecified. This is insufficient for us to understand firm's innovation strategies in response to green transformation that is deeply affected by public policies and political institutions, because innovation and technology management literature remains detached from political economy literature due to disciplinary boundary. A sole and narrow focus on the technological discontinuity and incumbent adaption is far insufficient to fully understand the political economy of green transformation.

2.5 Conclusion

In this chapter, I have discussed four major streams of literature motivated by interest in the political economy of innovation in green transformation that have their roots in three broad disciplines: economics, political science and management. To account for the directionality of innovation in green transformation and its driving forces, as well as its environmental and competitiveness consequences in developing countries is the central objective. Green industrial policy is an ideal starting and entry point as it is concerned with how green growth could be achieved through intentional intervention from the state. I have demonstrated that this nascent scholarship is developed very strong theoretical rationales for green industrial policy, but rarely explains clearly its influence on sectoral change, what makes it work or not, and the casual mechanisms. It is argued that this is due to an under-specification of directionality of innovation itself, and the surprising neglection of the strategic responses adopted by policy objects

(Zylberberg, 2017) – business firms – that are the major actors to embark on technological development and innovation and production activities.

Further, these forces do not work in isolation but interact with each other in complex ways and is bounded by certain "rule of games". Taking stock of the SSIP framework that explains innovation processes from a sector-centred perspective, I argue that existing approach is not sufficient to explain transformation of innovation systems. This results from a lack of dialogues between political science literature on green industrial policy and an evolutionary thinking of firm's innovation activities and processes in business and management studies. The absence of a political economy study of green transformation has not only limited our understanding of how green industrial policy is mediated and conditions in giving rise to certain sustainability and competitiveness outcomes in developing countries, and more profoundly, constrained the explanatory power of the innovation systems approach itself.

As this critical review has shown, the integration of several social sciences disciplines is needed to develop a competent framework to examine the topic, which is should not be specific to one sector in one country but uncover the regularity underlying the nature and working of green industrial policy, how focal business actors strategically innovation as a response, and how these eventually shape the path of green transformation. This does mean that the framework should be ignorant of contextual factors. Instead, as the neo-institutionalist approach to political economy and evolutionary economics has legitimately demonstrated, historical conditions and political economic contexts matter. Recognising this, the thesis attempts to fill the gap by first developing an integrated definition of directionality of innovation in green transformation of industrial sectors. To explain it from the perspective of state-business interaction, it modifies the SSIP framework toward an approach that bears the necessary explanatory power on system transformation. On such basis, a longitudinal, embedded case study is then conducted on

China’s early transition towards e-mobility to shed light on the casual pathways and mechanisms in the green industrial policy – directionality of innovation - sectoral change nexus.

Chapter 3 Analytical framework: Open system approach to SSIP

3.1 Introduction

Green transformation of industrial sectors lies at the core of green growth and industrialisation. It involves a fundamental shift of an existing sector towards sustainability and competitiveness in which process the innovation and diffusion of green technologies is a major driving force of system change. Innovation inevitably assumes a certain directionality, which has significant development consequences but remains substantially under-researched. It is not clear how innovation and technical change for green growth takes shape in early phase of transformation, what factors and forces explain the change and how these dynamics lead to sectoral change outcomes.

Through a critical review of several strands of literature, I have argued that this is due to four important reasons. First, directionality of innovation, in particular in the context of green transformation, is not yet specified. It is often used implicitly in normative dimension, i.e., agenda setting such as “green”, “clean”, “sustainable” (Lindner et al., 2016), but tells little about the concrete trajectories of technological development, learning and capability building. The latter is critical to understanding green industrialisation in developing countries. The second reason, which is more fundamental, is associated with the current conundrum of innovation systems approach (Carlsson et al., 2002). Innovation does not happen in isolation but is embedded in complex socio-technical systems. The system approach to innovation has the strength of decomposing the structure and agents of innovation and their interaction in shaping innovation process and its performance. But so far it lacks sufficient explanatory power for understanding the transformation of systems – at least in its current form (Weber & Truffer,

2017). Third, one important reason posing limits to the concept of innovation system is insufficient attention to political factors. While the "windows of opportunity" brought about by green transformation is often institutional and public policy driven (Lema et al., 2021), the role of government policy – in this thesis the focus is on green industrial policy – is largely absent from the explanation of system change in existing innovation systems framework. Fourth, policy studies including ST&I policies, green industrial policies and so on, tend to oversimplify the problem into a one-directional and linear relation, but neglects the complex interactions and feedbacks in the sectoral system and the strategic action and management of innovation conducted by the object of policy intervention – business firms in the focal sector (Zylberberg, 2017). These processes, rather than policies working automatically, shape the ultimate configuration of directionality of innovation and its consequences.

In summary, these four problems with the existing literature arise from a lack of analytically useful concept of directionality of innovation in green transformation, and the inability to explain system transformation in the current innovation systems approach, which is overly structuralist and in lack of openness to change forces, partly reflected in the neglection of the interaction between governmental policies and business firms. This does not mean that the innovation systems approach is no longer relevant. Instead, it will benefit significantly from cross-fertilisation with another two disciplines that put emphasis on agents of change and their heterogeneity: political economy and innovation management. To align these efforts, I adopt the ***"open systemness"*** approach to the current SSIP framework as an attempt to develop an analytical framework that provides the conceptual space to explain system transformation revolving around directionality of innovation.

To do so, this chapter adopts the ***appreciative theorising*** strategy, which Nelson and Winter (1982) characterise as developing a way of looking at phenomena and gives a language for discussing variables and their relationships. It may not develop specific hypothesis but provide

a way of analysing phenomenon of interest that single disciplinary perspective might not be able to do so. This is appropriate not only because the study seeks to understand processes, interactions and dynamics, but also allows for integration of different strands of literature to study complex problems associated with innovation aimed at encountering "grand challenges" (Kuhlmann & Rip, 2014) in industrial sectors. Specifically, the starting point is the SSIP framework (Malerba, 2002, 2004). Though the framework has undergone lots of abstraction and adaptation and can be very parsimonious (Kim & Lee, 2008), some critical reasonings and causal links useful for exploring system change get lost. SSIP framework in its original form is comparatively more relevant to the open systemness approach that I will discuss in later sections. This approach bears implications for all building blocks of the SSIP framework and leads to a coherent analytical framework that is able to analyse change, its driving forces and consequences. To say that a SSIP is an "open" system emphasises the openness of technological choice in early phase of green transformation – which is associated with the directionality of innovation, different types and locations of complementary assets in the changing industrial structure, multiple levels of institutional influence, and heterogeneity of business firms in the focal sector that strategically act on these fragmented but interrelated fields.

Following the re-interpretation of the SSIP framework, I zoom in to the level of firms and put forward "system building" to characterise how business firms in the focal sector strategically innovate in response to technological and institutional change. I provide a formal definition of "system building" by integrating the narrow definition in innovation management literature and the broad definition of socio-technical system literature, delineate it into four analytical elements and lay the basis for empirical analysis from a firm-centric perspective in the third empirical chapter.

The remainder of this chapter is organised as follows. Section 3.2 briefly introduces the open systems approach. Section 3.3 describes the building blocks of SSIP framework and section 3.4 on the re-interpretation of SSIP as an open system in the early phase of green transformation. Section 3.5 switches to the firm as the major agents of innovation activities and explains what "system building" is and how it is constituted. Section 3.6 summarises this chapter with brief discussions.

3.2 Political economy as an open system

An important distinction needs to be made clear between open systemness in this thesis as informed by political and sociological research, and the generally understood open system theory. Open system theory has its origin in biological discipline and influences organisation and management disciplines profoundly (Pondy & Mitroff, 1979; Von Bertalanffy, 1950). In organisation studies, open system provides a theoretical lens to view organisations as being open to the influence from their environment, and in behavioural terms organisations exchange information, resources and so on with their environment as well (Scott & Davis, 2015). The conceptual counterpart of the organisation as an open system is naturally the closed system (Scott & Davis, 2015). To say it is different does not mean that it is not irrelevant to this research; any studies that examine firm-environment interaction, be the extended resource-based view or open innovation, exactly follows this tradition.

But as for how we understand an innovation system or socio-technical system and explain system change, the open systemness approach is another thing that differs in the problems to be addressed and the theoretical core. It elucidates on the nature and status of the very "system" of political economy, society, and, of course, industrial sectors. Put forward by political scientists and sociologists that criticise and rescue the varieties of capitalism framework (VoC) (Hall & Soskice, 2001) from being unable to account for institutional change (Deeg & Jackson,

2007; Hall & Thelen, 2009), the notion of open systemness answers the need for a theory "that is not rigid and does not have fundamental difficulties in explaining change, but that at the same time acknowledges the necessity of a systems character of competitive political economies" (Becker, 2007, p. 263). Throughout the entire thesis, I use the term "open system" only to refer to the second meaning.

To be sure, open systems are systems in the first place because they need to perform certain functions. For example, it can be competitiveness of national economy in the VoC program, or products and services function in a sector that fulfils human needs in a distinct way compared to other sectors. However, the systemness of a political economic entity should not be produced solely from a functionalist logic. Rather, the system is open in the sense that many parts within it (e.g., firms and government) are relatively autonomous and hold reference frames of their own (Becker, 2007). Here, the reference frames refer to the different goals and objectives pursued by actors. As such, functionality itself can be ambiguous and impossible to predetermined very clearly, but is in the constant process of discovery, adjustment and redefinition.

The existence of different, contested and changing reference frames is critical to the political science and sociological understanding of open system. In a political economy, to the extent that the elements and actors are functionally related to each other towards a certain reference frame – with is understood as complementarity – the result of diverse reference frames and functions discovered along the way means that there are more than one way leading to the same or similar results. Thus, the *equi-functionality effect* exists and is common to an open political economic system. Institutional change, both incremental and radical, is hence possible because actors interpret their reference frames, defining functionalities and designing strategies in very different ways that enable breaking out from the existing political-economic equilibrium.

3.3 The original presentation of the SSIP framework

In this section I interpret the SSIP framework in its original version briefly to make clear its building blocks and the logical relations between them (Figure 3.1), and discuss how it can be mobilised to explain system transformation through an open systems approach. To begin with, sectoral system of innovation and production is defined as "a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products" (Malerba, 2004, p. 248). The first element of a SSIP hence is the product (or service; in the thesis I look at the manufacturing sector, hence refer to product thereafter). This is the "existential" element of a sectoral system, as without a particular set of products with unique design architecture and functions, economic activities could not operate properly, and societal demands cannot be met.

The knowledge base embodied in the products and artifacts of one sector differs from the other. Hence the second building block is the technological and knowledge regime of a sector. According to the evolutionary economics understanding, technological regime not only defines "the rule-set or grammar embedded in" searching activities, but also regulate the interaction between artifacts and actors relevant to technology development (Nelson, 1994; Rip & Kemp, 1998). Specifically, sectors distinguish from each other in terms of knowledge accessibility, tacitness, technology opportunity and appropriate conditions, etc., and this has consequences for learning and sectoral dynamics (Malerba & Orsenigo, 1996, 1997; Nelson & Winter, 1982). For example, compared to the automobile, computer and mobile phone industry has a higher level of modularity and less complexity in knowledge properties associated with product architecture.

The third building block is labelled as "basic technologies, input, demand and the related links and complementarities", reflecting the composition and relations between the artifacts, competences and activities relating to the product system and technology regime. Knowledge

domains differ across sectors not only in terms of the specific scientific and technological fields, but also the applications, usage and demand for sectoral products. This consists of an entire chain or flow of artifacts and activities with extensive links and complementarity. From a static view, linkage and complementarity can be understood as a structure where sectors are vertically or horizontally related as defined by the technological configuration of the sectoral products and their deployment in the market. More importantly, interdependency and complementarity are often dynamic as elements in the sectoral system keep changing and co-evolving. The real sectoral boundary is hence determined by these dynamic links, interdependencies and complementarities.

Learning activities eventually land on an agent, be it formal organisations, individuals or others. Among agents of innovation, firms are the key actors as they are involved in the innovation, production and sale of sectoral products as well as the generation and adoption of new technologies. In this regard, the sectoral system is characterised by firm heterogeneity and a variety of market and non-market interactions. Firms differ in their division of labour, competencies, experience and other organisational profiles. Apart from firms there are also non-firm organisations that make a difference to the creation and diffusion of knowledge, including public research institutes, universities, financial capital, intermediaries and so on. Logically, the type of inter-organisational interaction and network is the result of knowledge base, learning process, technology input and demand, and dynamic linkages and complementarity in the sectoral system.

Finally, all the learning processes and market and non-market activities and interactions take place in a certain institutional context that defines the "rule of games" (North, 1990). This can be sectoral specific institutions such as regulations and standards, as well as national level institutions such as the pattern of interaction between the state and business sectors, the characteristics of labour market and corporate governance (Hall & Soskice, 2001). Institutions

can also be informal (Casson et al., 2010), as manifested by the deeply rooted cultural tradition and mindsets of doing business that bear distinctive national characteristics.

Taken together, the above mentioned five elements constitute the core building blocks of a SSIP, which are logically connected instead of taking effect on their own in parallel to each other as later simplified models seem to present. Notably, the SSIP framework is developed based on the notion that sectors differ and it matters for the process and outcome of learning and innovation. It naturally has regional, national and more recently emphasised, global dimension. Hence a SSIP is embedded in a complex, multi-layered geographical setting.

3.4 The SSIP under green transformation as an open system

The SSIP framework itself is a flexible and implicitly open framework. The open system approach to political economy, featured by multi-layered, contested reference frames and equi-functionality, bears strong implications for explaining innovation system transformation. What the political economy literature has not made explicit but crucial to innovation systems is actor (firm) heterogeneity in the open system and the implication for strategic actions concerned with direction of change and models of innovation and production. This is especially important and relevant for understanding the configuration and transformation of innovation systems. Moreover, the SSIP framework in effect has an intrinsic open systemness character in its original presentation: it emphasises dynamics instead of static; it highlights heterogeneity in competences that reside in different firms; it pays attention to the dynamic complementarity and changing sectoral boundary; and it presents itself as a flexible framework instead of a rigid one. Nevertheless, this potential has not been activated in its development towards abstraction and parsimoniousness to be applied to a particular sector or explain the process of industrial catch-up.

However, both theories/frameworks have substantially neglected the "political" side of the economic and innovation systems. This is understandable, as the VoC program and many of its critiques takes firms as the central unit of analysis. So is the SSIP framework – and many other innovation system frameworks, where firms are the major entities of innovation activities. Some political scientists take a step further to advocate a renewed attention to the role of state and government, and thereby "bring the state back in" and bring the "political" back to "political economy" (Schmidt, 2007; Schmidt, 2009). While this is talking about the momentum of institutional change, I argue that this generally holds for any political economic system concerned with transformative change that features contested interests, mismatch in existing institutional set-ups and struggle for directionality of change and economic dominance. Therefore, a more appropriate innovation systems framework characterised as an open system should seriously account for governmental actions and policies as one important force of change and hence a more balanced analysis of state-business interaction. This is even more relevant considering that green transformation is often public policy driven (Lema et al., 2021). As such, the thesis does not negate the essential role of business firms as actors of innovation. But more importantly, both the role of state – understood as government and its policies and regulations and business firms should be viewed as agents of system transformation driven by innovation, hence their interaction makes substantial difference to system change direction and outcomes.

Another modification that needs to be made relates to the externalities and infant industry nature of sector-based green transformation. The "double externality" of green innovation (Rennings, 2000) means that the market demand for environmental products is insufficient, which is exacerbated by the fact that the green sector is immature. Moreover, the deployment and diffusion of green products does not happen automatically and involves significant innovation efforts to enable the product system to be really functionally applied and taken up

in the sectoral system. This is because immature technologies are argued to show deep interdependencies between production and diffusion. Therefore, a whole value chain approach is necessary to examine the innovation dynamics in an emerging green sector, especially taking stock of downstream activities, instead of solely looking at innovation and production as the label of the framework indicates.

With the two specifications made – open system and value chain approach, in the subsections that follow I re-interpret and modify the SSIP framework to examine system change in early phase of green transformation, with a more highlighted and balanced focus on the role of government policies and business firms.

3.4.1 Directionality of innovation

I have argued that a normative dimension of directionality of innovation is useful to advocate a more entrepreneurial policy paradigm, but insufficient for understanding the concrete learning processes and dynamics of capability building. Therefore, an integrated concept is put forward that attends to both normativity and positivity of direction of innovation in system change. It can be derived from the first two elements of a SSIP, namely the products and knowledge and technology regime.

To begin with, system transformation towards green growth involves "greening" the technological trajectory, that is, a shift in the technological regime on which basis greener products are designed, developed and produced. The notion of regime shift itself points to a directional change. In the context of green transformation, specifically, it means transforming from a polluting regime (e.g., ICEV) towards a cleaner regime (e.g., E-mobility) enabled by green technologies. This is how directionality of innovation is usually understood in the normative term at the macro-level. From an evolutionary economics perspective, which is a major theoretical basis for the innovation systems framework, regime shift can be interpreted

from the lens of cyclical model of technical change featured by overturning the existing dominant design of a polluting regime, followed by a period of "era of ferment" before another dominant design emerges in the cleaner regime (Anderson & Tushman, 1990; L. Tushman & Anderson, 1986).

Here, the key issue is not whether there would be a dominant design or not, but how "era of ferment", a selection process in times of regime shift in industrial sectors, takes shape. First, regime shift is not an automatic process simply because the emerging regime is cleaner, but a contested avenue where the two regimes co-exist and compete with each other for a considerable period of time (Foster, 1986). In the early phase of green transformation, there can be strong resistance to change due to path dependence of innovation and the persistence of established economic and non-economic interests (Downie, 2017; Lee & Hess, 2019).

Second and often neglected, regime shift is inherently an open choice, because green transformation itself tells nothing about the concrete technological trajectories reflected in the design of product system and the technological configurations undertaken by firms (Andersson et al., 2021). From the perspective of equi-functionality, there are often more than one concrete technological configurations that lead to similar result (greening the industry), albeit to varied extent – within the possibility scope of the cleaner regime, some technological configurations produce even better environmental or economic results than others. The early phase of green transformation features the co-existence of these multiple technological configurations (Fujimoto, 2017). These diverse technological solutions eventually boil down to sectoral products, hence the selection process features the co-existence of different product designs. They can be technologically and commercially immature, environmentally greener than the old regime products, and compete with each other for market dominance. For example, to make the automobile industry cleaner, the macro-level direction can be realised by fuel cell vehicles, battery electric vehicles, or hybrid vehicles, each reflecting different designs of the product

system. These different designs and technological configurations, though overall serving the same functionality – provision of means of mobility, target nuanced, heterogeneous market demands. Also, multi-tech firms have the motivation to differentiate their products in order to gain a competitive advantage (Freiberger & Swaine, 2000).

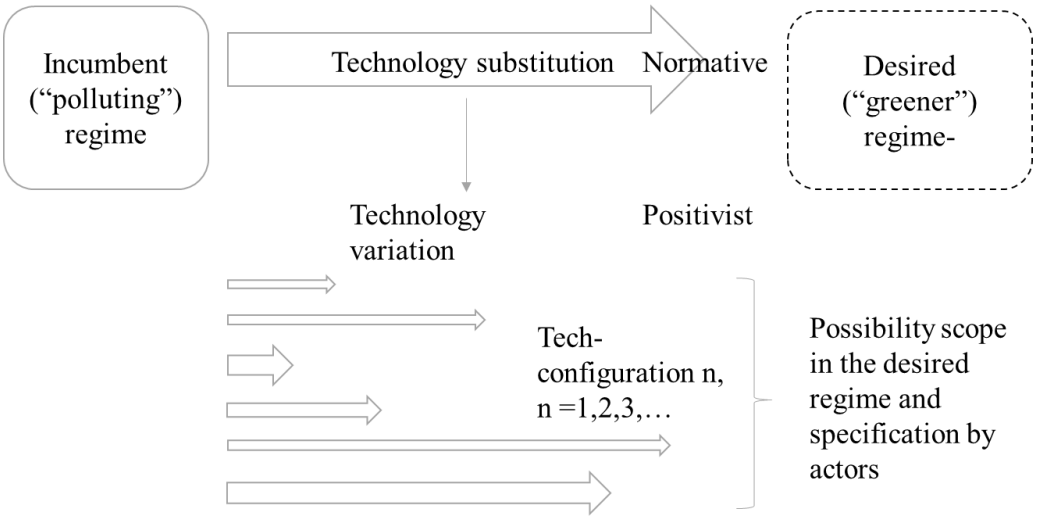


Figure 3-1 An integrated concept of directionality of innovation in green transformation

To this stage, it can be made clear that ***an integrated concept of directionality of innovation*** is manifested in the selection process during system change. Its normative dimension points to the desired direction whereby the function of the sectoral system can be achieved in a desired status, in this thesis, greener and cleaner, and more sustainable. This is primarily about the shift of technological and knowledge regime, together with the sector-specific products, from a polluting one towards a cleaner one. This dimension is called ***technological substitution*** (Figure 3-1). It is not an outcome or result, but a dynamic process of regime co-existence and competition. Because the nature of the sector remains largely unchanged and it is just that the sectoral system is transformed to take another form, the growth of one regime almost means the decline of the other, unless there is a significant increase in the aggregate demand for the sectoral products. The positive dimension of directionality of innovation is the specification of the cleaner regime in terms of the concrete technological configurations and product designs.

This forms the materialised pathways along with resources and assets are pooled and competences and capabilities are built. It features the co-existence of technological configurations and product designs and their competition for market share. This dimension is called ***technological variation*** (Figure 3-1), which is also a process, not an outcome or static status. The variation of technological configurations is objectively bounded by the state-of-art scope of technological possibilities, and further determined by the capabilities and strategic choice of actors from a subjective perspective.

Malerba (2002) also makes it explicit, drawing from existing literature on technology and technological change, that often in a sectoral system more than one technology is relevant and one could build a *technology-product matrix* that links the products of the sectoral system to a range of technologies. For multi-technology sectors and firms in green transformation, the matrix of different technological trajectories, configurations and product designs maps out the concrete direction of innovation that all add up to the emergence of the cleaner regime.

3.4.2 Market regime

Market regime characteristics and demand conditions are critical for the accumulation and scaling up of green innovations. For green innovation with societal objectives, market does not exist automatically but may sometimes emerge from interactions of economic activities and social political contexts (Mazzucato, 2018). There is no prior market demand ready for green innovations to be diffused but needs to be created and nurtured in the first place (Jaffe et al., 2004; Newell, 2010). On the demand side, market segmentation and customer preferences shape the actual pattern of green product diffusion. Because “green customers” purchasing green products mainly out of their environmental performance are the minority, more emphasis may still be put on existing functions and preferences (Oltra & Saint Jean, 2009). Therefore, the early stage of sectoral transformation is in need of market demand which is reflected in the

recognition and acceptance of customers despite the immaturity of the greener technological regime, until green innovations gradually scale up from small niches to larger, stabler market conditions (Geels, 2018; Sopjani et al., 2019).

Given its underdevelopment and importance in the early stage of green transformation, the market regime of a SSIP is an important realm of strategic actions by governmental and business actors. Government policies have a role to play in market formation and demand creation at the initial stage of sectoral change. Because the stage of transformation features incomplete information, market feedback is critical, which can be improved through information disseminating policy instruments that facilitate the circulation of this public goods. Policy learning also takes place simultaneously, for if certain programs are not effective as expected, then the process of reflection and problem-shooting contributes to the elicitation of precious product and market related knowledge. For firms, because customers do not have complete information on green technologies and products on the demand side, they need to engage actively in user education so that such information could be sufficiently communicated (van Mierlo & Beers, 2020). In turn, as firms do not have complete information either, user feedbacks are essential sources of new knowledge and information that helps firms continuously improve their products (Malerba & Pisano, 2019).

3.4.3 A value chain approach to characterise artifacts and linkages

This relates to the third building block of the original SSIP framework but takes a step forward to engage a formal value chain approach. The products specific to a sector and underlying technological and knowledge regime characteristics define the type and scope of competences in a SSIP. Similarly, directionality of innovation embodied in the technology regime and products building blocks has consequences on the type and structure of input, demand, linkages and interdependencies in the sector. Because green transformation puts heavy emphasis on

demand creation and market diffusion of green technologies and products (Mignon & Bergek, 2016; Palm, 2022), a whole value chain approach is necessary to examine the innovation dynamics in the changing sectoral system. By value chain, it draws attention to not only production process, but also preproduction (e.g., design) and postproduction (e.g., marketing, distribution), hence extends the analytical boundary of the SSIP. Informed by but unlike the dominant global supply chain framework that focuses on global division of labour (Gereffi et al., 2005), in this thesis value chain denotes the full input and output flows of technological competences that functionally constitute the innovation, production and diffusion of green technologies.

The sector under green transformation is called the ***focal sector***, where products are developed. Situated between input and output relation that turns green technologies into products. The activities conducted at the focal sector are the overall design of the green product's architecture and business strategies, mobilising and integrating technological and non-technological resources to develop, manufacture and produce the products (i.e., system integration).

Input relation extends upstream to various segments that make up the different layers of a product system. For a multi-tech sector, the ***upstream value chain*** refers to the flow of technology competence from sub-components, components, subsystems to product systems. Each level may have its own diverse designs and configurations. The accomplishment of a product system marks a "break point" in the value chain (Sturgeon, 2002), after which products are deployed and diffused in the market. For sectors in green transformation, the ***downstream value chain*** does not naturally pre-exist, or exist automatically. Without prior demand created, the deployment and diffusion of green products would involve intensive efforts in marketing, service, infrastructure and so on, hence is an important part of the artifacts and linkages in a sectoral value chain. Both upstream and downstream value chains provide necessary complementary assets for the focal sector activities and artifacts (Markard & Hoffmann, 2016).

Complementarity arises when the value of a combination of specific elements or assets is greater than the sum of the value of each individual element. It is not only central for emergence of novel technologies, relevant for technological know-how and strategy making at the firm level (Teece, 1986, 2018), but also critical to building up of innovation systems (Bergek et al., 2008; Malerba & Nelson, 2011). In the emergence of a greener regime, complementarity is dynamic instead of static (Malerba, 2002); the linkages and interdependencies keep evolving as the relative importance and maturity of value chain segments change over time and new technologies are incorporated into the sectoral system.

Note that the value chain approach points to a sequential process according to flows of technological competences and input-output relations between artifacts and activities, but not a linear one. The diffusion of green products is especially important for the improvement of product designs and production, hence further facilitating product diffusion in turn. A virtuous cycle is therefore desired among the focal sector, upstream and downstream segments. To this stage, the value chain approach to examine the input, demand and linkages and interdependencies in a sector is illustrated as follows (Figure 3-2).

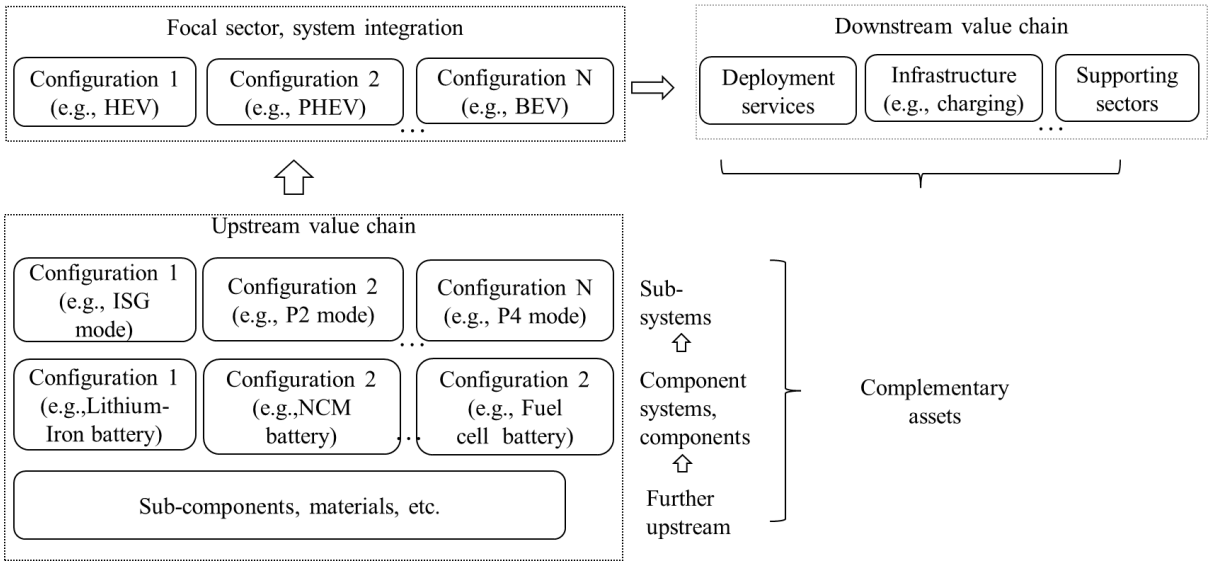


Figure 3-2 A value chain approach to basic techs, input, linkages and complementarity[2]

3.4.4 Firms, networks and interactions

A sectoral system is primarily defined by the products and technology and knowledge regime, and its boundary is *ad hoc* determined by the related input, demand, linkages and dynamic complementarity. These artifacts and their interrelations are eventually reflected in the type, composition and interaction among firms and non-firm organisations that carry out market and non-market exchanges.

To be sure, from the perspective of SSIP, ***firms (or business firms)*** refer to those business establishments in the focal sector, not all the vertically or horizontally related sectors (Figure 3-3). In a multi-tech sector, or modern large corporations with a multi-tech profile, they are characterised as ***system integrators*** (Hobday et al., 2005; Prencipe et al., 2005). It is important to distinguish business entities in terms of their location in an innovation system relative to firms in the focal sector, because different locations bear implications for the scale and nature of innovation challenges to be addressed (Adner & Kapoor, 2010). Specifically, along the value chain, upstream firms belonging to various layers of input relations are called ***suppliers*** and downstream firms that engage in the deployment and diffusion of green products, such as infrastructure providers, are called ***complementors***. Suppliers are functionally necessary to fulfil the technological task of a product system, through the provision of different levels of input artifacts supported by their specialised competences to the system integrators. Complementors provide other artifacts and services other than the product system to enable these already accomplished products to be successfully used and adopted and realise their functional value in the end users. For example, battery manufacturers are suppliers to an OEM, while a complementor could be responsible for installing charging ports for the electric car.

[2] Author's elaboration based on the case of electric mobility.

These firms along the value chain are complementary to each other and engage in market and non-market interactions. Market interactions involve the supply of materials, subcomponents, components, component systems, subsystems and so on, as well as the distribution and deployment of green products. System integrators in the focal sector face the classical “make or buy” choice and the extent of vertical (dis-) integration (Platts et al., 2002). Moreover, because production and diffusion of green innovation is highly interdependent when the emerging sector is immature, these firms are involved in complex networks with complementors and suppliers for value creation and value capturing.

There are also non-firm organisations that have a direct impact on firm innovation in the sectoral system. Universities and public research institutes provide important source of technological knowledge and human resources (Fu & Li, 2016; Zhang et al., 2019), through which focal firms are able to build up absorptive capacity along the direction of technical change. Financial resources from banks and capital market, both at home and abroad, are critical for firms so as to survive the “valley of death” (O'Sullivan, 2009). In addition, intermediaries are suggested as important participants and drivers in shift towards green paradigm (Kivimaa, Boon, et al., 2019; Kivimaa, Sampsa, et al., 2019) because they connect other actors and function as nexus of information, resources and knowledge. Users, a major constituents of market regime, are important drivers of product innovation in “era of ferment” in the sense that they facilitate diffusion and provide feedbacks on new products (Jørgensen, 2012).

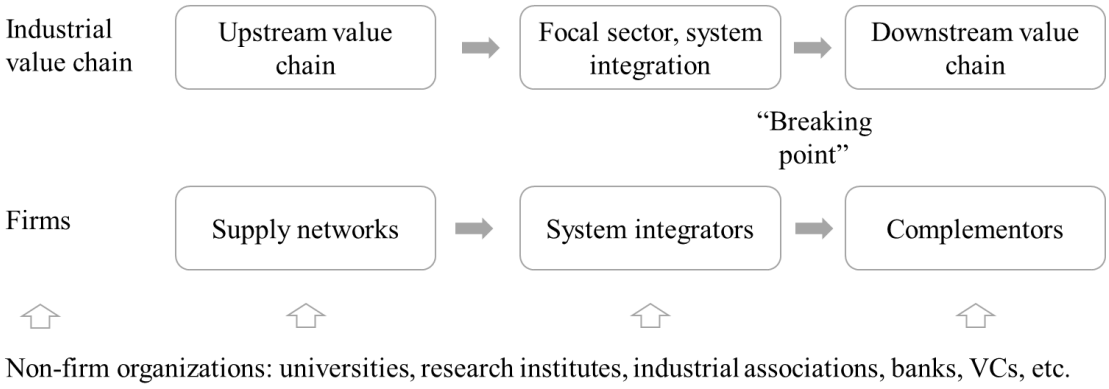


Figure 3-3 From value chain flows to firms and non-firm organisations and their interactions[3]

Firm heterogeneity is a key feature of a SSIP. This can hardly be well explained by neo-classical assumption of modern firms but is a major conceptual component in evolutionary economics and evolutionary theory of the firm. In the latter tradition, firms differ in a variety of aspects. In a sectoral system, knowledge and learning plays a central role. It is highly idiosyncratic at the firm level (Foray, 2004) and require a certain amount of absorptive capacity for firms to incorporate and integrate new knowledge overtime (Cohen & Levinthal, 1990). In times of sectoral change with entry and exit of firms more frequent than usual, the difference between incumbents and new entrants has implications for learning processes, competitiveness and industrial structure (Hardstone, 2004; Schumpeter, 1950). Moreover, they may play different roles in times of system transformation that potentially create winners and losers from the process. Despite that increasing study shows the limitations of "incumbent trap" (Bergek et al., 2013; Leonard-Barton, 1992) and challenges faced by new entrants due to lack of resources and capability accumulation (Eggers & Park, 2018), this debate has not been settled, especially in face of early phase green transformation. However, the difference between incumbents and new entrants in a developing country may soon give way to the systematic

[3] Author's elaboration

technological gaps between these indigenous firms and global forerunners, the latter usually being large MNEs with strong knowledge regime and political economic powers.

Firm heterogeneity can be further shaped by the institutional environment they are embedded in. The neo-institutionalism literature in organisational studies points out that firms may have different "reference frames" as they are more or less autonomous entities in the broader politico-economic system (Becker, 2007). For example, in green transformation, firms have to explore and manage the balance between competitiveness and sustainability goals given the requirements by national regulations. Moreover, their institutional environment can be complicated by ownership type and sub-national institutions (SEGAL & THUN, 2001b; Sun et al., 2018; Thun, 2006), which makes difference to the incentive to conduct R&D for technological developments. Particularly, ownership type is an important moderating factor in examining transition economies where state ownership is used as a method of economic management by the central government (Nolan, 2001).

3.4.5 Institutions: green industrial policy as "endogenous institution"

Firms do not innovate and strategise in isolation but are embedded in the external social-economic context. In a sectoral system of innovation, various types of institutions define the "rule of games" (North, 1990) that affect actors' behavioural patterns and performances. For the purpose of focus, the study particularly concentrates on the role of state and governmental policies as "endogenous institution" (Geels, 2014) that have a more direct impact on innovation activities in the sector system of interest. Governmental policies and regulations play a major role in all sectors by influencing the rate and direction of technical change, organisation of innovative activities and innovation performance of firms (Malerba & Nelson, 2011). Because of the institutional and endogenous nature of green transformation (Lema et al., 2021),

government interventions aimed for a green techno-economic paradigm are widely accepted and practiced.

More specifically, I focus on green industrial policy and its role in the transformation of innovation systems and firms' strategic innovation as a response. Existing literature offers a limited number of definitions of "green industrial policy". Rodrik (2015) and others (Kemp & Never, 2017; Schmitz et al., 2015) present a very strong theoretical case for green industrial policy as a much needed policy approach and point out some of its key characteristics without clearly defining what it is. Yet other studies tend to relate green industrial policy to certain type of policy instruments and practices (Harrison et al., 2017; Matsuo & Schmidt, 2019). Perhaps a more explicit definition is provided by Altenburg and Assmann (2017, p. 11), according to whom green industrial policy refers to "including *any* government measure aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy". It departs from traditional means of industry in terms of focusing on environmental externalities, steering of investment behaviour, enhanced uncertainty as well as many policy interfaces. It inevitably relates to industrial competitiveness in developing countries so that they seize and exploit the windows of opportunities to catch up with global forerunners (Keun Lee & Franco Malerba, 2017b; Malerba & Nelson, 2011). The notion of reconciliation of green growth and competitiveness presents the conceptual core of green industrial policy, whereas an overly broad definition would result in endless count of policy categorises and instruments that may lack analytical rigor and focus. Anzolin and Lebdioui (2021) pays special attention to the multi-dimensionality of green industrial in its interpretation. Focusing on the policy objectives and challenges in climate change mitigation, they differentiate between consumption centred dimension, firm level sustainability dimension, and the productionist, innovation-centred dimension. This informs my conceptualisation, whereas is still not systematic enough. The current thesis goes

further by focusing on the industrial value chain of green structural change and the embeddedness of green industrial policy in the open SSIP. Because structural change of industrial sectors is the intervention objective of green industrial policy, therefore this thesis limits the scope of green industrial policy to those governmental interventions that affect sector-specific supply side and demand side of green technologies and innovations, both directly using targeted measures and indirectly transmitted through value chain activities. While more remote environmental and consumption policies that have very weak connections with innovation and production activities in the sectoral system, for example, the advocation of using cleaner and public transport, is exclude from the definition.

Therefore, it is advanced that instead of being characterised as a certain policy program or a mix of policy instruments, green industrial policy is better understood as an evolving portfolio of multiple level institutional, regulatory and policy specifications. It affects firm innovation in various ways through interaction with and the interaction between the building blocks in a SSIP and the feedback. It provides direct incentives, such as subsidies or tax reduction for the adoption of green technologies/products, or R&D support, that are aimed at "crowding in" firm-level innovation input for green technologies (Mazzucato, 2015; Nemet & Kammen, 2007). Green industrial policies also affect firm level innovation indirectly through interaction with the properties of the technological and market regime conditions. For example, lowering the entry barrier of the green sector would possibly invite more players in the field, hence bringing more vibrance and dynamism typical in the Schumpeter Mark I regime to the Mark II regime (Malerba & Orsenigo, 1995). Some regulations would also play a market-creating role, in the sense that they restrict the consumption of polluting regime products while awarding the usage of greener albeit less mature products (Oltra & Saint Jean, 2009). All these works together to shape the technology and market incentives faced by firms in the focal sector under green transformation.

3.4.6 Interaction with other layers of innovation system

Sectoral system of innovation, production (and diffusion) of innovation has a geographical dimension, which matters a lot for the early phase of green transformation because the resources and competences needed for the initial development and deployment of green technologies and products are scarce and distributed. They often extend beyond the organisational boundary of large corporations in multi-tech sectors (Brusoni et al., 2001). SSIP interacts with various other layers of innovation systems at the regional, national and global level, which creates both synergies and tensions for the green transformation.

Regional innovation system (RIS) has a direct and intermediate impact on sectoral innovation system. Business firms would prefer to source knowledge and resources that are available locally, so that transaction costs would be low thanks to geographical and cultural proximity (Gereffi et al., 2005). Besides, the extent of knowledge diversity and relatedness, the building of important infrastructure, the existence of industrial clusters, frequent flow and exchange of information and personnel, etc., are all proved to critical enabling factors of innovation according to economic geography literature. The national innovation system (NIS) is also crucial for system transformation. Often only national-level institutional change can be more capable of solving problems of widespread spillovers and externalities. Moreover, as innovation is risky and costly, R&D programs, mobilise financial incentives and technological expertise and university-industrial linkages at the national level could play a positive role in facilitating firm-level innovation efforts. The conditions for successful green innovation transcend national boundary as well. At the initial stage, the deployment of green technologies and products often starts from the domestic market. But for developing countries, firms find it important to source knowledge, skills and resources globally in non-conventional ways (Fu & Zhang, 2011; Lema et al., 2015). This not only applies to the traditional sense of industrialisation and upgrading when latecomer firms participate in GVCs to achieve

technological learning and industrial catch-up (Humphrey & Schmitz, 2002), but also the context of green transformation when developed countries are still in global technological frontiers despite narrowing gaps. Therefore, in the nascence of sectoral change, the global innovation system (GIS) can be a good complement to other domestic layers of innovation systems (Binz & Truffer, 2017; Lema et al., 2018; Pietrobelli & Rabellotti, 2011).

3.5 Firm-oriented perspective and system building

3.5.1 Firm-oriented perspective to bridge micro-meso level dynamics

In the early phase of green transformation, firms are both constraining force and enabler of system change because innovation is path-dependent on the one hand, while their innovation and production activities concerning green technologies have sectoral level consequences on the other. In times of green transformation, which is often institutional and endogenous in nature (Lema et al., 2021), business firms respond to policies and regulations issued by the public sector and strategically innovate in order to adapt, survive and change the competitiveness landscape. In such a process, their activities and processes of innovation and production naturally modify the resource portfolios, assets, competences and linkages and networks in the sector undergoing transformation.

Focusing solely on organisations or their interaction with "external environment" hardly add knowledge on how firms act as the agent of system change that is comprehensive and complex. Hence, it is important to link the micro-level and meso-level dynamics so that structure-agent interaction in driving change can be more thoroughly understood. The recent development in TIS scholarship, actor-oriented analysis, is useful to conduct this task. The perspective is initially put forward by Markard and Truffer (2008) particularly to understand functions of technological innovation systems by linking the strategies at the firm level and resources and capabilities at the system level (Markard & Truffer, 2008). This thesis takes a step further to

contextualise the perspective in SSIP undergoing green transformation and examines how firm's innovative activities respond to institutional change and translate into sectoral dynamics and performance.

3.5.2 System building: an integrated definition and its analytical elements

1) From system integration to system building

The thesis advances that the innovation strategies and processes and the accompanying value chain activities can be formally characterised as "system building". It is not new to use the term "system builders" to denote the potentially active role of agencies, often business actors, in organising new resources and networks for transformation (Fallde & Eklund, 2015; Shove & Walker, 2007). However, the term is under-conceptualised and only serves as an impressionist and heuristic device to imply that agencies' action contributes to the formation of emerging systems and their strategic choices make a difference. Whereas it does not tell what the role involves of business firms in terms of innovation strategies and activities and does not open the black box of the co-constitutive process between firms and system change.

An analytically sound and workable definition is in need to bridge the micro-meso level dynamics with a firm-oriented perspective. While there is no formal definition of system building itself, existing innovation management literature has well documented "system integration" as a "core capability of modern corporations" (Hobday et al., 2005). "System integration" is also adopted by transition study and science and technology studies (STS) authors to denote the "management" of the entire socio-technical system toward sustainability (Fallde & Eklund, 2015). These two versions of "system integration", one narrow version -- innovative activities conducted by corporations revolving its product system (Hobday, 2005; Prencipe et al., 2005) and one broad version, i.e., resource mobilisation of a socio-technical

system, could be fruitfully bridged with an analytical focus on firms and their interaction with the system undergoing radical change.

The narrow version of system integration has a military and engineering origin in highly developed economies such as US, but gradually spreads to civilian products and evolves to encompass a strategic business dimension (Sapolsky, 2005; Walker et al., 1988). With a firm-centric focus, a narrow definition concerns firms and other agents bringing together components, subsystems, software, skills, knowledge and human resources, etc., to produce a product. It has two levels of meaning. Internally, firms develop and integrate the inputs they need to produce a new product. Externally and more importantly, they access and integrate various resources, components, knowledge and capabilities to accomplish the innovation and production task (Hobday et al., 2005). In sum, it refers to the ability to combine diverse knowledge bases and physical components into functioning systems (Davies et al., 2011).

To understand the analytical elements of system integration, it is necessary to look into its "two faces" (Gholz et al., 2018). According to the authors, in the first face, lead firms in a multiple-technology, multiple-component sector as the system integrators, make key decisions regarding the overall architecture of the (complex product system), the form, fit and function of its subsystems and design trade-offs among various performance dimensions. The second face of system integration is to turn these design principles and calibrations into reality. That is, system integrators coordinate distributed capabilities and learning processes carried out by networks of specialised designers, equipment suppliers and component manufacturers. Following this narrow definition, system integration includes at least four analytically different but interrelated key elements: design rules down the product hierarchy, diverse knowledge bases, physical components, and the method to source and coordinate these resources and capabilities among suppliers.

In a broader term, according to Hobday et al. (2005), system integration could be generally understood as defining and combining together all the necessary input for a system and agrees on a path of future systems development by coordinating firms, government agencies, regulators and a range of other actors. In the early phase of green transformation when the deployment and diffusion of green technologies is critical, system integration means engaging fully and extensively with complementary assets along the whole value chain. For example, in the case of electric mobility, system integration requires wider coordination with firms in battery charging/swapping facilities and energy systems, as well as new assets in inter-sectoral interfaces, industrial standards and even transportation systems. Hence the broader definition looks beyond product system and examines the dynamics and functioning of a socio-technical system as a whole. It emerges from the imminent challenge posed by problem- or challenge-oriented system transformation.

Integrating the narrow and broad versions of "system integration" hence leads to a firm-oriented definition of "system building" that systematically account for firm innovation activities and processes in times of system transformation that links organisational level behaviours with system-level dynamics. Here, ***system building*** is formally put forward as *a dynamic portfolio of innovation processes and value chain activities, drawing and integrating resources within and outside of the existing sectoral boundary, that aim for the emergence of an alternative system along the desired direction*. In the context of green transformation, the desired direction is perceived as sustainability and competitiveness.

2) Analytical elements of system building

Delineating the concept of system building leads to four interrelated analytical elements: a) direction of innovation; b) design rules and knowledge integration; c) dynamic positioning along the industrial value stream; and d) sources of technology and resources.

a) Directionality of innovation

Recall that directionality of innovation in "era of ferment" of green transformation refers to selection processes of: (1) technological substitution, i.e., technological development that departs from the existing polluting regime to a desired regime ("green" regime); and (2) technological competition and variation, i.e., the co-existence of different technological trajectories and solutions that fit into the greener regime an compete for market dominance. At the level of firms, this could be understood as the extent to which a firm in the incumbent industry regime is involved in the development, commercialisation and deployment of the desired regime (green technologies), and the specification and diversity of technological trajectories in the realm of green technologies at the corporate level. In operational terms, this can be observed by how firms are balancing business associated with green technologies and polluting technologies, how many technological trajectories it pursues in green technologies, and the specific technological configuration(s) on which firms focus most innovative efforts.

b) Design rules and knowledge integration

Revolving around a firm's specification of technological trajectories in the "green" regime, the firm decides on the design rules of their product system at different levels down the hierarchy, the concrete technological parameters and trade-offs (Gholz et al., 2018), as well as its depth of knowledge integration (Brusoni et al., 2001). Taking e-mobility as an example, if an incumbent OEM decides to roll out a BEV model, then it needs to further decide: what is the product architecture? Which price and market segment to target? What performance criteria should be applied to those products (e.g., drive range, energy efficiency, vehicle weight) and what is prioritised given limited resources and technological progress in the nascent sector? In sum, this analytical element relates to the configuration and extent of product and technology innovation efforts made by firms given their chosen direction of innovation in technology and

business strategies. This is an integrated strategic decision which should be examined as a whole, instead of any specific technological decision in isolation.

The design rule of the product system deals with the type of product architecture and integrated performance (Coronado Mondragon & Coronado Mondragon, 2018). This element is closely related to the first analytical element, the directionality of innovation, in the sense that the greater extent of technological substitution away from the existing technological regime, the more radical design rules will result. This means visible changes in the product architecture. Moreover, to the extent that core competence is altered, component system innovation would also be expected. These radical shifts require intensive technological and learning efforts to develop and master a novel set of design, new product development and product integration capabilities. Whereas a system integrator can choose its depth of knowledge integration to abate its innovation challenges. If it has limited knowledge at lower levels of the product system, and/or it finds it less cost-efficient to develop on its own, then it has the choice to prescribe the desired performance requirements and outsource component and sub-component design and development to specialised suppliers. Through reducing the depth of knowledge integration, innovation challenge would be ameliorated, with the system integrator's attention mostly paid to product architectural innovation and product system design.

c) Dynamic positioning along the industrial value stream

This element refers to the actualisation and realisation of desired direction of change and design rules, through concrete activities in design and development, product system integration, manufacturing, production, marketing and services along the industrial value stream (Davies, 2004). In the first place, the basic and minimal position of a system integrator is to embark on component assembling, product system manufacturing, and production of the assembly goods (in the automobile industry, it should be commodity goods instead of heavy capital goods). Furthermore, this analytical element concerns how system integrators in the focal sector

coordinate upstream and downstream complementary assets and activities in order to deliver their products to the end users (Gholz et al., 2018; Hobday, 2005). To be specific, the upstream aspect concerns the decision of the extent of vertical integration and the corresponding production activities (Perry, 1989). A system integrator can choose to outsource design and production of product systems to rather integrated suppliers on one extreme, or adopt a fully vertical integration model, or any division of labour in-between with its suppliers. Regarding the downstream aspect, system integrators also need to decide how they engage with complementors and infrastructure providers in order to deploy green products in the market and upscale the diffusion of these products (Rothaermel, 2001; Wadin et al., 2017). In the very early phase of sectoral change, infrastructure for the emerging regime would be under-supplied given very limited diffusion of the new products, which is the typical "chicken-egg problem" faced by socio-technical system transformation in the beginning (Leibowicz, 2018). Therefore, a system integrator especially needs to tackle this problem in order to deploy the product in the market. It may consider doing on its own in a limited scale, or collaborate with external, more specialised partners to reduce costs and achieve a slightly higher level of economy of scale (Tariq et al., 2017).

d) Sources of technology and resources

System builders mobilise and integrate various sources of technology and resources to deliver the product and socio-technical system functionality along the desired technological paths. For a complex product sector, though of commodity goods rather than capital goods, system integrators are at least basically specialised in product system design and assembling. They coordinate various external resources from multi-tiered suppliers to achieve this, not limited to selective subsystems and components. Moreover, complementors of a distinctive set of assets and resources are more probably sourced externally. It is increasingly impossible for firms to accomplish all technological and commercial tasks especially in times of radical technical

change. The imperative of green transformation amplifies this by creating tremendous needs to explore various technologies, products and business models when they have to experiment using very scarce and distributed resources. Hence an important facet of this analytical element is the practice of open innovation and its combination of indigenous innovative efforts (Chesbrough, 2006, 2016; Fu & Gong, 2011; Rangus et al., 2017). Technologies and resources therefore come from a variety of possible sources within and beyond the sector, including suppliers, competitors, complementors, infrastructure providers, adjacent sectors where technological and knowledge recombination is activated, consumers, as well the triple helix actors and others (e.g., intermediaries, financial market, etc.). As the interplays of a SSIP with different other layers of innovation systems indicate, it is important to draw supply network resources regionally. While for developing countries, firms need to access more advanced technologies and more sophisticated know-how from the global innovation system. Besides, they need to participate in national-level standard setting so that economy-of-scale is possible.

3.6 Summary and conclusion

This chapter lays out the over-arching analytical framework of the thesis. Innovation systems approach has provided a critical lens to probe into learning dynamics and sectoral change process, but so far it is insufficient to understand the conditions, driving forces and patterns of transformation of innovation systems, especially the kind of change that involves significant externalities such as green transformation. Motivated by this important gap, a conceptual and theoretical attempt is made in the chapter to modify the sectoral system of innovation and production framework so that radical system change can be more thoroughly understood. Specifically, I activate the theoretical core of the open systems approach of studying institutional change in political economic systems, and through the lens re-interpret the SSIP framework in the context of green transformation. The “appreciative theorising” strategy

adopted seeks to integrate political economy literature in the neo-institutionalism tradition and innovation systems framework to develop the explanatory power that previous innovation system approaches have been in lack of.

Both literature puts the innovation activities of firms at the centre. The open system approach initially emphasises different reference frames faced by firms in a loose systemness, the functional complementarity of institutional arrangements in the political economy, and equi-functionality in achieving the functionality – innovation performance and economic competitiveness. Revolving around firm innovation, which is highly heterogenous, the SSIP framework starts with products in a sector and the underlying knowledge and technological regime as the foundation and defines the sectoral structure and boundary through the resulting linkages and interdependencies in artifacts and activities, and corresponding firm and non-firm networks. Learning and innovation dynamics are bounded by institutions.

The open systems approach to sectoral system of innovation and production results in a political economy explanation of direction of innovation and sectoral change in early phase of green transformation ("era of ferment"). To this stage, it can be concluded that the open systemness approach to SSIP in the context of green transformation is characterised by five aspects (Figure 3-4): directionality of innovation as a bounded open choice; equi-functionality to be greener; dynamic complementarity and changing sectoral boundaries; strategic action by heterogenous agencies (firms, state, etc.); interaction of other different layers of innovation systems (RIS, NIS, GIS, TIS, etc.).

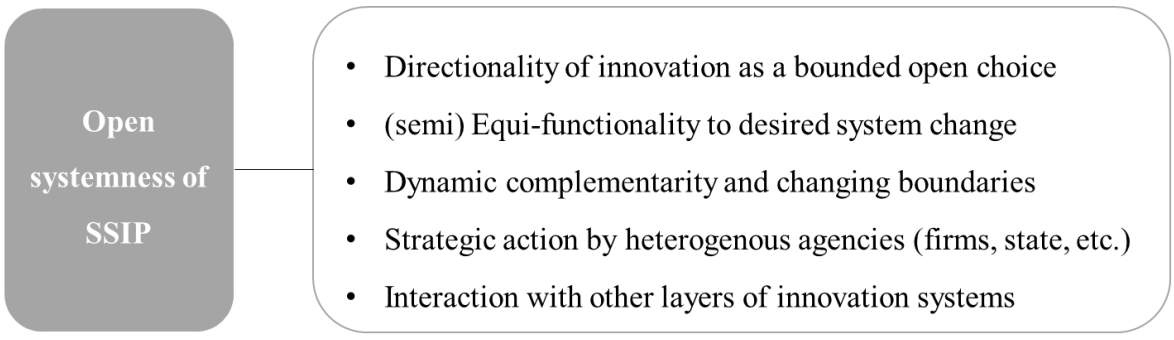


Figure 3-4 The five core elements of an open systemness approach to SSIP[4]

I put forward an integrated understanding of directionality of innovation that combines the normative agenda of green transformation – a regime to green regime, and the positivist aspect – the technological configurations that realise the agenda in various ways and to varied extent. This corresponds well to the notion of "era of ferment" in the cyclical model of technological change in evolutionary economics, as well as the point of equi-functionality to achieve specific goals (here, green transformation of a sectoral system). The path of technical change is not predefined, nor fully known beforehand; the actual exploration and experimentation of firms towards the greener regime forms the *ad hoc* directionality of innovation in a positive term. Hence, this point of openness is reflected in the diversity of technological configurations within the possibility scope and design architectures of green product systems adopted by firms, and the emerging knowledge and technological regime that underlies this change.

These diverse designs and configurations are materialised in complex linkages, input and demand and inter-dependencies of the artifacts and activities in the sector. Basic technologies and inputs are clearly defined by the technological configurations and designs, which form the upstream competences and activities in relation to the focal sector. Firms in the focal sector act as system integrators that bring these inputs into a green product system. What requires attention is that the formation, accumulation and scaling up of the greener regime depends heavily on deployment and diffusion of green products, which is supported by various complementary assets in the downstream. The flow of value chain activities naturally connects the supply side (technology regime, design and production) and demand side (market regime) of green technologies and products. A value chain approach is hence formally put forward, that covers segments of innovation, production, deployment and diffusion – with product system

[4] Author's elaboration

integration as the breaking point – to better understand the transformation of sectoral innovation systems.

The logical outcome of directionality of innovation is that there are different approaches to input-output-demand relations, linkages between artifacts and activities and firm and non-firm networks. Firms thereby need to continuously make strategic decisions on specifying the direction of innovation and coordinate and integrate various resources and competences to bring it into concrete product systems. What especially matters here, apart from the building blocks discussed above, is the institutional regime. Because of the public goods characteristics of green innovation and the "double externality", government policies often drive or facilitate the momentum of green transformation. Therefore, the government and its policies are not simply an "environment" actor in the innovation system, but an important endogenous force of system transformation. In developing countries and emerging markets, the design and implementation of green industrial policy to foster structural change in industrial sectors is a major point of state intervention and constitutes what is referred to as the "endogenous institution" within the system.

Firms in the sector under transformation are the main entities that alter the system of production and consumption through their activities. To systematically understand how they strategically respond to the change that is significantly affected by governmental policies and regulations, I define firms' innovation strategies, activities and processes as "system building" and delineate it into four interrelated elements. Doing so creates the analytical space to understand micro-meso level interactions and how firms' engagement in system building translates into sectoral dynamics.

Therefore, with a modification to the SSIP framework through an open systemness perspective, the overall analytical framework is illustrated as below (Figure 3-5):

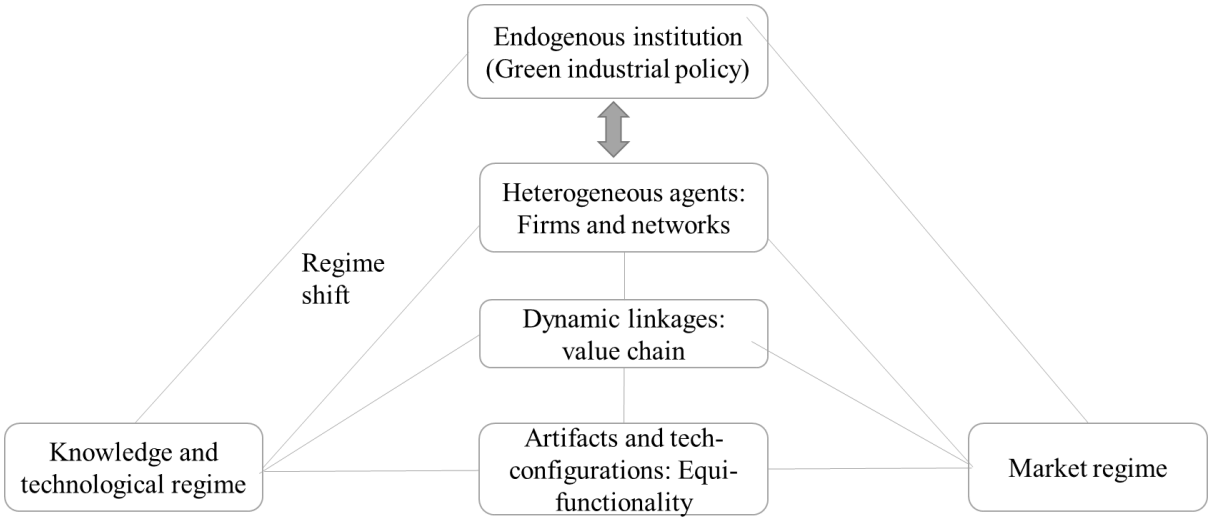


Figure 3-5 The SSIP framework from the perspective of open systemness[5]

[5] Author's elaboration.

Chapter 4 Methodology

4.1 Research design

4.1.1 Embedded case study

The case study approach is adopted as I address “how” and “why” questions (Robert K. Yin, 2013) in the thesis and prior theoretical knowledge on the phenomenon is insufficient (Eisenhardt, 1989). Moreover, when a contemporary phenomenon of interest is inseparable from its context, case study is an ideal choice; let alone that context itself – institutional regime in the open sectoral system - bears explanatory power (Robert K. Yin, 2013). I don’t use quantitative method because the plethoric articles studying the impact of government policies and programs have been insufficient for understanding the evolutionary, endogenous and interactive processes of change in learning and industrial dynamics. Case study, by contrast, enables investigators to go into the depth of a phenomenon, unveil its dynamism and complexity and account for historical contingency. A further specification is the longitudinal case study design (Mills et al., 2010) as I am interested in the evolutionary dynamics of system change in the unfolding green transformation in industrial sectors and its driving forces.

Under this overarching research design, I adopt an embedded case study approach. This is because the thesis essentially looks at the interaction between system and organisational level dynamics. Hence an embedded case study method allows for interrelating and integrating variables and findings from different facets of the case and sub-units of case inquiry (Scholz & Tietje, 2002), e.g., considering the interaction between different building blocks of the SSIP and firm heterogeneity. In the thesis, the basis case is the industrial sector (electric mobility), and sub-units are business firms in the focal sector. The first sub question examines the

influence of green industrial policy at the sectoral level, and the second and third sub-questions address system – firm interaction, hence involves both meso and micro levels of analysis.

Thus, there are multiple units of analysis. In the first empirical chapter, I focus on policy instruments and regulatory tools at the sectoral level issued by the central government. Regarding innovation activities and directionality of innovation, the unit of analysis is the entire sector, with relation to its upstream and downstream sectors. In the second sub-question, I look at the interaction between meso-micro level dynamics from a firm-centric perspective, hence the unit of analysis is both the sector and firms, and additionally group of firms that exhibit similar innovation dynamics. The third sub-question looks at the innovation activities solely at the firm level, where each individual OEM is the unit of analysis.

4.1.2 Case selection

(1) China's transition to electric mobility in the automobile industry

The rationale for selecting China's early transition to electric mobility is set up in the introductory chapter. This sub-section provides further specifications to clarify and bound the scope of analysis. While the entire automobile industry (including electric mobility) is very broad and complex, I focus on the segment of system integration and product manufacturing, which is where OEMs conduct their activities of innovation and production. For focus of analysis, I examine passenger vehicles and in principle do not include other light-duty or heavy-duty vehicles into analysis. This is because passenger vehicles are commodity goods mostly targeting individual consumers who are diversified, demanding and drive cars in various places, which makes innovation challenges far harder, more complex and product market competition more fierce than heavy duty vehicles. Heavy duty vehicles, by contrast, have limited market demand and competition, and are often used in more fixed and predictable situations such as highways, airports and ports, etc. There is also less imperative to raise cost-performance and

product quality and function than passenger vehicles. However, this does not mean that I do not discuss them at all. Though downstream OEMs can be highly heterogeneous, they both rely on similar complementary assets, especially power batteries and charging infrastructure, and require system integration capabilities to perform innovation tasks. Due to this interrelatedness, I discuss the role of heavy-duty vehicles and buses where necessary while focusing on passenger vehicles.

(2) The selection of firms

The selection of case firms is guided by principle of "theoretical sampling" (Robert K. Yin, 2013). I look at OEMs in the focal sector that have entered market-oriented production and deployment of EVs up to 2020, and have been affected by green industrial policy in China to varied extent and responded to green transformation adopting different innovation strategies.

The selection of firms for sectoral level and firm-level analysis follows different criterion. At the sectoral level (to address the first sub-question), I look at the entire sector (passenger vehicle, EV) and also analyse its vertically related sectors (e.g., power batteries) in China in the global context. The imbalances and fragmentation within the sector could be partly manifested in ownership structure. The first category is SOEs that have been traditionally involved in inward FDI in the automobile industry. But even among SOEs, there are huge differences. For example, some report to central government State-owned Assets Supervision and Administration Commission of the State Council (SASAC), while some report to SASAC at provincial or city level. There is also another important historical difference I need to draw attention to. In the growth of automobile industrial industry in China, a group of SOEs received support from the state since the 1980s in China's industrial policy approach to "trade market for technology". This was done by forming joint ventures (JVs) with global OEMs (e.g., VW, GM, Ford, etc.).

The first bunch of SOEs are called “Three Big and Three Small”[6], including three large centrally affiliated SOE groups, namely FAW, Dongfeng and SAIC, and three relatively large locally affiliated groups (compared to other local firms), namely those in Beijing, Tianjin and Guangzhou. These SOEs were the formal carriers to attract and land FDI from the global automobile industry. However, the capability building outcome is at most mediocre (Nolan, 2001; Thun, 2006)[7]. Another group of firms consists of domestic “latecomers” that emerged later and were not supported by large scale industrial policy support. Although some of them still formed JVs and received some degree of policy support, they benefited less than those promoted as “national champions” from policy rents and early market premium. Up to now, all SOEs have established indigenous brands in passenger vehicle business. Naturally, the second category refers specifically to JVs formed between SOEs and MNEs. The third category is private firms that have emerged despite institutional and policy barriers and contribute a lot to cost innovations in China’s indigenous automobile industry. Despite that FDI regulations is set to loosen in the 2020s, no fully foreign owned automobile companies have so far landed (Telsa only opens a mega factory in China, not investment of a company).

As for the second and third sub-questions where I examine innovation strategies and processes of automobile firms, I limit myself to only *indigenous brands in the passenger vehicle business*. JVs’ decision-making is hugely influenced by their headquarters, and their institutional structure and capability development are in drastic difference from indigenous brand. Moreover, data availability through interview has high barrier for a doctoral thesis, hence I only discuss them where relevant, but do not treat them as major object of analysis. Another criterion applied for firm case selection is that indigenous OEMs’ passenger business should

[6] “三大三小”: "Big Three" refers to the three major car bases of FAW, Dongfeng, and SAIC; "Three Small" refers to the three small car bases of Beijing Jeep, Tianjin Xiali, and Guangzhou Peugeot.
[7] It is not the objective of this chapter to go into details of automobile industrial policy in China. For more background knowledge and related research, please refer to Thun (2004,2006).

be undertaken by the immediate direct subsidiary of the parent group. For example, the SAIC Motor Corporation Limited has immediate capital control over SAIC Motor Passenger Vehicle Co., Ltd., and the latter engaged in technological development and product deployment of electric passenger vehicles under indigenous brands (e.g., Rowe). The selection of focus unit at other automotive corporations follows the same criteria. I do not look at those by JVs or non-passenger vehicle branches, nor small brands by second-tier or even third-tier subsidiaries because their organisational structure is different and that their companies are at a far smaller scale.

With this basic specification, I try to maximise between-firm variation not only because the consideration of multiple case studies, but also the thesis's interest on firm heterogeneity. This firstly involves difference in ownership structure (SOE versus POE, and SOEs of different levels of state assets management), historical difference (with or without JVs with MNEs in the ICEV business), different locations, etc. Moreover, I not only include very successful EV manufacturers, but also those with mediocre performance and even failure. This can allow for theoretical replication to increase external validity (Robert K. Yin, 2013). As a result, a total of twelve EV manufacturing firms are selected to conduct multiple case studies at firm-level analysis. This is not an exhaustive list, of course, but is as comprehensive as possible, while reaching the recommended maximum ideal number of multiple case studies (Robert K. Yin, 2013). Descriptive information on these firms is given in Chapter 6.

4.2 Data collection

4.2.1 Primary data collection and fieldwork

The data on firms' perception of green industrial policy incentives, their strategic responses and innovation processes does not always manifest itself in open-access, structured formats. Interview is an important data source of the case study to elicit information on motivations,

incentives, strategies and processes of innovation. The majority of interviews I conducted according to the original research design were semi-structured, face-to-face interviews before the outbreak of covid-19 pandemic, and during the period when pandemic was under control and travel for research was allowed again. The other interviews were conducted remotely when I was travelling in China but could not meet informants in person because of lock-down or travel restrictions, or when I returned to Oxford and requested supplementary interviews to fulfil data collection to fully address the research questions. Each interview lasted from one hour to one and a half hours, at most two hours on a few occasions.

To conduct the face-to-face interviews, I undertook a total of nearly one-year fieldwork in China's major automobile industrial clusters covering more than twelve cities. Informants included policy makers and policy consultants at the level of central and local government, business managers (medium to senior ranking) in automobile groups and component supply firms, technological professionals and experts, as well as analysts from consultancy companies and industrial intelligence service providers, etc.

Because many of the informants involved in policy making or business management were well established and prestigious in society, I followed the guideline of elite interviews (Harvey, 2011; Richards, 1996) throughout the process of consent seeking, conversation and follow-ups and feedbacks. Consent seeking was achieved through both oral and written formats, depending on the specific occasion and channels through which contact was established. I found oral consent especially important because of the elite status of many informants and the social network they were involved in. Before each single interview, I did sufficient "homework" to prepare myself as a researcher with a certain level of expertise about the sector and knowledge of their work and organisations. During the interview process, I started with open-ended questions and then followed up with more formulaic questions because business elites do not generally like to be confined (Healey & Rawlinson, 1993). I also kept in mind paying attention

to informants' personalities, keeping flexibility and maintaining a good atmosphere during the interview, and trying to receive some feedback afterwards. Some interviews with business firms were luckily accompanied by factory tours.

The access to key informants was initiated by a research stay at School of Economics and Management (SEM), Tsinghua University for three months, and a research associate intern at China EV 100, a critical think-tank that coordinates policy making, industrial strategies, technological development and management in the EV sector. Through the two institutional affiliations, I was able to access other informants through a snowball sampling process, until important figures in the sector were largely covered. One critical intermediation brought about search stay at SEM was the Tsinghua University Automobile Industry Alumni Network which had local branches in regions of automobile industrial clusters. Many alumni held engineering or management positions in their companies and introduced me to further interview opportunities. During the covid-19 pandemic, part of the interviews was conducted online using digital tools (Zoom meeting, phone calls, etc.). Through all these means, a total of 83 effective interviews (not including historical interviews) were conducted (Table 4-1). For interview outlines, see Appendix A. Interview questionnaires.

Table 4-1 List of interviews

	Number of interviews		
	Interview conducted by the author	Historical interview	Total hours of interviews
National industrial policy	9	2	12.5
Local government	7	3	11.75
OEMs (EV makers)	42	10	58
EV Component suppliers	7	2	15.5
Technological professionals, consultants, intermediaries, etc.	18	6	32
Total (interviews)	83	23	129.75
Factory tours	6	/	/

4.2.2 Secondary data

Due to the complexity and multi-facet nature of empirical facts, different sources of secondary data are combined for the purpose of clarification, complementary and triangulation (Renz et al., 2018). They include various types of publications, statistic database, documentations, archival records, and online media reports, etc. (Mills et al., 2010). For example, the China Automotive Industry Yearbook and Energy Saving and New Energy Vehicle Yearbook are very useful open publications. Business reports, archives, official websites, stock market analysis report and prominent consultancy company reports (e.g., McKinsey) are also consulted.

Due to the outbreak of covid-19 pandemic, some access to informants was blocked and lost, therefore I needed to find alternatives. Two means of secondary data collection prove to be very useful. The first one is historical interviews where the targeted informants addressed the same or similar questions on other occasions. The second one is livestream of those

informants' speeches or conversations with hosts at international, national and industrial level forums.

4.3 Data analysis

4.3.1 Content analysis

I conduct content analysis as one of the qualitative data analysing strategies. Two specific approaches – conventional and directed – are used in combination (Hsieh & Shannon, 2005). Although the entire data analysis is guided by the SSIP framework, the framework is more indicative than specifying explanatory factors or causal mechanisms. Hence *conventional content analysis* is adopted as existing theory and literature is limited. In the initial stage of qualitative data analysis, this inductive approach allows more nuanced concepts, categories and new insights to emerge from data rather than be biased by preconceived categories (Kondracki et al., 2002). For example, in studying the role of green industrial policy at the sectoral level, I probe into the documents, archives and semi-structured interview records to identify different policy priorities and regulatory perceived by different stakeholders and make sense of the influence of policy incentives and their interaction with other building blocks in the sectoral system, when useful concepts and mechanism emerge, I then group them into meaningful clusters (e.g., positive network effect along the industrial value chain) for more analytical procedures.

The investigation of firms' strategic responses in terms of directionality and system integration strategies is more theoretical-informed, hence primary and secondary data is analysed with a *directed approach* in a more structured and deductive manner [8] (Mayring, 2019). This

[8] This is not to say that the content analysis itself or the research method deductive. Here it means that compared to conventional approach, content analysis for the second and third sub-question is more guided by and frequently referred to the specific analytical framework in the chapter. The actual data analysis process is arguably a combination and iteration between deductive and inductive approaches.

approach helps validate and extend theories and identify relationships between concepts and categories. However, content analysis does not go too far beyond conceptual development or model building (Lindkvist, 1981). Theoretical development and inference drawing can only be realised through combination with other more analytical strategies such as within-case explanation building and cross-case synthesis.

4.3.2 Process-tracing

At the sectoral level, i.e., for the first empirical question, process-tracing is applied as a data analysis method (Bennett, 2010), as the chapter seeks to understand the causal mechanisms between green industrial policy and directionality of innovation in sectoral change. Because the two variables are supposed to bear causal relation according to existing literature and initial empirical insights, but the mechanism is unclear. Therefore, in this case study process tracing is applied as a means of theory building (the other two types of process tracing is theory testing and outcome explanation) (Bennett, 2010). This is especially suitable for building middle-range theories that both attend to contextual factors and elicit causal mechanisms that are generalisable. This process-tracing does not start as a blank paper, but is conducted within the analytical framework of the SSIP under green transformation as a (semi-) open system and the sector from a value chain perspective.

4.3.3 Within-case analysis: explanation building with logic model

I proceed with within-case study to reconstruct innovation processes at the firm-level using the analytical strategy of logic model (Figure 4-1). This is an emergent technique in doing evaluations and studying theories of change (Funnell & Rogers, 2011), and is frequently adopted in research on organisations and businesses. Because the research questions ask about the process and driving forces of change from an evolutionary perspective, explanation building with logic model has the merit of taking into contextual factors and teasing out

variables that really matter in the change process. For case study in this thesis, explanation building with logic model consists of two levels of analysis.

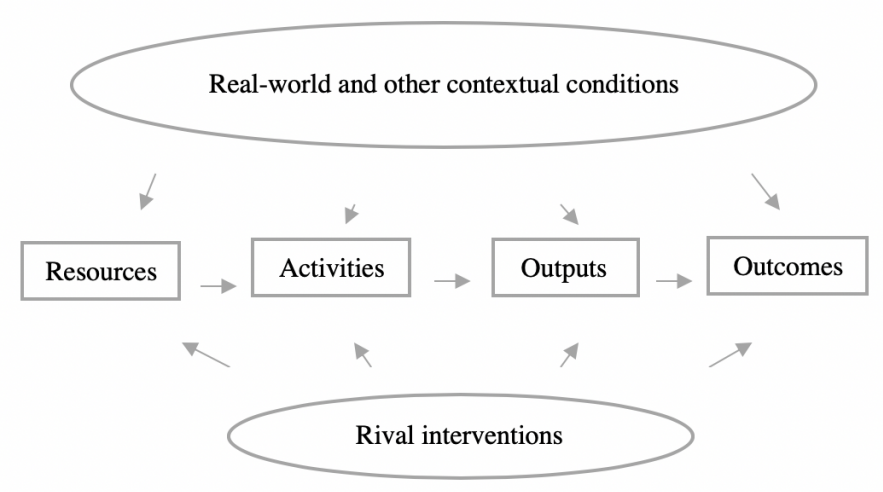


Figure 4-1 A simplified illustration of logic model[9]

At the level of firms and their interaction with institutional regimes, I apply logic model to construct two lines of analysis, both longitudinal. The first line of analysis addresses the second sub-question, i.e., how firms respond to green industrial policy differently. I look at the mediation of firm-centric incentive structure and moderation by firm-level characteristics. The second line of analysis addresses the third sub-question, i.e., how firms' innovation processes and activities differ revolving different direction of innovation and how they translate into system level dynamics and outcome. I organise data according to analytical elements listed in the analytical framework as well as from initial insights from content analysis by chronological sequences. To build compelling explanations, I look at how these elements interplay and co-evolve over time.

One issue concerning within-case explanation building is to improve internal validity by attending to rival explanations (Gibbert et al., 2008; Robert K Yin, 2013). I therefore analyse contextual factors in the case, not only because organisations are inseparable from context, but

[9] Adapted from Yin, R. K. (2013). *Case study research : design and methods* (Fifth ed.). SAGE.

also that contextual factors, exogeneous or endogenous, can contain rival explanations. For example, revocation of government subsidies on EV, unexpected radical technological breakthroughs, or internal changes in the organisation, etc.

4.3.4 Moving from single case analysis to cross-case analysis

For the second sub-question, cross case comparison and synthesis is the inherently needed by the nature of research question itself – to understand and explain difference. Because cross-case comparison is guided by an overall analytical framework and clear analytical elements, the analysis follows structured, focused comparison (George, 2019; Sivesind, 1999). Zooming in to more details in the second question, for firms exhibiting similar behavioural patterns in terms of innovation strategies, I select multiple firms for the same or similar kind of behaviours to increase variation and as a measure to improve external validity. The basic principle I adopt for examining convergence and divergence among firms is the classical joint method of agreement and difference (Levy, 2008; Mills et al., 2010; Seawright & Gerring, 2008). This applies to the understanding of firm heterogeneity in directionality of innovation in response to green industrial policy intervention. Interestingly, the different components of "directionality of innovation" at the level of firms consist of inequivalent independent variables, thus I look at the concomitant variation during the comparative analysis (Robert K. Yin, 2013). It can be viewed as a sophisticated version of joint method and enables the investigation of the degree that outcomes are associated with causes (Mills et al., 2010). Such flexibility to causal inference adds to the iteration in cross-case synthesis and comparison, until the explanation is saturated.

For the third sub-question, the same set of OEMs are analysed in a more inductive manner. I start with the construction of logic model for two firms that are consistently different in the scope of technological variation. Then following the logic of replication, I switch to look at

other firms and refine the model, until a more comprehensive and generalised conceptual model of OEMs' performing system building emerges from the cross-case synthesis.

4.4 The use of computer assisted qualitative data analysis

Apart from manual analysis, I use computer assisted qualitative data analysis (CAQDAS), specifically, NVivo as an important tool to support the content analysis, single-case story constructing and cross-case comparison (Wickham & Woods, 2005). Though the tool itself is by no means a substitute for the work done by the researcher, it is widely believed to be useful for the generation, refinement and test of theories, and adopted in case studies (Dalkin et al., 2021). Because my research involves some extent of iteration between data, research questions and conceptual and analytical framework, the use of NVivo is especially useful for progressive focusing (Bandara, 2006; Sinkovics & Alfoldi, 2012). Concretely, the software is used in the "middle" of the analysis. I do not introduce it until I have an initial list of concepts, variables and data according to the general analytical framework. NVivo is then used to organise, structure, compare and refine them, round by round, until a valid pattern is identified – by the researcher myself. In the iteration, through the use of NVivo to present, interpret and relate data, I can better see the connection between different concepts and variables, hence draw casual links and generalise explanations on such basis. To cultivate my skills, I have taken methodological courses offered by Oxford IT learning centre and open access online tutorials. This learning experience proved to be useful.

4.5 Research ethics

My collection and process of data and writing up has followed the research ethics principles (Ryen, 2011). The fieldwork was conducted upon approval of research ethics application in Oxford. All interviews were done after consent was sought from respondents, who were also

fully informed about the research topic, recording of the interview, usage of data and how their information is processed. Before data collection I asked whether they were happy with the interview being recorded. If so, I proceeded and loaded afterwards the voice recordings to my laptop folder that was protected by password only I knew. If not, then I took manual notes with paper and notebook given their consent to do so. All data is strictly confidential and for academic purposes only, and no third-party access is allowed or possible.

Respondents are anonymised or pseudonymised, and in writing up I make sure that their identity could not be traced indirectly via information provided in the text. One exception is when I quote sentences from openly published materials, especially what executives and top management team say during media interviews, strategy launch meetings, or other publications relevant to my thesis. Their names are used directly through quotation under such circumstances because data is already transparent and open.

4.6 The ecosystem of electric mobility in China

4.6.1 A glimpse EV technologies

The rise of EV sector can be viewed as a technological regime shift in a mature automotive industry. An electric vehicle is a vehicle powered by an electric motor, instead of an internal combustion engine (ICE), and the motor is run using the power stored in the batteries. The green regime shift in the automobile industry sees product architectural, design and functional diversity, which a paper by Fujimoto (2017) has well described (Table 4-2):

Table 4-2 the architectural diversity of EV products

	G-ICEV	*D-ICEV*	*HEV*	*PHEV*	*ICE-REV*	*FC-REV*	*BEV*	*FCV*
Energy efficiency	X	X	X					
Acceleration								
Max. speed								
High perf. range			X	X	X		X	
Recharge time							X	
Station density						X	X	X
Quietness								
NOx/PM emissions		X						
Safety								
Fun to drive								
Vehicle cost						X	X	X
Operating costs								

Notes: X = estimated critical function (the gap between required functional levels and current performances is large).

Given the diversity and wide range of technological possibility in the regime shift, there are at least three major types of electric vehicles that are commercially deployed in the market, namely battery electric vehicle (BEV), hybrid electric vehicle (HEV) and fuel cell electric vehicle (FCEV). The BEV relies solely on the battery as the driving force and uses a motor and converter to replace the gearbox. The HEV is powered by two sets of sources: an internal combustion engine and an electric motor. HEV uses a gasoline-powered internal combustion engine at high speed and electricity when speed is low. Between HEV and BEV, there is plug-in hybrid electric vehicle (PHEV) that is propelled by certain combination of ICE and electric motor. It can work on power batteries alone but with limited drive range (e.g., 50km or 70km), or work on ICE alone. This is flexible and the combination between the two power modes has the benefit of adjusting power system and fuel consumption to the least energy-consuming status. The FCEV utilises hydrogen that generates electric energy as a power source after chemical reaction with oxygen. Additionally, some OEMs experiment with range extender electric vehicle (REEV), which is propelled by an electric motor, but the electricity is supplied by an attached engine in the powertrain.

Due to the diversity of EVs and different regulations among countries, no "dominant design" has emerged from the sector (Fujimoto, 2017). The technological trajectories in EV production and diffusion exhibit cross-country differences. In Japan, HEV dominants the market; in the US and Europe, different technology pathways compete for dominance, especially BEVs and PHEVs; and in China, BEV occupies lion market share. In the year 2017 in China, 75% of the issued EV passenger car models were BEVs and the rest were primarily plug-in HEVs (PHEVs) (23%) and a slight portion of FCEVs (about 2%) (Figure 4-2). The sales data is slightly different, but BEV is the absolute technological configuration of EV models in China's production and deployment.

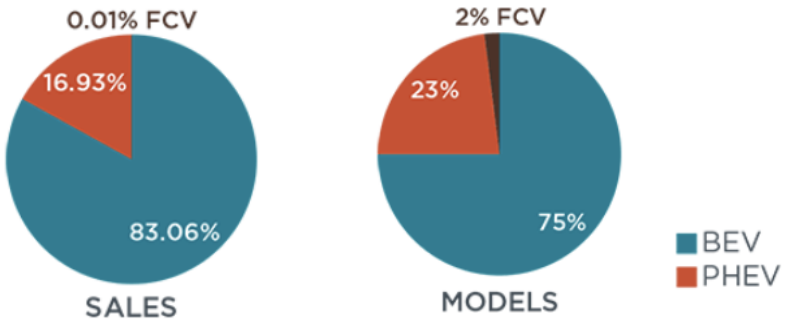


Figure 4-2 The composition of technology trajectories in terms of sales and EV models[10]

4.6.2 The development of China's EV sector in the global context

The history of EV dates to the mid-19th century in Netherlands, Hungary and the United States, but were beaten by the combustion-engine cars due to the relatively low cost and technological improvements of the latter ones (Matulka, 2014). EV greets its resurgence in the 1990s because of the increasingly urgent needs for energy saving and environmental protection. "EV1", the EV model released by General Motors (GM), was the first of its kind produced by a major

[10] "Comparison of the electric car market in China and the United States", https://theicct.org/publications/comparison-electric-car-market-china-and-united-states

automaker. Various firms started to manufacture EV since then and global competition intensifies with the technological progress and market expansion of EV.

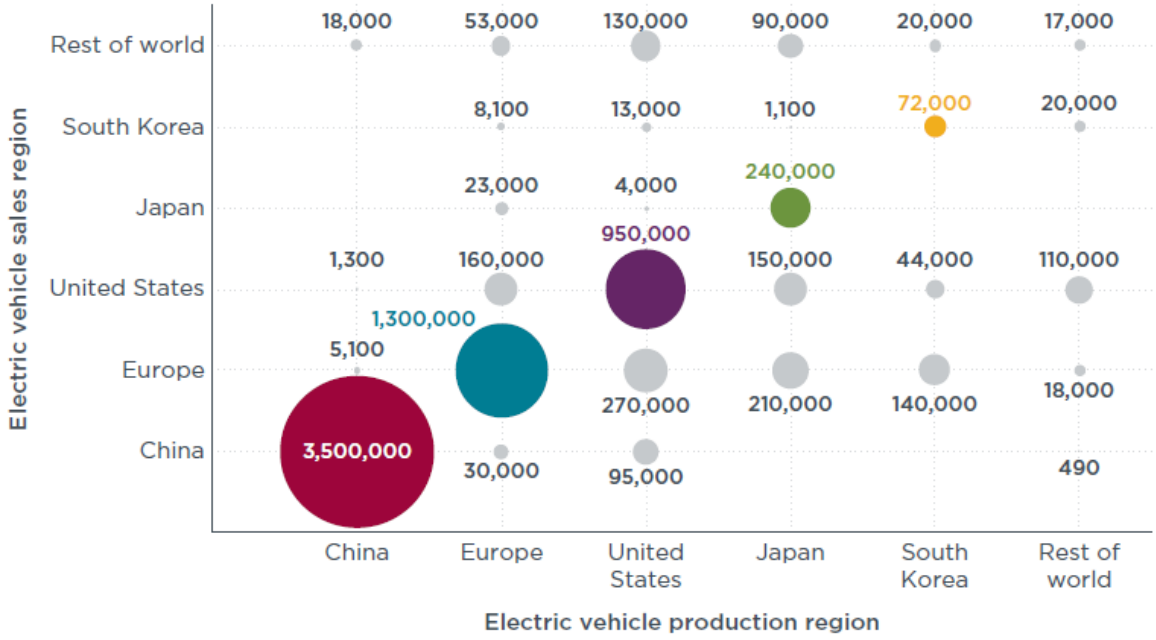


Figure 4-3 Electric vehicle production region worldwide[11]

The figure above (Figure 4-3) shows the total new light-duty EVs deployed by where they were sold (vertical axis) and produced (horizontal axis) from 2010 to 2019. It can be seen that China takes in lead in EV volumes in terms of both production and diffusion, with Europe, the US, Japan playing a major role. Figure 4-4 below further shows the cumulative trend overtime. It is worth noting that policy makers in China use the term "New Energy Vehicle" to include the types of vehicles that use alternative energy (electricity, hydrogen, etc.) instead of fossil fuel, while "electric vehicle" is defined according to the application of electric motor in the power system. However, as there are only BEVs, HEVs (including PHEVs) and FCVs in the current passenger car market, here I use EV and NEVs interchangeably to specifically refer to these three categories of electric cars unless otherwise stated.

[11] Source: ICCT report website.

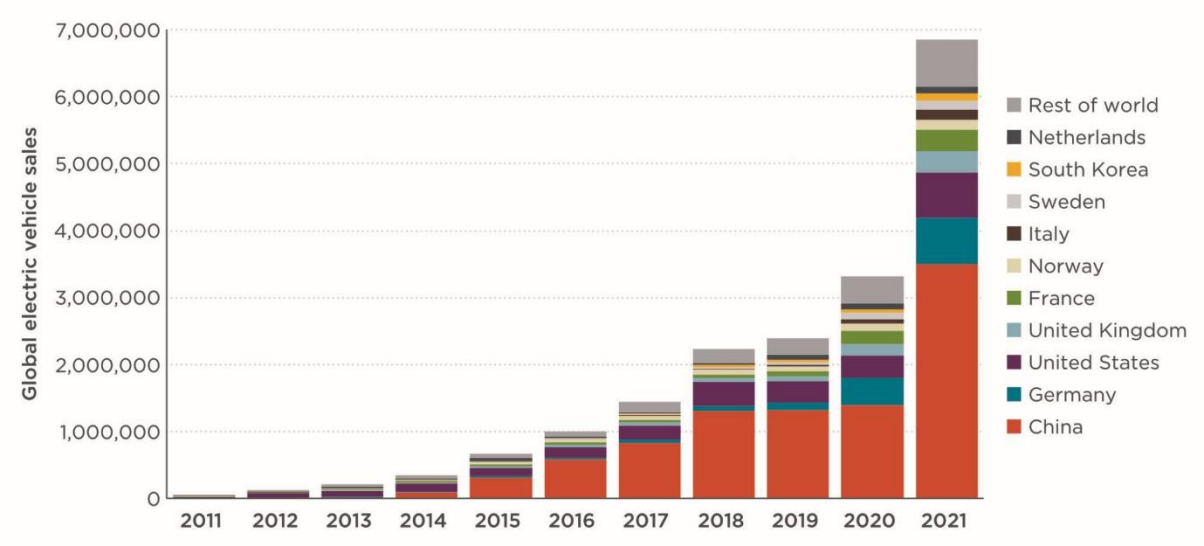


Figure 4-4 Annual electric vehicle sales globally by market from 2011 to 2021[12]

4.6.3 Description of China's electric mobility ecosystem

(1) The industrial architecture in electric mobility sector

- Firms in the focal sector

The number of EV manufacturing firms has been ambiguous even until nowadays. According to a report by the Wallstreet Journal in the middle of 2018, there claimed to be 487 whole vehicle EV manufacturing companies, but the statistics remained as speculation[13]. In March 2019, the National Big Data Alliance of New Energy Vehicles first disclosed that accumulatively 635 manufacturers registered on the platform and 486 of them succeeded. This figure only refers to registration and does not exclude commercial vehicle manufacturers. In terms of actual production, there are 79 automakers that have real electric passenger car production capacity, according to the official statistics from the MIIT released in June 2019[14]. Among these firms, 11 of them are new entrants into the market as EV startups, 17 are

[12] Data source: ICCT, https://theicct.org/publication/global-ev-update-2021-jun22/
[13] "China Has 487 Electric-Car Makers, and Local Governments Are Clamoring for More". https://www.wsj.com/articles/china-has-487-electric-car-makers-and-local-governments-are-clamoring-for-more-1531992601
[14] Data from the official website of China MIIT.

incumbent joint ventures (or the corresponding branches) automakers, and the rest of them are incumbent domestic automakers. Although there is a lack of accurate, credible numbers, nearly 73% of all the EV volume is concentrated in around a dozen EV manufacturing firms that produced a cumulative output of nearly 550,000 vehicles before 2019.

EV manufacturers that are incumbent automobile firms can be classified into three categories. The first category is SOE of indigenous car brands that report to central government SASAC (e.g., FAW, Dongfeng, and Changan) or local government SASAC branch (e.g., BAIC, SAIC, GAC, and Chery, etc.). Such enterprises occupy an important position in the sector. The second category is private owned OEM of indigenous car brands, such as BYD, Geely, Great Wall Motor, etc. These enterprises are relatively latecomers compared to the first category backed by state capital and are important players in China's industrial catch up in automobiles. The third category is Joint Ventures (JVs) between SOEs and global brands as an early industrial policy tool to foster technology transfer, albeit with very limited success. Notably the introduction of EV models to China's market is heavily influenced by the decision from MNEs' headquarters, rather than industrial policy in the host country.

The EV volume produced by new entrants are comparatively smaller in scale. By new entrants, I refer to those who start car manufacturing business especially for electric mobility without previous background in automobiles. A huge number of startups have appeared since 2014, and the existence of most of them is very transient. Many died soon after their establishment and had no EV model launched in the market. The several EV startups that have survived until now and have eye-catching performance include NIO, XPeng, Li Auto and so on. They largely have a certain degree of background in ICTs and focus their value propositions on connectivity, customer services and "intelligent" vehicles.

- Complementors (suppliers, infrastructure and service providers, etc.)

Switching to core components, they are currently mainly provided by specialised component suppliers, while OEMs are making efforts to have more control over the supply chain themselves. In terms of power batteries, there are still more nuanced differentiation between battery packages, battery modules and battery cells, as well as BMS, hence suppliers are highly heterogeneous in the beginning. Nowadays this sector sees growing concentration, with CATL, BYD, Gotian, etc., being major battery suppliers. Electric motors are less complicated, and some suppliers, such as Jing-Jin Electric Tech (JJECN), are established exclusively for EV power systems, while some incumbent suppliers add electric powertrain to their R&D and production portfolio, for example, HASCO Group, an integrated supplier of SAIC. Still, because this line of components is less demanding than power batteries, many OEMs are able to internalise it, such as Changan and others.

The use of power batteries in EVs objectively require supporting charging infrastructure, hence battery charging ports and stations, or battery swapping stations and the grid form an important part of the electric mobility value network. Charging ports can be divided into two types: DC fast charging and AC slow charging. Some of them are for individual households, some are for organisations, while others are for public use (e.g., shopping malls, highways, parks). Since 2014, China has gradually opened up market access to the charging infrastructure business to non-SOE investors to accelerate the construction of charging ports. From 2010 to 2018, the number of charging piles in China has grown from more than 1,000 to more than 800,000. The regional concentration of public charging ports is relatively high, with big cities such as Beijing, Shanghai, Guangdong and Jiangsu accounting for 46 % of the overall installation. However, this related sector is less concentrated as the technology and investment barrier is lower than EV and its core components. Currently both firms from the state and private sector play an important role. Within the state sector, the State Grid Corporation of China (SGCC) and China Southern Power Grid (CSPG) are the two major contributors to charging infrastructure and its

intersection with the grid and energy network, the latter belonging to their original areas of businesses and expertise. The two gigantic SOEs have the advantages of building charging infrastructure in locations and scenarios that private businesses find less cost-efficient and foresee limited economic return. By 2019, in terms of the construction of inter-city charging ports and stations, the “ten vertical, ten horizontal and two rings” fast charging network of the State Grid has covered 49,000 kilometres of expressways, connecting 171 cities in 19 provinces. In the private sector, several firms specialise in building and operating charging ports and charging stations in cooperation with utility companies and OEMs, such as TGOOD and Star Charge. However, startups including NIO and XPeng are also involved in providing their own battery charging ports and services in order to distinguish themselves from incumbent OEMs. Apart from battery charging, NIO persists in battery swapping and cooperates with SGCC to achieve economies of scale.

Another part of the value work in electric mobility concerns the usage of EVs. While some EV models go to public sector procurement and private purchase, the majority of them are running in the market in the form of 2B business. This gives birth to various service providers. One type of service providers is established especially for EVs, for example, Caocao Mobility created by Geely to deploy its EV models, as well as Changan Mobility by Changan, and later T3 mobility jointly operated by FAW, Dongfeng and Changan, the three SOEs managed by the central government SASAC. The second type of service providers is car sharing and ride hailing platform companies that previously operate ICVEs and later add BEVs into their business, and prominent examples are DiDi, a counterpart of Uber. In such cases, EV manufacturers put their models on the DiDi platform to operate in the market. The third type of service provider consists of digital platforms of a different kind, especially high-precision map and navigation. For example, A Map and Baidu Map both have portals where EV models belong to the overall ride-hailing pool. The fourth type is the traditional taxi fleet, where the

operating companies buy hundreds or thousands of EV models from an EV manufacturer and run their business as they used to. These various service provisions enable the deployment and diffusion of EV models when EV manufacturers find selling EVs to individuals is a very challenging task.

(2) The government

- Central government

The State Council represents the level of the central government. It proposes macro level strategic planning and guidance for the development of the EV industry, and stamps on the technology roadmaps to achieve sustainability and action frameworks for policy support. The national strategy for electric mobility issued by the State Council belongs to the broader macroeconomic and social development planning, such as those articulated in the "*Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries*" in 2010, "*Made in China 2025*" in 2015, etc. At the same time, it forms an indispensable part of the industrial strategy of the automobile industry, such as the 2009 "*Automobile Industry Adjustment and Revitalisation Plan*", 2012 "*Energy Saving and New Energy Automobile Industry Development Plan (2012-2020)*" and so on. These macro level strategic plans establish the long-term vision of the future development of the automobile sector and its role in the wider context of sustainable development.

On the basis of the higher-order economic and industrial strategy established at the State Council level, more than a dozen of ministries, departments or commissions at the central government level hold administrative responsibility for concrete policy making, tool design and implementation revolving around electric mobility. Among them, four stand out as major actors: Ministry of Finance (MOF), the Ministry of Science and Technology (MOST), National Development and Reform Commission (NDRC) and Ministry of Industry and Information

Technology (MIIT). Because they often compose and issue policies together, they are called "The Four Ministries and Commissions". There is a division of labour among them. NDRC and MIIT are responsible for regulating the automobile product market, price, resources, industrial entry/exit, etc. The "*Administrative Regulations for Newly Established Pure Electric Passenger Vehicle Enterprises*" jointly issued by these two branches, for example, modified the market entry rules in the EV industry by lowering the entry barrier to new entrants that are specialised in BEVs. The function of the MOF is to draft, clarify and implement fiscal and taxation policies related to the deployment and diffusion of EVs in the marketplace. It is also an authoritative source of pecuniary support for EV subsidies. In cooperation with the State Administration of Taxation (SAT) and the MIIT, MOF has implemented tax incentives, fee reductions and other policies to reduce the cost of EV products and their usage. The role of MOST is mainly reflected in the support for the R&D and capital investment into EV technologies.

In November 2013, the State Council approved the establishment of an inter-ministerial joint meeting framework for energy conservation and new energy vehicle industry development led by the MIIT, to strengthen coordination between central governmental ministries and accelerate the promotion of EVs. The joint meeting is annually participated by MIIT, NDRC, MOST, MOF, and more than ten other branches responsible for energy, urban planning, housing, etc. These additional ministries and departments in the central government, or at the central level, also play an integral role in shaping the governance framework and policies for electric mobility in China. For example, the Ministry of Transportation (MOT) oversees the safety standards of EVs, issues relevant technical requirements and approves or disapproves the revision of standards in the transportation sector.

- Local government

Local government is responsible for implementing these strategic plans, policies and regulations. In the "Ten Cities, Thousand Vehicles" program, the government in the ten pilot cities were responsible for demonstration of EVs and reach the deployment target. The private purchase subsidy scheme was firstly carried out by six pilot cities, where local government provided intensive supply and demand policy support to facilitate the production and uptake of EVs in the local market. Because China is a unitary state, local government does not have the comparable decision-making authority, but there is still leeway in designing the concrete policy measures and the methods of implementation. This brings two aspects of nuances. First, local government nominally complies with central government requirements, but can actually circumvent some of the orders or take advantage of them for local economic welfare. This is well captured in the fragmented authoritarianism literature from the perspective of vertical coordination (Mertha, 2009). Second, and a related aspect is that local protection is prevalent when it comes to the allocation and returns to policy rents (Oh, 2013).

(3) The policy landscape in China revolving around electric mobility

In the field of electric mobility, Chinese government has launched to date the most comprehensive "mix" of policies to facilitate the technological development, industrialization and diffusion of EVs, covering the entire innovation chain and industrial value chain. This is not a pre-designed policy system, but is the result of continuous learning and adaptation in the unknown and unfolding process of sectoral change. It is beyond the scope of this thesis to undertake a systematic and comprehensive study of the "policy mix" revolving around electric mobility in China. However, it is still important to give an overview of the policy landscape, based on existing literature, and point out major policies and policy change milestones that are especially influential.

There is a growing body of literature on the evolution of Chinese government policies on green transformation in the automobile industry that provide useful and valid insights on the policy

and institutional dynamics. While different categorisations and criterion of inclusion leads to varied number of policy documents and instruments, lots of literature on policy studies find over 200 policies at the central government level relevant (Song et al., 2023; Yin & Huang, 2023). From a value chain perspective, an earlier study indicates that there is a shift from government-selection to market-selection and from producer-orientation to market-orientation in the innovation policy mix in China's clean mobility transition from 1991 to 2015 (Xu & Su, 2016).

During the last decade, China whole-heartedly embraced EVs and made them a much higher priority than have other countries (Kennedy, 2018). Despite the massiveness, it is important to point out several major policy milestones and characteristics in China's EV sector. Scientific exploration of EVs was already supported since the 1990s under some departmental programs (MOST), whereas the formalised nationally funded R&D took place during 2001-2008, almost covering two five-year-plans (FYPs). This electric vehicle major project was one of the 863 Major Projects. Up to 2008, over five hundred EVs (including buses, sedans and other vehicles) were delivered and demonstrated in the Beijing Olympics.

Seeing the progress and potential, policy makers decided that the industrialisation and diffusion of EVs should be put on the agenda in 2009. This attempt lasted from 2009 to around 2012, which overall is called the "Ten Cities, Thousand Vehicles" and consists of two parts. The first part is the support for deployment and diffusion of electric buses that adopt EV or HEV solutions starting from 2009. In 2010, this extended to private purchase subsidy electric passenger vehicles, first starting with six pilot cities and then to 25. However, the result seemed to be quite unsatisfactory as opposed to the 500,000-target expected in 2015. At the same time, a fierce controversy was going on regarding the technological trajectories of electric mobility, especially in terms of whether to continue to provide policy support for HEVs or focus on battery-based solutions. The debate was settled in 2012, when "*Energy Saving and New Energy*

Automobile Industry Development Plan (2012-2020)" formally established the "pure electric drive" strategy. In the two years that followed, policymakers in the central government re-affirmed that policy support for electric mobility transition would continue.

Therefore, since 2015, the private purchase subsidy scheme, combined with other diversity of policy tools, expanded to the entire nation. This is accompanied by a gradualist phase-out mechanism, with the number of subsidies decreasing overtime, which eventually phased out entirely after 2020. The subsidy scheme experienced continuous adjustment in the process as well, including change from subsidising battery size to power density and a set of integrated performance parameters, the inclusion of local government subsidies in 2015 and cancellation in 2017, and subsidies additionally awarded to charging infrastructure, to name a few.

Another notable policy instrument is the introduction of "dual credit system" as a regulatory framework to further induce technological innovation in EVs among OEMs. This was partly informed by the zero-emission vehicle (ZEV) scheme in California, US. In 2017, MIIT issued the "Measures for the Parallel Management of Average Fuel Consumption and EV Credits for Passenger Car Companies". According to the policy, a "dual credit system" was rolled out to calculate two types of credits: first, corporate fuel consumption (CAFC) credits, which are negative; and second, new energy vehicle (NEV) credits. OEMs with positive net credits get an amount of financial award and vice versa. Initially, this policy was issued and implemented only preparatory, and did not take substantial effect before 2018. Besides, this policy did not embody the selectiveness in green industrial policy as much as the "pure electric drive" strategy. Hence while acknowledging that this policy measure and its influence was more or less in place, the thesis mainly focuses on the "pure electric drive" technology strategy and its supporting policy and regulatory measures.

4.7 The four phases in China's electric mobility transition for empirical analysis

In this last section, for analytical purpose in the subsequent empirical chapters, I divide the over two decades' electric mobility transition in China into four phases that exhibit distinctive characteristics. Because the thesis examines the effectuation of green industrial policy and firm innovation in response, and the fact that electric mobility transition is deeply shaped by institutions, the division of phases is based on important policy and institutional change, and the value-chain stages of sectoral transition itself.

Phase one: from early 1990s to 2008. The stage features the initial technological exploration in the EV regime with multiplicity of technological trajectories and solutions. Policy support features national-level R&D projects. EV prototypes were demonstrated in the 2008 Beijing Olympics.

Phase two: 2009-2012. The period marks the establishment of "pure electric drive" strategy in industrial policy, and the small-scale, deployment of EVs supported by private purchase subsidy scheme in six pilot cities.

Phase three: 2013-2015. The period marks adjustment to industrial policy, institutional change, and the expanded, yet still small-scale deployment of EVs supported by private subsidy.

Phase four: 2015-2020: The period marks a comprehensive set of industrial policy support for the large-scale deployment and diffusion of EVs, with phase-out mechanism to the subsidy scheme, and return to technological multiplicity in 2020.

Chapter 5 Green industrial policy and directionality of innovation in the changing sectoral system: Case study on China's early transition to electric mobility

5.1 Introduction

Amidst the "Fifth Great Surge of Development" (Perez, 2013), sustainable development has been a rising imperative for all countries which requires a transition of the socio-technical system propelled by green innovations (Schot & Geels, 2008; Yap & Truffer, 2019). Such a paradigm shift opens the so-called "green windows of opportunity" for countries, which is institutional and endogenous in nature because of the public goods characteristics of the green techno-economic paradigm (Lema et al., 2021). This highlights the role of state in the transition dynamics by utilising a wide range of policy tools, as articulated in environmental economics, innovation policy and sustainability transition literature. Particularly, an entrepreneurial and mission-oriented policy approach is advocated to tackle "grand societal challenges" (Mazzucato & Robinson, 2018).

Developing countries face a dual challenge of continuous economic development and creation of techno-institutional systems that decouple economic development from resource depletion and waste production. Such a dual challenge in revising economic structures presents a strong case for green industrial policy, which takes the angle of industrial policy but goes beyond the scope of industrial policy, emphasising at the same time the wealth creation and economic decoupling dimension of policies (Kemp & Never, 2017; Rodrik, 2015). Following Altenburg and Assmann (2017), ***green industrial policy*** is defined as "including any government measure

aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy" (Altenburg & Assmann, 2017, p. 11). It departs from traditional means of industry in terms of focusing on environmental externalities, steering of investment behaviour, enhanced uncertainty as well as many policy interfaces. Furthermore, it inevitably relates to industrial competitiveness in developing countries so that they seize and exploit the windows of opportunities to catch up with global forerunners (Keun Lee & Franco Malerba, 2017; Malerba & Nelson, 2011).

In addressing the dual challenges, the ***directionality of innovation*** (Acemoglu et al., 2012; Acemoglu et al., 2016) is important because any specific technological innovations have consequences that are often complex and cut across multiple environmental and economic systems. It also affects the subsequent path of technological development and capability building as well as the prospect of transformation towards sustainability. However, the role of green industrial policy in shaping directionality of innovation is poorly understood. In the literature review chapter, it has been pointed out that this is partly due to the under-conceptualisation of directionality of innovation itself. Therefore, this chapter uses the definition given in Chapter 3, the overall analytical framework, as the starting point (see also 5.2 in this chapter).

Even more problematic is how green industrial policy is defined, its relation to various types of policy, and the extent to which the black box of green industrial policy is opened. Existing empirical studies either study green industrial policy from the perspective of certain policy instruments, or "best practices" in a country (Harrison et al., 2017; Matsuo & Schmidt, 2019; Pegels & Lütkenhorst, 2014b). This sometimes overlaps with environmental economics and environmental and innovation policy literature in terms of the "induced innovation" argument and various versions of "Porter's hypothesis" (Acemoglu, 2003; Ambec et al., 2013; Nemet & Kammen, 2007; Popp, 2002). However, this understanding of green industrial policy is partial

and piecemeal. It lacks the holistic approach to the kind of sector-based state intervention that strives for both sustainable development and competitiveness, not only focusing on the focal sector but also paying attention to complementary assets along the value chain. Another problem with this literature is that the causal link between green industrial, direction of innovation and the subsequent outcome is either taken for granted or oversimplified. These studies seem to treat the relation as uni-directional and static, without sufficiently appropriating that the selection process is embedded in a sectoral system that is undergoing structural change with complex interactions and feedback loops. Empirical evidence that helps to uncover this complexity and offer in-depth understanding of the concrete effect of green industrial policy is scarce, let alone in emerging economies and developing countries.

It is the motivation of this chapter to fill these gaps in literature by providing a comprehensive and systematic analysis of the effectuation of green industrial policy in shaping directionality of innovation in early green transformation in the industrial sector, by embedding the casual relation in the evolving SSIP as an open system, and uncovering the causal mechanisms underlying sectoral dynamics. Before setting out the analysis, the chapter also defines the "architecture" of green industrial policy so that an analytical boundary is drawn on a holistic understanding of the concept.

The empirical analysis is conducted on the case of China's early transition to electric mobility at the sectoral level (early 1990s to 2020). A longitudinal, single case study design is adopted to reach in-depth, evolutionary and holistic understanding (Street & Ward, 2012; Robert K. Yin, 2013) of the change process and driving forces. The early green transformation in the automobile sector is divided into four phases for analytical purpose: 1) phase one, early 1990s to 2008, technological exploration; 2) phase two, 2009-2012, the establishment of "pure electric drive" industrial strategy and initial experimentation in industrialisation and commercialisation of EVs; 3) phase three, 2012-2015, adjustment and consolidation of

industrial policy, continued experimental deployment and diffusion of EVs; and 4) phase four, 2015-2020, expanded industrial portfolio and large-scale deployment and diffusion of EVs (for more details, see Chapter 4 in methodology). Because the case study is guided by an overall analytical framework built on SSIP and green industrial policy (section 5.2), the method of content analysis (Hsieh & Shannon, 2005; White & Marsh, 2006) and process-tracing as the data analysis techniques (Bennett, 2010) are applied to uncover the causal relations and mechanisms. The data analysis is iterative until a simplified, generalisable (at the middle-range) explanation (Bennett, 2010) is developed.

This chapter contributes to literature in the following aspects. Firstly, it adds to the understanding of directionality of innovation especially in the context of green transformation through developing an interdisciplinary framework. Second, by highlighting the institutional aspect of green industrial policy, it contributes to the in-depth understanding of the political economy of technological regime shift in sustainability transition. Thirdly, green industry policy scholarship has been criticised as being "strong in theory, ambiguous in practice" (Rodrik, 2015), whereas this research takes an in-depth dive into the empirical case of a multiple technology sector in an emerging economy to elicit the processes and mechanisms at work. Focusing on industrial value chain and complementary assets, it bears implications for other sectors that have wide environmental and economic consequences as well.

The chapter proceeds as the follows. Section 5.2 describes the analytical framework of this paper. Following a brief description of research method in section 5.3, section 5.4 analyses in detail the content, characteristics and effectuation of green industrial policy in each phase. Section 5.5 points out the unintended yet non-accidental consequences of green industrial policy. Section 5.6 concludes with main findings and discussion in relation to existing literature. Limitations are pointed out with an agenda for future research.

5.2 Analytical framework

5.2.1 Directionality of innovation in early phase of green transformation

In Chapter 3, an integrated definition of directionality of innovation is developed to incorporate both the normative ("Grand challenge", here, green transition) and positive (material, e.g., technology, design and networks) dimensions of change. It is useful to briefly revisit the concept here in this section. Because green transformation is goal oriented and does not specify the pathways to achieve it, a natural starting point is that there is technological multiplicity in the "material" side of sectoral change. This is even more the case when transformation of the SSIP is in "era of ferment" before a dominant design emerges (Anderson & Tushman, 1990). Therefore, directionality of innovation refers to two interrelated selection processes: a) *technological substitution*, a regime shift that aims to use green technologies to replace polluting technologies; b) *technological variation*, design co-existence and competition where multiplicity of technological solutions fulfil the "green" objective. Therefore, directionality of innovation concerns moving away from the current technological regime, which is unsustainable, to a greener technological regime, which features technological multiplicity. This is illustrated in the figure below (Figure 5-1).

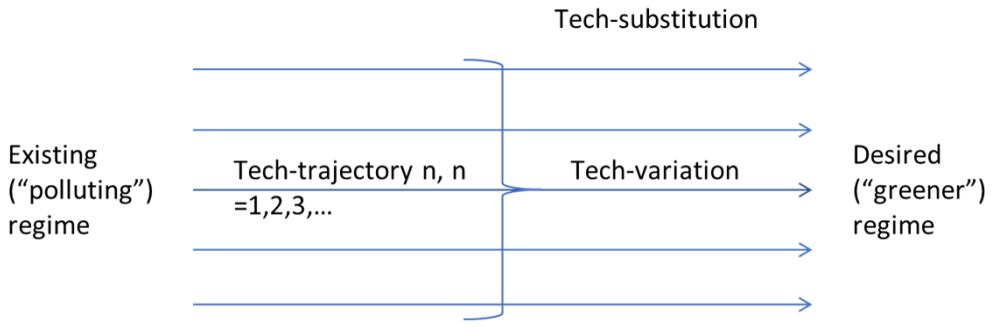


Figure 5-1 Conceptualising "directionality of innovation" in green transformation[15]

[15] Author's elaboration.

Taking electric mobility as an example, the directionality of innovation concerns departure from existing ICE regime as well as the specific technological trajectory (or trajectories) in the EV regime, namely, low-emission ICEVs, HEVs, PHEVs, BEVs and FCEVs, etc. Fujimoto (2017) has pointed out the potentially long-lasting diversity of product architectures in the automobile industry in its green transition, as each technological solution addresses certain function better than others while lags in some other parameters.

5.2.2 Green industrial policy and directionality of innovation in the SSIP

In the overall analytical framework (chapter 3), it has been put forth that green industrial policy is multi-dimensional (Anzolin & Lebdioui, 2021), and should be best studied not as a single policy instrument or a mere combination of different instruments, but rather an evolving portfolio of institutional frameworks, and regulatory and policy specifications, that together facilitates the structural change in an industrial sector towards both sustainability and competitiveness objectives. Further, the portfolio is not composed of any random clusters of policies but has multiple layers. This chapter elaborates on its architecture which consists of four levels: a) political commitment and alignment; b) industrial strategy; c) regulations and policy instruments; and d) institutional and policy change overtime.

First, as the very early phase of sectoral transition often faces ambiguity, scepticism and resistance, political commitment and alignment is essential to build consensus and proactively shape expectations toward the prospect of technological substitution (Avelino et al., 2016). It is about making the normative dimension of directionality of innovation convincing to societal actors and facilitate collective sense-making. The second layer is industrial strategy, which defines the objective and roadmap of a technological regime shift (Costantinia et al., 2017; Rogge & Reichardt, 2016). Among multiple potential technological trajectories to achieve the goal, it is the critical feature of green industrial policy to “endogenise” the regime shift towards

the comparative advantage of a country. Put it another way, green industrial policy often has the inclination and capacity to intervene into the process of technological variation. To realise the stated strategy, a portfolio of governmental policies and regulations are in place that create the incentives for business actors along the industrial value chain to develop green technologies, and create synergy between sub-systems to drive and sustain sectoral change (Hepburn et al., 2018). Last, institutional and policy change is necessary and should be timely when new problems emerge and new realities render existing frameworks no longer applicable. It concerns political realignment (van Bree et al., 2010) to continuously shape and modify consensus, change in industrial strategy to incorporate co-occurrent opportunities from various sources (Lema et al., 2021) so that sectoral transition momentum is kept. It also deals with changing a portfolio of policies and regulations to tackle different challenges in different stages of sectoral change, for example, when it proceeds to a later stage, the building up of complementary assets becomes increasingly important to the deployment and diffusion of green products in the marketplace. Nevertheless, there is no priorly existing nor fixed, stepwise, and one-for-all cuisine for a country/sector to follow, so sectoral change is persistently an open question and government needs continuously engage in learning and adjustment in the process. This is not about mere passive adaption, but also proactive foresight and envisioning based on informed sense-making.

Green industrial policy through multiple levels of regulations and policies can directly affect the cost structure in green technologies, and the demand and supply side of green innovations. For example, the state often helps to make green products affordable by offering incentives such as subsidies or credits (Czarnitzki et al., 2011) given their public goods nature. Policy measures can also be applied to facilitate the diffusion of green innovations by creating the synergies between vertically and horizontally related sectors, for example, subsiding infrastructure. Green industrial policy can also work indirectly by affecting the demand

conditions of green products, for example, through public procurement that creates market space for the green regime as an “infant industry”.

However, green technological development and the selection process is embedded in the complex interactions within the changing sectoral system, and affected by technological and various non-technological factors. The interaction between green industrial policy and directionality of innovation is not uni-directional and should not be over-simplified. From the perspective of SSIP as an open system, this chapter focuses specifically on the diverse technology-market-product matrix, where different combinations of technological solutions and market segmentations in face of technological multiplicity make the actual working of green industrial policy not a straightforward, mechanical but an evolutionary process and in a fashion of complex adaptive system (Hall & Clark, 2010; Inigo & Albareda, 2016). Because of the multiplicity of technology-market-product matrix, even the same policy instrument does not work out evenly across the matrix. Some change the cost structure of green technologies, while others tend to reinforce path-dependence in the existing polluting regime. A simple example is that in emerging economies there are a huge group of price-sensitive consumers that are willing to pay for affordable cost innovations and more reactive to the similar amount of subsidies, compared to those prefer sophisticated and luxury products. Therefore, the effectuation of green industrial policy is only possible when taking the interactions and feedback in the sectoral system into consideration. The analytical framework for this chapter is thus framed as follows (Figure 5-2):

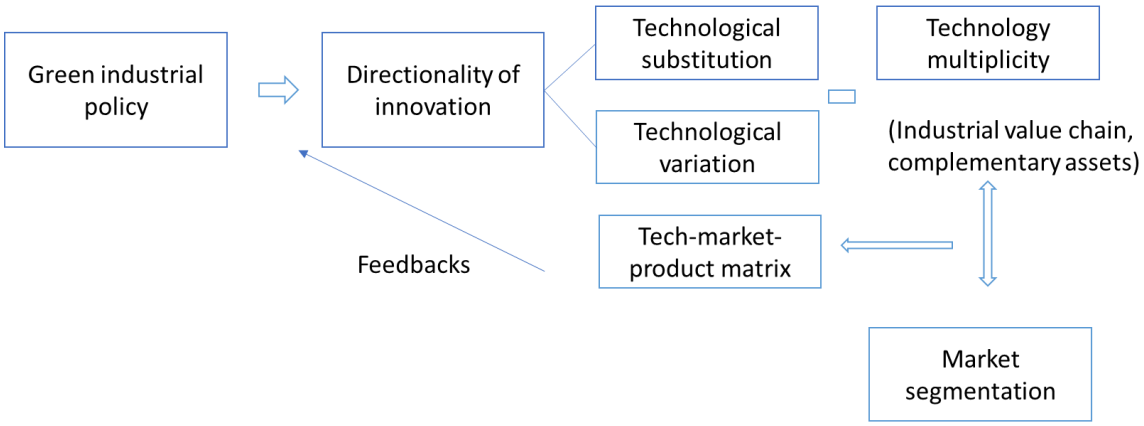


Figure 5-2 Analytical framework of this chapter[16]

5.3 Method

This chapter conducts a case study on China's early transition to electric mobility in the automotive industry. A case study research design is ideal for addressing questions of "how" as in this paper, which focuses on the processes and interactions and takes an evolutionary perspective to industrial policy and sectoral change (Eisenhardt, 1991; Robert K. Yin, 2013). The analysis is at the sectoral level. As methodological design is elaborated in Chapter 4, this section does not go to details but revisit the major points here.

The chapter follows the four-stage division of the sectoral change process from early 1990s to 2020 laid out in methodology part (Chapter 4). It is useful to revisit it here in the figure below (Figure 5-3), but this section does not repeat the description here.

[16] Author's elaboration.

	Phase one (1990s-2008)	Phase two (2009-2012)	Phase three (2013-2015)	Phase four (2015-2020)
Policy dimension	National ST&I policy support	The establishment of "pure electric drive" and private subsidy scheme	Adjustment to industrial policy and consolidation of the "pure electric drive" strategy	Comprehensive industrial policy, phase-out mechanism of private subsidy scheme, and return to technological multiplicity
EV regime dimension	Technological exploration with multiplicity of trajectories and solutions	Small-scale demonstration and deployment of EVs in pilot cities	Expanded, yet still experimental deployment and diffusion of EVs.	Large-scale deployment and diffusion of EVs.

Figure 5-3 The four phases in China's electric mobility transition (1990s – 2020)[17]

Each stage features certain composition in green industrial policy that interacts with the technological and market regime in the changing sectoral system. Content analysis (Hsieh & Shannon, 2005; White & Marsh, 2006) is used to understand the implication of different policies (at multiple levels), glean out major events and changes, and identify the initial linkages between various building blocks in the sectoral system. Process-tracing is applied to further develop, verify and consolidate the causal mechanisms (Bennett, 2010). Through the inductive case study analysis situated in the overall framework SSIP (as an open system), the chapter unpacks the interaction between green industrial policy and other building blocks along the industrial value chain of the focal sector under green transformation and systemise the causal mechanisms by elucidating on the feedback in the sectoral system.

[17] Author's elaboration.

5.4 Longitudinal case analysis

5.4.1 1990s-2008: ST&I policies and early technological exploration

Governmental support for technological exploration in the form of small R&D programs at a very early stage. Since the late 1980s, China sporadically explored a full range of green technologies in the automotive industry in patchworks. With the motivation to reduce green-house gas (GHG) emission, these explorations were funded by MOST and conducted jointly by universities and the industry. For example, Tsinghua University, Southern China University of Technology, together with GM and Toyota, developed several BEV prototypes that were demonstrated in Guangdong Province. In the beginning of 21st century, the urgency to relieve air pollution led to the "Clean Car Action", which involved S&T policy support for a variety of alternative energy vehicles at the national level[18]. Within this action, the deployment of Liquefied natural gas (LNG) vehicles as commercial vehicles and taxis achieved moderate success in limited market space.

It was in the process of "Clean Car Action" that EV received growing attention and was later supported independently and disproportionately by MOST within the framework of the 863 Major Project throughout the 10th and 11th five-year plans. One important reason underlying this change was that China's policy makers believed EV would be the future direction of automobile industry and intended to seize this opportunity to narrow the technological gap with global industrial forerunners. According to one insider: *"While undertaking the 'clean car', we targeted the pollution produced by car, and also considered energy security. At that time, we actually began to do EV, but used a very, very small amount of money to start an EV*

[18]"Opinions on implementing 'Air purification project – Clean Car Action'", issued by 14 ministries led by MOST, Sept. 1999.

project…but until the 863, an idea was born, that was to improve the technological development in China's automobile industry through EV." (Interview P1-01)

In the 863 EV Major Project, the exploration of EV technologies exhibited the layout of *"Three verticals, three horizontals"* [19] (Figure 5-4), which was put forward by Mr. Gang Wan, then the minister of MOST. R&D projects engaged multiple trajectories spanning from incremental solutions such as HEV as well as radical ones such as BEV and FCEV that did not rely on fossil fuel. At the same time, technological developments were also funded in fields of general component technologies, including power batteries, electric motor and powertrain and electric control systems.

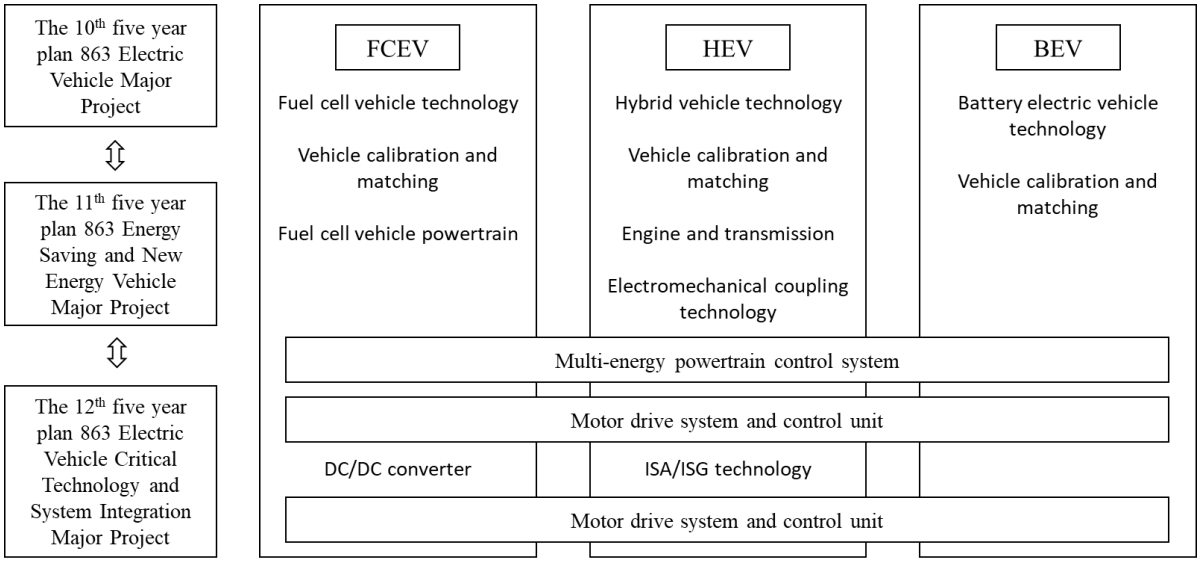


Figure 5-4 "Three verticals, three horizontals" R&D layout in EV technologies, 863 Major Projects[20]

The 863 Major Project spent around 20 billion RMB funding technological exploration and initial development of EV product prototypes. The massive R&D programs were primarily led by universities in cooperation with OEMs and component suppliers. These programs further

[19] Specifically, 'three verticals' refers to the three technological trajectories, and 'three horizontals' refers to basic technological domains in EV, i.e., battery and battery management system, electric motor and control system and multi-energy powertrain control system. In the meantime, technological standards, infrastructure and policy and regulations were also highlighted as 'three platforms' complementary to technological efforts.
[20] Adapted from figures in Energy Saving and New Energy Vehicle Yearbook 2017.

leveraged knowledge and technological capabilities from partnerships with global OEMs and component suppliers, which were also keen in developing EV technologies. Although this was insufficient for incentivising considerable firm-level R&D efforts, these programs created the avenue for initial partnerships and inter-organisational networks and nurtured technological and engineering know-how for subsequent technology development.

Among the various R&D projects cooperated by universities and the industry, major emphasis was actually put on HEV that among all the technological solutions were most technologically and commercially mature compared to other solutions and did not rely on charging infrastructure. Besides, at that time, the then state-of-the-art battery technology was lead-acid battery and Nickel–metal hydride (NiMH) battery. The latter was too heavy and had low power density and hence uneconomic and unfeasible for BEVs. It did not come as a surprise that many domestic OEMs undertaking 863 Major Projects focused on HEV and its sub-systems, which was also envisaged as the strategic direction for themselves. By contrast, BEV and other battery-based technologies only received minor attention and support due to technological immaturity and high costs.

5.4.2 2009-2012: the establishment of "pure electric drive strategy" and technology-specific subsides

The outcome of the two-stage 863 EV Major Project was partly reflected in the successful demonstration of over 500 EVs at the 2008 Beijing Olympics, mainly hybrid electric buses and sedans and some BEV buses. The Chinese government intended to facilitate the industrialisation and commercialisation of EVs in the coming years and listed electric mobility as one of the seven "strategic emerging industries" in 2010. In 2009, a demonstration scheme

named “Ten Cities, Thousand Vehicles”[21] was initiated in the public transportation sphere, which offered financial subsidies to electric buses (including HEVs). Very soon in the next year, the central government also started to subsidise the deployment of EVs in the consumer market, by launching the EV private purchase subsidy scheme in 2010 in six pilot cities[22]. The subsidies were intended to cover the cost of power batteries - the core component in the EV regime which took up around 50% of the total cost of a BEV. The four ministries, namely MOST, MOT, MIIT and NDRC, jointly implemented and monitored this pilot scheme.

When it came to financial subsidies on products, a critical question emerged regarding which technological trajectory (trajectories) it should target. This inevitably turned state support for electric mobility transition into industrial policy. In effect, the controversy over which technological solutions were to follow had existed for a long time, both in China and worldwide. While the subsidy scheme was still in fermentation in 2009, the majority of indigenous OEMs were prepared to commercialise their HEV models. They formed an alliance called T10, meaning top 10 OEMs in China which represented over 80% of domestic market share, to proactively lobby central government policy makers for subsidies on HEVs. Indeed, industrial strategy before 2009 framed it as “electrification of the automobile power system” signalled technological multiplicity as a continuation of the basic layout of 863 Major Project.

However, high-ranking officials in MOST and prestigious technological professionals with background in the automobile industry strongly insisted that China could only achieve the green leapfrogging by focusing on battery-based technologies, as the technological gap in ICEs was too large to overcome. And one practical consideration was that if subsidy was to hand out

[21] The program was launched with a goal for 10 cities to add 1,000 NEVs annually over 3 years. It quickly expanded to incorporate 25 cities. However, the majority of cities did not achieve their respective goals.
[22] Initially the central government selected five pilot cities based on their automobile industrial basis and demonstration outcome of EVs. These pilot cities are Shanghai, Changchun, Shenzhen, Hangzhou, Hefei. However, Beijing city government lobbied strongly and entered the pilot program as well, making the total of pilot cities being six when the scheme was implemented.

to HEV models, then none of the domestic OEMs would be competitive given that Toyota was ready to enter Chinese market with its highly competitive and mature HEV models (e.g., Pruis). *"Toyota had several HEV models ready to have scale production in China. But our country must have such consideration, that our money is limited, and we want to improve our own technologies. We do not say it, but everyone knows it. Subsidy on PHEV actually promoted hybrid technology development."* (Interview P1-02)

The technological catch-up and leapfrogging argument resonated with the mindset of top leaders in the State Council and leadership of CCP. As a result, the debate on technological trajectory was temporarily settled in 2012, when a seminal policy document was published, i.e., *Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020)*. In this national level policy document, the electric mobility transition was formulated as "new energy vehicles" and established the "pure electric drive" technological strategy. It stipulated that only EV models following this strategy could receive private purchase subsidy in a large amount. Instead, HEV was classified as "energy saving vehicles" and only received a minor amount of money (3,000 RMB for each model). The subsidy for HEVs was eventually cancelled after 2012. This underlying rationale was articulated by a policy consultant:

> "*Looking at global technology development, it was impossible for us to overcome hybrid technologies. In hybrid technologies, the gap between us and Japan and Germany was rather large. Even we did it on big vehicles (buses), moving from big vehicles to small vehicles (passenger cars) was very difficult. Besides, it was still energy saving and fuel economy, and it still did not get rid of petrol, right? So, it was the idea of the entire policy-making level that we should go for BEV in only one step*." (Interview P1-03)

The consequence of such technology-specific industrial policy was fundamental. For HEV technological trajectory, a 3000-RMB subsidy for a single purchase, which was presumably

able to cover the mere additional cost in batteries, could hardly make HEV product cost competitive compared to mature ICEVs, let alone best-selling HEV models produced by global forerunners, especially Toyota Prius. By contrast, selling one passenger BEV or PHEV meant a total subsidy of up to 120,000 RMB, which was nearly half of the entire product market price. Seeing little cost competitiveness in HEVs, R&D projects in this technological trajectory were almost suspended by the majority of incumbent domestic OEMs. They in turn switched to develop and commercialise BEVs which were simpler in technology, shorter in product development cycle time, as well as generated considerable revenue from government subsidies. As a result, despite early technological accumulation and commercialisation preparations for HEVs, most indigenous OEMs modified their corporate strategies by incorporating BEVs and/or PHEVs as future direction for green transformation in order to qualify the subsidy criterion (Table 5-1). Interviewees from several OEMs explained how their strategies were affected:

> "*We had considerable achievements in hybrid vehicle technologies in 2005. In 2005 and 2006, our HEV models were close to commercialisation. Later, because the direction of state policy changed, then we started to do BEVs in 2012 and 2013*." (Interview B4-01)

> *"Until 2014, our major line is still hybrid vehicles, and until we realised that the government no longer subsidised it, we had to quit on this."* (Interview B1-01)

> *"When it (subsidy scheme) was figured out, the policy was already there, what should you do? Do you want the subsidy or not? If you do, then more subsidy or less do you want? It was only subsidy in the beginning, (firms) followed its baton. Later they required on the power density, electric drive range, after fulfilling this you can*

receive certain amount of money. Then people further followed the baton." (Interview B1-03)

Table 5-1 Best-selling passenger EV models by the end of 2012[23]

EV model	Vehicle type	OEM	Cumulative sales by 2012
QQ3	BEV	Cherry	3129
Tongyue	BEV	JAC	2485
e6	BEV	BYD	1690
F3DM	PHEV	BYD	1201
E150	BEV	BAIC	644
Saibao	BEV	Hafei	281
Rowe E50	BEV	SAIC	238
Ruiqi M1	BEV	Cherry	152
SPRINGO	BEV	SAIC-GM	14

5.4.3 2013-2015: Political realignment and enhanced industrial policy for the "pure electric drive" strategy

(1) Political realignment, institutional change and articulation of technology strategy

Compared to the deployment goal set in the Energy *Saving and New Energy Vehicle Industry Development Plan (2012-2020)*, the first round of demonstration and deployment (2010-2012) proved a failure with only 10% of the target met. The majority of domestic automakers became quite suspicious about the prospect of EVs and at a time, R&D and production activities on EV in the sector almost came to a stop. Because the central government had invested so many resources, and that the sectoral transition was eminent, China's political authority found it necessary to align political support for the transition and to keep the momentum. Vice Premier Kai Ma, Premier Keqiang Li and later President Jinping Xi successively paid factory tours to OEMs including BYD, Chery and SAIC before 2014.[24] Closely following these factory tours, the four ministries responsible for private purchase subsidy scheme announced that central

[23] Blue book of China's NEV industry 2012, CSSAP; CAAM. Note: Chery used lead-acid battery for its BEVs.
[24] http://www.xinhuanet.com/politics/2014-05/24/c_1110843312.htm

government would carry out the second phase of subsidy scheme continuously during 2015 and 2020. This was formally reaffirmed in the *Notice on Continuing the Promotion and Application of New Energy Automobiles* in 2013, with an unchanged emphasis on the "pure electric drive" strategy. The political commitment for the highest level of Chinese authority reassured both OEMs and component suppliers of the prospect of prolonged sectoral transition toward electric mobility. With these articulations of state support from the highest level of political authorities, political uncertainty in the sector was greatly reduced. This strongly shaped expectations of firms both within and outside of the automobile industry.

> *"The input from policy is not just about money. The mere articulation of clear policy support means confidence for us."* (Interview B12-01)

> *"Initially we thought the factory tours by Kai Ma would end up with nothing and each ministry making their own voice. But it turned out that he and Miao Wei[25] were serious about that, and the State Council issued policy document…Policy has a pulling effect. Although we will develop EVs whether there is policy support, but it is not good for us to 'sing alone' without response. Now it makes us more confident to move forward."* (Interview B3-03)

The lesson from earlier subsidy scheme (2010-2012) was that only subsidy on the end product was not sufficient to kick start spontaneous private consumption without availability of and cost reduction in complementary assets. Since the second phase and afterwards, central government put more emphasis on the construction and roll-out of battery charging/swapping infrastructure to accelerate the pace of EV diffusion[26].

[25] 苗圩（1955.05.20 -）, Minister of MIIT during the time of interview.

[26] Guidance on accelerating the deployment and of new energy vehicles, issued by the State Council, China central government, July.2014.

To achieve this, political realignment was realised to better build cross-sector complementary assets which spanned different policy jurisdictions. In 2013, an inter-ministerial coordination mechanism consisting of thirteen central government ministries was established, which included additional ministries responsible for transportation governance, energy sector, urban and land planning, etc., apart from the initial four ministries involved in the private purchase subsidy scheme. This inter-ministerial coordination mechanism, as an important step of institutional change in the governance framework, required that all the departmental leaders responsible for electric mobility met once a year to specific ally discuss problems encountered, the solutions to them, and the action points for each department in charge.

(2) Consolidated and expanded regulatory and policy portfolio: enacting on the industrial value chain

Following the political articulation and alignment revolving continuous support for sectoral change under the "pure electric drive" strategy, policy measures were consolidated, refined and expanded, mainly aimed to solve the problem of the chicken-egg problem with complementary assets upstream and downstream the industrial value chain. In the focal sector, the private subsidy scheme continued while the subsidy measures were refined to reduce the "subsidy fraud" behaviours among OEMs. Two important criteria were introduced. First, the number of subsidies one vehicle sales received should be evaluated based on the electric drive range of the vehicle, and this was tightly related to power density of batteries. The longer the drive range was, the more one EV model would be subsidised. The intention was apparently to push for technological developments in the supply chain. Second, a phase-out mechanism was introduced, which stipulated that the amount of money on subsidy was to reduce on a yearly basis until it would eventually exit in around 2020. The rationale was to gradually shift market protection for EV regime towards market-based competition.

At the same time, to solve the problem with under-developed power battery technologies and the supply chain, a very important R&D program sponsored by the national government was carried out. The program was called New Energy Vehicle Technology Innovation Project and was mainly supported by MIIT, MOST and MOF, with the objective of developing high density power batteries that enabled long enough drive range for EV models to be accepted by customers. Different from the earlier 863 Major Project that facilitated technological exploration, this project had the mandate that OEMs and battery supply firms undertaking the R&D project should have applied the developed technologies and had enhanced EV models delivered in the market upon completion of the project. A total of 25 firms, including OEMs and battery supply firms closely working with each other, participated and about half of them eventually met the requirements[27]. The major technological breakthroughs from patchwork and prototype towards industrialisation and commercialisation were attributed to this often-under-rated R&D program. "…*And then (2012,2013) internally we had a team on BEV, and by working with the national Innovation Project, 300 million RMB, we gradually gained momentum in BEV, and had EDO BEV model, from 160km, 180km to 300 km*." (Interview B1-01)

Switching to downstream complementary assets, financial incentives were also rolled out to support the building and operation of charging infrastructure. In 2015, the government started to subsidise power battery charging/swapping facilities. Different from directly giving money to all the rollout of charging/swapping facilities, this incentive was offered as an award to localities whether the deployment rate of NEVs was relatively high and local government had concrete action plan and implementation measures to scale up charging/swapping facilities[28]. Moreover, to qualify for this financial award, local governments were required to remove entry

[27] Those firms that failed to fulfil the objective returned the money to the government.
[28] Notice on award for construction of new energy vehicle charging facilities, issued by the Four Ministries, Nov.2014

barriers erected towards non-local firms if they wanted to be qualified for this financial award. Based on EV's deployment statistics in 2013 and 2014, some cities were awarded up to 100-million-yuan, which was in turn spent on more infrastructure.

Policy instruments were issued and implemented by other ministries in the central government that aimed to overcome non-financial barriers to deployment of EVs. Specifically, NEB and MOHBURD required in new urban planning standards that newly built residential communities must incorporate charging points into its planning and construction. Administration of Quality Supervision (AQS) and National Standards Committee (NSC), together with NEB, MIIT and MOST, initiated amendment of the national standards of electric vehicle charging interfaces and communication protocol by negotiating with and consulting OEMs and utility companies. This helped solve the incompatibility between EVs and charging facilities in the earliest subsidy scheme when much infrastructure was left unused and useless afterwards.

Vehicle ownership and usage costs were further driven down by policy measures targeting the upstream energy sector. To reduce electricity price for EV usage, NDRC issued *Notice on Issues Concerning Electric Vehicle Electricity Price* in 2015, according to which industrial electricity price applied to battery charging and swapping for business, while residence electricity price applied to households. For the power grid transformation cost was calculated into power transmission and distribution prices for grid firms. These measures combined to standardise and drive down the cost of supply and usage of charging infrastructure. It additionally standardised the way that cost of using battery charging facilities was calculated and hence provided a universal pricing reference to infrastructure operators.

With these concerted measures implemented and continuous increase in EV sales, the number of available public charging ports increased significantly after 2015 (Figure 5-5).

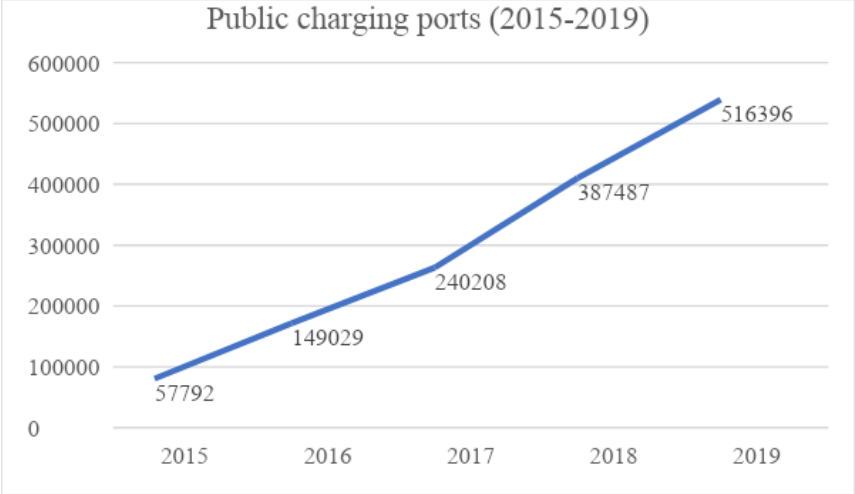


Figure 5-5 Number of public charging ports in China during 2015-2019[29]

The local government in several large cities implemented demand creation policies that limited market access to ICEVs and directed it to EVs. In particular, responding to traffic congestion and air pollution with surging personal vehicle ownership, Beijing had very strict ICEV licence plate measures that rendered the probability of getting such a licence plate very small each year. However, if consumers wanted to buy an EV instead, there was no licence plate access restriction instead, nor did they need to que for several years to get one. Similar measures were taken in Shanghai and Shenzhen, where the diffusion and market penetration of EVs also benefited greatly from locally based demand creation policies. According to a survey conducted by China-US New Energy Vehicle Policy Lab in 2016, if subsidies were eliminated, around 60% of respondents would give up buying EVs. In terms of favourable demand creation regulations that reduced the invisible cost of vehicles, if there were not separate licence plate policy for EVs, over 70% of respondents would not consider EVs, and 25% respondents in Shanghai and 10% respondents in Beijing would delay purchasing EVs. [30] Ownership cost of EV was additionally reduced by environmental and transportation policies that postulated that EV was exempt from purchasing tax and vehicle and vessel tax as well.

[29] Blue book of China's NEV industry 2012, CSSAP.
[30] Blue book of China's NEV industry 2017, CSSAP.

(3) Rent creation, state R&D program and localisation: the rise of power battery sector

Private purchase subsidy scheme was helpful in significantly reducing the cost of EVs and hence improving the cost-efficiency of green products relative to ICE-based products. According to the subsidy specification, OEMs were offered a combination of subsidies from both the central and local government for EV sales in the consumer market. In the sector's nascence, the power battery as the core component of EVs represented nearly 2/1-1/3 of the total product cost. Taking several levels of government subsidies together, an EV manufacturer could receive a maximum total of 120,000 RMB, and in some cities 140,000 RMB. This amount was calculated based on projection of EV cost and potential cost reduction in case of technological advancements. Such amount of money significantly changed the cost structure for EVs.

Despite the subsidy phased out on a yearly basis, the private subsidy scheme continuously worked to reduce the cost of EVs. Throughout the decade (2010-2020), a total of 120.6 billion RMB from government was paid to qualified EV manufacturers[31]. Taking BYD as an example, although it was well-known for being a competent indigenous OEM in China, the majority of its net revenue was attributed to the subsidy scheme, without which the company could hardly have sustained its EV business and even survival over the decade. Now it enjoys the highest EV sales volume in China's domestic market and is also very successful in the electric bus market segment worldwide.

The policy rent from the private subsidy scheme were transmitted to upstream technologies through the industrial value chain. Starting from 2015, large-scale deployment of EVs

[31] While no official statistics on total subsidy amount was released, an independent think-tank calculated this result based on subsidy scheme, product lists and EV sales data. See: https://xueqiu.com/2571631511/159769378

expanded to the whole country, and private purchase subsidy scheme added important technological parameters, especially vehicle electric drive range and battery power density[32], into qualifying criteria with the intention to boost technological progress in the upstream sector. To be qualified for the highest amounts of subsidy, OEMs tried to source power batteries that had the most power density on the premise that they did not add too much weight or had safety concerns. A majority proportion of government subsidies received by OEMs hence went to competent power battery suppliers, which worked hard to meet the technological criterion assigned by their downstream customers. "*In the beginning, there was hardly technological development in vehicles and batteries. However, (with the subsidy) it required a certain electric drive range, and safety. This represented a kind of 'market demand' on its own. Battery firms had to work hard to mee the requirements from OEMs. Without such 'demand', there would be no technological progress*." (Interview P1-04)

Due to the annually rising technological requirement on battery power density, battery firms' technological and product development efforts were concentrated on battery cells, a major sub-component that primarily defined power density and hence EV drive range. In technological terms, battery power density largely depended on specific types of cathode material used, and some materials enabled higher power density than others in their chemical nature. When MOST encouraged technological exploration in power batteries via the 863 Major Project, limited technological progress in the battery industry worldwide rendered BEV rarely a viable commercial option. A solution put forward by BYD, an early mover in EV manufacturing in China, was LiFePO4 battery, which was low-cost, safe but enabled limited drive range. This solution was temporarily adopted by several domestic EV manufacturers while better

[32] <Notice on financial support policy for deployment and diffusion of new energy vehicles during 2016-2020>, April.2015, issued by the Four Ministries.

alternatives remained to be found. Several other EV manufacturers such as Chery and JAC also adopted the Iron-based battery solution to commercialise their short-range small BEVs.

However, in the middle of the 2010s, there were major breakthroughs in battery technologies pioneered by Japanese and Korean firms. They were at the frontier of material science and were able to produce high power density batteries that enabled several hundred kilometres' EV drive range. Different from BYD's solution mainly based on Iron, their batteries were built on a combination of NCM[33], a solution mainly based on Lithium, that worked to maximise power density on the premise that the products were safe to use in cars. Seeing the promising technological developments in the global frontier, Chinese government intended to strengthen the technological and production capabilities in the domestic power battery industry along this direction. They pondered that this would reverse the condition in previous ICEV regime where China had a weak supply base in the automobile industry despite several decades technological learning from global OEMs. It was out of the motivation to make NCM-battery-based BEVs commercially viable and competitive that the central government launched a new R&D program, New Energy Automobile Industry Technology Innovation Project. "*At the time of the Innovation Project, battery in China used was still mainly LiFePO.4. NCM had not grown up yet. But its power density was higher, it was more advanced. Therefore, we decided that we must move on to NCM, and in the Innovation Project, we specifically require NCM. The country wants to facilitate technological improvements*." (Interview P1-05)

Despite that some projects did not deliver in the end and had to return money to funders, successful projects were indeed seen in the EV consumer market after 2015. More importantly, this contributed to the critical rise of a leading battery supply firm in China, CATL, which acquired the technological and production capabilities in NCM solutions after working with

[33] N refers to Nickel, C refers to Cobalt, and M refers to Manganese.

several downstream customers with R&D expenses supported by the central government. One important technological professional who once worked closely with CATL at the strategic and technological level recalled:

> "*Back to 2004, I advised ATL*[34] *to start power battery and energy-storage battery projects. This project won awards in Guangdong province. CATL was only established in 2011, and its early technology can be traced back to the projects with ATL. In 2012, we helped CATL to obtain an R&D project of over 1,00 million RMB from MIIT to work on power battery. In the beginning, many people were quite sceptical. When the project concluded in 2015, they eventually accomplished the objective*."[35] (Interview T1-01)

Technological improvements in power battery were a continuous process and extended beyond 2015. Over the years, NCM battery configuration had evolved from 5:3:2 to 6:2:2 to 8:1:1[36], with a very high level of Nickel, a major chemical contributing to power density contained in batteries working effectively with other chemicals in NCM batteries. With the continuous commercialization of EVs in the market and technological efforts among major battery supply firms to meet their customers' requirements, battery power density rose dramatically in five years' time and the unit costs of power batteries decreased sharply, reaching a 240Wh/kg level in 2018, an 150% increase compared to 2012 [37] (Figure 5-6). Leading battery supply firms were able to develop battery cells that have power density beyond what subsidy policy stipulated. As a result, the electric drive range of BEVs extended to a large extent. By June 2018, average BEV electric drive range increased from 160km in 2014 to 320km in 2018. This enabled the industry to fulfil two years in advance the 300km target put forward in *Energy Saving and New*

[34] ATL was the predecessor of CATL.
[35] This is not to say that CATL's progress in power battery is only attributed to the R&D project. Actually, many other factors were also important, for example, CATL's cooperation with downstream customers on sourcing power batteries. However, the role of the R&D project is still valid.
[36] The ratio refers to the composition of the three elements, N, C, M in the battery cell. For example, 8:1:1 means that among the three elements 80% was Nickel.
[37] Evaluation on the progress of implementing Technological Roadmap for Energy Saving and New Energy Vehicles, 2018, published jointly by SAE-China and Toyota in 2018.

Energy Vehicle Technology Roadmap (2016). As the "heart" of a BEV, power batteries saw a significant increase in power density.

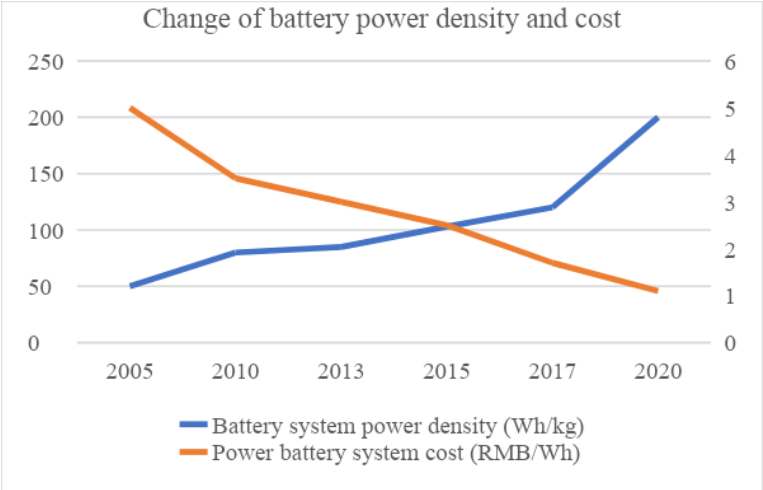


Figure 5-6 Change of battery power density and cost over time[38]

Therefore, the simultaneous developments discussed in this section (5.4.3) from (1) to (3) tell a story of iterative positive feedback along the entire industrial value chain, accompanied by the expansion of the value chain itself. A policy consultant summarised the picture very concisely with regard to the role of government:

> "*So, the role of government is well reflected in China. Without the efforts by multiple levels of government, it is impossible that EV industry grew up so quickly. Consumers first need to accept the product, right? Second, the cost should go down. The kick-start of these things is very difficult. This is why technologies in the U.S. and Europe are not problem, but it is challenging for them to go to the market. Consumers need to be satisfied and then motivate firms to do it. Firms see the volume and then are willing to do it. Once they do it, they compete with each other, and are better and better, and*

[38] Data source: China's Association of Power Sources. See: http://www.ciaps.org.cn/info_list.php?letter=d&mid=21

quality is improved. Now the cost of battery has already went down to less than 1 RMB, around 0.6 RMB." (Interview P1-06）

5.4.4 2015-2020: Industrial policy renewal and the return to technological multiplicity

Despite the continuous growth of EV sales over the decade, the nascence of the sector meant that technological substitution still had a long way to go and the sectoral transition would be prolonged. The mere electrification of the powertrain system of the vehicles did not solve the incentive problem because on one hand, cost was raised and function was limited, and on the other hand, the technological change did not offer added value. In the process to make EV products as attractive as possible, business firms worked hard to integrate emerging technologies from adjacent sectors, especially connectivity and autonomous driving from IT and ICT industries to offer cutting-edge functions and services. These technologies were thought of as "disruptive" because they could genuinely fulfil potential needs and create additional economic value (Christensen et al., 2013).

Since 2016, more and more EV manufacturers formulated their corporate technological strategy integrating these technological innovations and related changes in business models, terming it as "CASE", which refers to connected, autonomous, ridesharing and electrification. They actively cooperated with IT and ICT corporations to develop service-oriented product functions which were delivered as an inherent and value-adding part of EV models, such as infotainment, social media, moderated human-vehicle interaction, etc. For instance, SAIC, the local SOE in Shanghai City which had long worked with GM and VW, launched its "New CASE" corporate technology strategy in 2016. This was immediately implemented by a strategic collaboration with Alibaba in developing Zebra IOS dedicated to EV electric control systems.

Industrial practitioners in the automotive industry, who already engaged with digital technologies and automobile electronics for some time, resonated with this because the electrified powertrain had the advantage of being more compatible with electronical configuration compared to mechanical configuration of ICE. *"Autonomous driving and connectivity naturally favour 'pure electric drive' cars… EV is the best carrier of these technologies because the responsiveness of traditional mechanical structure of ICEVs cannot keep up with the information processing and data analytics speed required by smart, connected cars."* (Interview B5-01)

Because the advancement of ICTs and the fourth-industrial revolution (4IR) technologies was already another important area of emerging technologies and state ST&I policy support, once the industrial convergence between the automobile and ICTs was seen and turned out promising, the green industrial policy institutionalised this convergence in the renewal of industrial strategy. This was early hinted in *Made in China 2025*, where both "energy saving and new energy vehicles" and smart, connected cars were mentioned. The two trends then co-occurred first in 2017 *Automotive Industry Mid-and-Long Term Development Plan* and then eventually formally formulated as part of industrial strategy as articulated in 2020 *New Energy Vehicle Industry Development Plan (2021-2035),* where connectivity and autonomous driving was emphasised as an inherent element of EV industrial strategy. Recall that in the 863 Major Project the "three horizontals" only talked about the different technological trajectories in the EV regime (Figure 5.1). This was modified in the aforementioned 2020 policy document into including another "three horizontals", namely power battery and management system, electric motor and vehicle electronics and connectivity and intelligent technologies (Figure 5-7).

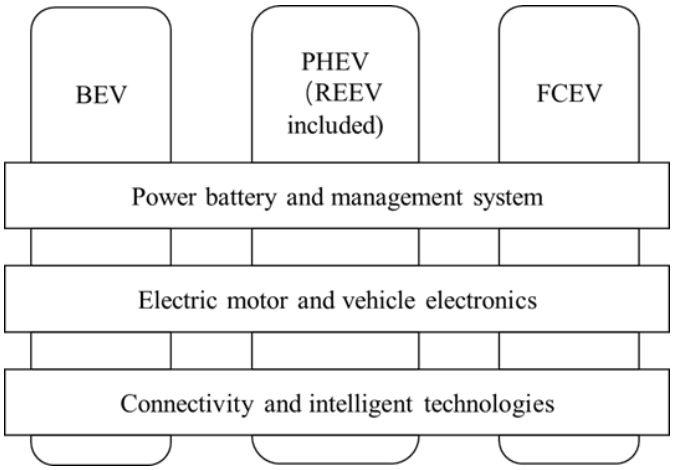


Figure 5-7 The new "Three verticals and three horizontals" in the 2020 NEV industrial strategy[39]

5.5 The dark side of state intervention into technological variation

5.5.1 Capability gap in the formative phase of green transformation

(1) Technological capability gap in BEV trajectory

Although technological progress in the upstream power battery sector was achieved which helped drive down EV cost, the technological capability in the formative phase of the EV sector was still limited. The fact that BEVs no longer relied on highly complex ICEs did not mean that product integration capabilities became unimportant; by contrast, such capabilities were still consequential because it affected the overall product quality and function. Without sufficient technological capability accumulation, it was impossible to realise "corner overtaking" in a short time window starting from a weak basis.

This was exacerbated by the fast-rising technological criterion on EV drive range and battery power density. For OEMs, in order to get qualified for the subsidy scheme under such circumstances, they were incentivised to manufacture EVs that could maximise subsidies for

[39] Author's elaboration based on the policy document.

each EV model. However, because subsidy criteria were dynamically modified on a yearly basis, while new product development cycle time in the automotive industry usually ranged at least 3-4 years, it was almost impossible to deliver matured and high-quality EV products to the consumer market in a short time. They were otherwise inclined to manufacture quick-to-market EVs so as to capture as much subsidy as possible in a volatile environment. This meant that technological efforts in EV product development were inevitably compromised, going hardly further than meeting technological criterion prescribed by the subsidy scheme. A common strategy was to design and manufacture EVs based on adaptation of existing ICEVs models. Innovative efforts on product architecture only involved minor modification to vehicle chassis in order to accommodate the new powertrain. This led to some opportunistic behaviours among EV manufacturers and as a response, the government raised stringency on rent management. Of course, there were factors that discouraged effective commercialisation of new products at a very early stage, such as lack of complementary assets and economy of scale from the supply side and lack of market acceptance in the demand side. However, directed industrial policy towards a radical innovation path, oriented to compressed catch-up and assisted with heavy subsidies, created rents for some OEMs that distorted incentive for product innovation.

Technological progress in the upstream sector saw performance overshooting but was confined to the lower levels of the product hierarchy. Quickly responding to rising technological and product parameters from downstream customers meant that power battery suppliers concentrated their technological efforts in the subunits of the core component, which required least of sub-system integration capabilities. As a result, though power density at battery cell's level among top Chinese battery suppliers was close to that of global forerunners, it was far from comparable in terms of power density at battery module level and battery system level. Moreover, in the process of fast turn-out, a disproportionate attention to raising power density

led to insufficient technological efforts in ensuring battery safety. The partial performance overshooting in subcomponents otherwise led to "reverse salient" (Hughes, 1987) problems for new products. One weakness in an important product function parameter rendered the product as an integral one less attractive to customers.

Hence the technology-specific green industrial policy featuring subsidy support for technological trajectories less commercially mature partly resulted in capability gaps in the desired trajectory. On one hand, downstream OEMs, incentivised by huge amounts of policy rents but constrained by technological capabilities, mostly undertook very moderate product innovation. On the other hand, upstream firms achieved technological overshooting but more at the sub-component level than component level, in order to adapt to compelling downstream demands, lacked accumulation of integration capabilities that were necessary for long-term capability building and product quality.

(2) Technological capability gap in untargeted directions

Under the "pure electric drive" technological strategy and corresponding technology-specific private subsidy scheme, HEV was not supported. The consequence was that the sector lacked capability accumulation in hybrid electric vehicle powertrain, which shared a lot of commonalities with different powertrain configurations as long as any certain combination of electric motor and ICE was involved. This in turn limited the technological development of the product subsystem in PHEV technological trajectory. Especially, electromechanical coupling system technology constitutes the core powertrain technology that connected the core components from ICEV and EV regime respectively and was vital to integrated product function and performance. Due to the high technological barrier in this trajectory, while all indigenous OEMs designed and produced BEVs, there were only a limited number of OEMs that had successfully commercialised their own PHEVs. SAIC and BYD are the two OEMs among them with outstanding performance in the domestic market. This originated from early

experimentation and benefited from continuous technological accumulation over the years with demand creation support from local governments. For other car manufacturers, due to lower subsidies compared to BEVs and lack of technological capability accumulation, the incentive to develop in-house PHEV technologies was very low.

5.5.2 Negative market feedback and potential risks of technological lock-in

(1) Limited market acceptance of green products

Capability gap in the sector's nascence limited the market performance of EV products. In the BEV technological trajectory, due to moderate innovative efforts at both product and sub-system levels among EV manufacturers, manufacturers' attention was drawn to how best to be qualified for the subsidy scheme, hence customer needs were less considered in the new product development process. The mere replacement of the powertrain made BEV's quality and performance compromised[40].

Switching to vertically related sectors, technological overshooting in specific parameters in core components did not necessarily result in absolutely better performance in end products. The fast adoption of a high-power-density solution meant that more Nickel was used in a battery cell's chemical components which was unstable in chemical nature. As a result, battery safety became an issue for BEVs with long electric drive range. For an instance, from January 2018 to April 2019, at least 30 vehicle fire incidents happened because of battery safety related problems (Table 5-2), including circuit failure, short circuit resulting from design flaws, on fire while charging, etc[41].

[40] Shere adaptation of vehicle chassis caused imbalance to vehicle weight distribution, and hence reduction to vehicle drive range but increase in energy consumption. Moreover, power batteries were liable to be exposed to the outside, posing a threat to battery and vehicle safety.

[41] Blue book of China's NEV industry 2019, CSSAP.

Table 5-2 Fire/Smoke incidents related to power battery from Feb. to June 2019[42]

Time	Location	Battery type	Fire incident source
2019.02	Shenzhen	Unknown	Self-ignition while driving
2019.03	Shanghai	NCM18650	On fire while charging
2019.03	Guangzhou	NCM18650	Self-ignition
2019.04	Hangzhou	NCM	On fire while charging
2019.04	Shanghai	NCM18650	Self-ignition while in parking state
2019.04	Xi'An	NCM	Battery short circuit due to battery being hit
2019.04	Hangzhou	NCM	Unknown reasons
2019.04	Hubei Province	LiFePO4	Trunk on fire, battery intact
2019.04	Hangzhou	LiFePO4	Unknown reasons
2019.05	Ningbo	NCM	Self-ignition while parking
2019.05	Shanghai	NCM	On smoke while set aside, no fire incidents
2019.05	Dingzhou	NCM	On fire while driving
2019.06	Changzhou	NCM	Self-ignition while driving
2019.06	Yichun	NCM	Self-ignition while driving
2019.06	Chongqing	Unknown	On fire while charging

Customer acceptance of EVs as green products was therefore limited. Customers generally held a sceptical attitude towards BEVs, partly because inferiorly designed and developed BEV models left an impression of low quality, low-end product and unreliable functions. Furthermore, when the diffusion of EVs in the consumer market was assisted by fast technological progress in battery cells that raised drive range, battery and vehicle safety became the major concerns among customers because the negative consequences of this performance insufficiency shadowed the increase in vehicle drive range. The consumer market was offset by frequently occurring fire and smoking incidents related to batteries.

[42] NCM 18650 refers specifically to the type of battery used by Tesla EVs. This is an incomplete summary but covers the majority of incidents.

PHEVs had a consistently moderate market share. Several important product parameters concerning hybrid technologies, especially fuel and electricity efficiency and the switch between two power modes, were not as competitive as those manufactured by JVs whose headquarters had continuous exploration in multiple technological solutions of electric mobility. When subsidies gradually phased out and China's determination of a technological regime shift was increasingly articulated, JVs started commercialising PHEV models more actively based on their mature product platforms. Their PHEV models soon took the place of many of China's indigenous OEMs. By 2018, among 22 PHEV manufacturers that had scale-production and car models marketized in China, 12 of them were JVs, which took up 20% of China's PHEV market within only two years and challenged the dominance of incumbent BYD and SAIC.

(2) Potential technological lock-in: the unintended consequence of technology-specific industrial policy

Due to high costs and immature technologies and products, EVs were not the primary choice for consumers. Even with heavy subsidies in place, customers still had concerns over product quality and cost performance compared to highly mature ICEVs. Moreover, because product variety was limited due to technology-specific industrial policy, customer choice was confined to a few EV models. The actual commercialisation pattern of EVs in the private market was strongly shaped by the characteristics of China's consumer market, including both market segmentation and heterogenous customer preferences. Notably, a large proportion of private purchase BEVs consisted of small BEVs, mostly A0 and A00 size segments. The concentration of EV sales in the small-size, low-cost market segment is attributed to the fact that China still holds a huge low-income population despite being a middle-income economy. For the gigantic price-sensitive income group, cheap products were attractively affordable when subsidies were calculated in. Buyers could tolerate compromised product quality and functions at a discounted

price as long as their basic needs were met. Hence, high price elasticity of demand created the condition for low-price small-sized BEVs to be accepted by this income group. This is the reason why the best-selling model in early phase of private purchase subsidy was the QQ model, a cheap and small BEV model manufactured by Chery, even though it was not even supported by subsidy scheme because of loading lead-acid batteries. Other BEV models sold well were manufactured by JAC, Zotye and BAIC, which were popular among two groups of consumers: one group was like those purchasers of Chery QQ, from rural-urban intersections outside of large metropolises; the other group was urban commuters who generally did not require luxury cars but were in need of cheap and convenient means of transportation for work and family. Among these models, 40% of them were priced even under 100,000 RMB after subsidy, and some models sold by BAIC, JAC and Zotye could be as cheap as around 50,000 RMB.

On the other extreme, some OEMs tried to integrate the best available power battery technologies and ICTs to offer luxury BEVs. These models were often large in size in the SUV market and priced over 300,000 RMB. However, the target group was far smaller compared to the lower and lower-medium income group. Despite new entrants such as NIO could sell around 10,000 BEVs per month throughout the years, this market remained a small niche market.

What was missing was in-between in the technology-market matrix. It was hard for EV manufacturers to upgrade their products and technologies for medium-sized market segments where consumers were generally more demanding on product quality and functions. PHEV was technologically more suitable for the middle-size segment[43] than BEV because it did not require long-drive-range power batteries or had heavy reliance on charging infrastructure. But due to a lack of technological capability accumulation, its market share was only moderate.

[43] This is based on the results by China-US New Energy Vehicle Policy Lab that conducted a survey in 2016-2017. Detailed results are available in China New Energy Vehicle Industry Development Report 2017.

Even at the same price after subsidy, consumers were inclined to choose ICEVs instead of PHEVs. Therefore, PHEVs were mainly operated in 2B businesses in the format of mobility service by companies that were new subsidiaries or cooperated with EV manufacturers.

Treating EV as a whole, what mostly contributed to purchase decisions was cost efficiency in the lower-end market segment, assisted by favourable demand creation policy in localities where EV licence plates were far more accessible than ICEVs. In subsequent years of EV diffusion, small and cheap BEVs still occupied the majority of total sales in the private market, with a proportion of around 70%. Even in 2020, the two most popular BEV models were still of A00 size, manufactured by GWM and BGMW[44] respectively. The challenges in technology and product upgrading risked technological lock-in to the small-sized BEV market segment. As pointed out earlier, despite startups such as NIO imitating Tesla commercialised luxury, big-size BEVs, this only remained as a niche market without any significant diffusion to a larger scale. This is not to say that one technology is superior or inferior to others, whereas the initial intention to narrow down technological and industrial gaps with global forerunners through technology-specific industrial policies was somewhat compromised through the feedback loops explained above. With JVs and foreign firms growingly active in electric mobility transition, competitive pressure in the middle-sized segments became severe.

5.6 Conclusion and discussions

This chapter draws on the case of China's green industrial policy in the nascent electric mobility transition to investigate its role in shaping the directionality of innovation in early phase of sectoral green transformation. Two important conceptual and analytical points are taken into consideration. First, green industrial policy is poorly defined in literature, and no

[44] BGMW is unique in terms of its ownership type. It was established by SAIC-GM, a joint venture between SAIC and GM group, but it was created as an indigenous company. It has two car brands, Wuling and Baojun, both producing small passenger vehicles.

consensus has been reached to date. This thesis understands it as a portfolio of multiple levels of institutional, regulatory and policy specifications, that combine to push for the structural change of industrial sectors towards sustainable development and competitiveness. In a sense, the idea of "policy mix" (Rogge & Reichardt, 2016) is reflected here. A further specification is that the sector-based green industrial policy should not be an endless list of policy instruments, but should bear direct implications on structural change, along the industrial value chain under state intervention. Therefore, irrelevant and distant policy instruments are not analysed. This is the boundary drawn on the "architecture" of green industrial policy. Second, the effectuation of green industrial policy on directionality of innovation is embedded in the SSIP as an open system. The causal mechanism is hence examined from the perspective of interaction and feedback loops in the changing system.

With these conceptual and analytical specifications, the sectoral level empirical analysis uncovers several important aspects of the role of green industrial policy in the early stage of sectoral green transformation.

First, learning and adaption takes place frequently at the multiple levels of green industrial policy. This supports the literature on policy learning and experimentation (Bennett & Howlett, 1992; Connor & Dovers, 2004; Grin & Loeber, 2017) and highlights the significance of multi-level learning along the industrial value chain. Moreover, this does not involve only passive responses to emerging problems, but also proactive envisioning and institutionalising emerging opportunities within and outside of the sector that could be mobilized to add to the incentive for change.

Second, the effect of green industrial policy could only be well understood when it is studied as a holistic and systemic one that interacts with the other building blocks in the SSIP. Existing literature argues that rent management is the "heart" of green industrial policy (Schmitz et al., 2015), whereas this is not the full picture. The creation and flow of policy rents should not only

target end product, but also complementary assets that are functionally necessary for the deployment and diffusion of green technologies through the value chain. Beyond policy rents, it is also found that national-level R&D programs play an important role in forming the initial absorptive capacity (Cohen & Levinthal, 1990) in the sector through funding and the programs themselves as platform for partnership and networking. In the case study, without the 863 Major Project and the New Energy Vehicle Technology Innovation Project, technological development at the product system and core component level (power batteries) would not have been achieved. Innovation policy should focus on network orchestration and be governed by a clear and testable performance criterion, and this is an indispensable part of green industrial policy in early phase of sectoral change.

Third, in face of technological multiplicity in a complex product sector in its green transformation, a holistic approach to green industrial policy could facilitate the process of technological substitution through intervening the process of technological variation. This involves designing the policy incentives towards selected technological solutions that are supposed to cultivate competitive advantage. Resources and capability building efforts are hence concentrated on certain design rules, artifacts, assets, networks and exchanges. This is not an echo of the "winner-picking" argument in the conventional industrial policy debate (Pack & Saggi, 2006), but how green industrial policy can realistically elaborate on and tailor the fuzzy and ambiguous opportunity space presented by green transformation of industrial sectors. For emerging economies and developing countries, state intervention can assume proactively more directionality (Mazzucato, 2011, 2015) that aims to achieve both sustainability and competitiveness goals.

Taking the three points above together, I turn to the fourth point, the casual mechanisms that green industrial policy concretely shapes directionality of innovation and facilitates sectoral change. I hereby put forth not notion of "***dynamic institutional complementarity***" to denote

the mechanisms. It consists of two aspects. The first aspect concerns the complementarity between multiple levels of the architecture of green industrial policy itself. It argues that policy instruments should be complemented by a) political steering – that deals with the normative agenda and alignment of political support, and b) industrial strategy – that concretises the tactical dimension of sectoral change. The latter especially reflects the material reality and the selectivity in specifying what path is/paths are taken in face of ambiguous technological frontier. The approach is dynamic in the sense that the multiple levels continuously adjust in the unfolding green transformation.

The second aspect concerns how a holistic approach could facilitate directed innovation. Four co-existing mechanisms are at work and complement each other: *cost reduction, demand creation, technological learning and capability building, and positive network effect*. The most direct effect of green industrial incentives is to significantly reduce the cost of green technologies facing both the producer and consumer, and create a market niche for green products to be deployed and experimented through in a small scale. With the coupling of supply and demand side conditions, EV manufactures can on the one hand, invest more money in R&D activities in the EV regime, and learn from product deployment, user interaction and problem-solving. At the same time, policy rents are partly transmitted to upstream to component suppliers. Sustained by certain size of market demand, buyer-supplier relation is built up, and learning further takes place between them. This in turn generates networks effect by improving the product quality, contributing to cost reduction, and increasing the supply of green products – hence improve the economy-of-scale. These four mechanisms work together and form a positive feedback loop for technological substitution.

However, selectivity in specifying technological variation should not mean the early termination of other technological solutions in the variation scope. An important lesson learnt from the case study is that green industrial policy may bear unintended consequences that turn

out the be counter acting. China's technology strategy to drive green transformation in the automotive industry was radical and highly selective. The disproportionate support of BEVs and PHEVs over other technological solutions reflected the "green leapfrogging" rationale due to presumed comparative advantage in the new technological regime. However, this created technological capability gaps in the nascent sector across a variety of technological trajectories such that market demand for value for money green products was insufficiently addressed. As a result, most EV sales went to the lower-end, small sized market segment. By contrast, due to a lack of technological accumulation in other trajectories, further capability upgrading is encountered with challenge. Realising this problem, the 2.0 version of technology roadmap for electric mobility transition in 2020 re-incorporated hybrid technologies as an important pillar to decarbonise the automobile industry.

From an innovation system perspective, the unintended consequences of state intervention into technological variation are not accidental but caused by the interactions and feedbacks in the variegated SSIP. Because it is OEMs that respond to the industrial policy incentive, most of their innovation efforts are channelled towards the low-end, small-sized segment that are cost-efficient for both EV manufacturers and price-sensitive consumers. A minor proportion goes to luxury, large and high-tech equipped BEVs (SUV). Innovation efforts in the middle-sized segment, that had been most challenging for Chinese car makers and seen fierce competition, were less intensive. In this segment, PHEVs are less favoured given the high rents and lower complexity of making BEVs. In the corresponding ICEV regime, this is the segment that indigenous brands make intensive upgrading efforts to compete with JV brands that are growingly tapping down the technology-product spectrum. However, the largely absent innovation efforts in this segment reduced technological accumulation among OEMs, except some incumbent OEMs that were reluctant in embracing the "pure electric drive" strategy (this proves to be important, and will be explained and analysed in the second sub question). The

implication is that technological multiplicity should not be overlooked even industrial policy is directional. Otherwise, it would be detrimental to the "ladder of growth" in the "middle of the pyramid" (Brandt & Thun, 2016; Thun, 2018) and prove to be the bottle neck that constrains structural change in the long run. This is figuratively illustrated in the figure below (Figure 5-8) (not an accurate depiction of realities).

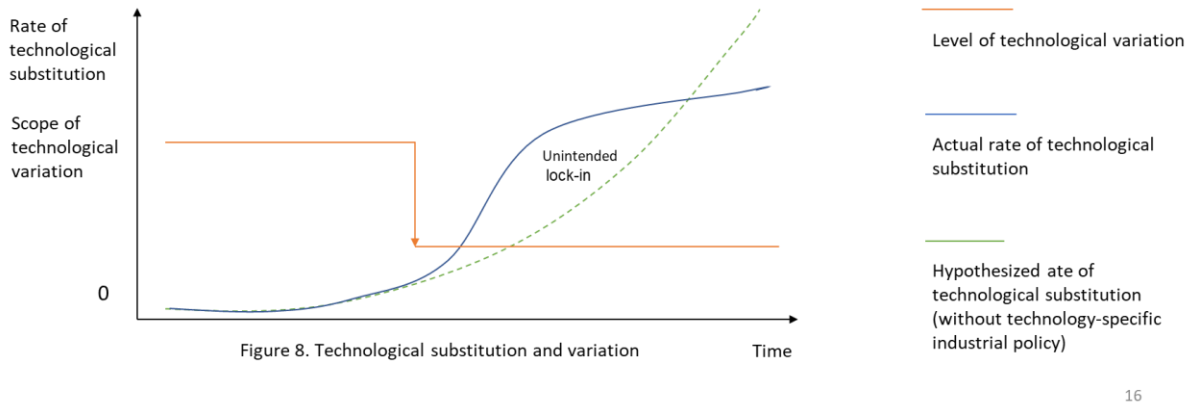


Figure 5-8 Directionality of innovation under technology-specific state intervention[45]

There are several limitations to this chapter which points out several directions for future work. First, this chapter adopts a case study approach to analyse the consequences of governmental intervention and focuses on the feedback mechanisms in a qualitative research design. Quantitative methods would be useful to test, verify and refine the findings, and present a more accurate picture of the change process and mechanisms. With this objective, advanced system dynamics and scenario modelling techniques (Holtz et al., 2015; Walrave & Raven, 2016) may have the potential. Second, this chapter has examined the short-term impact of industrial policies, while the medium and long-term role of state in directionality of sectoral transition and system performance remains an open question. Third, how green industrial policy interacts

[45] Author's elaboration based on theoretical insights from the case study.

with global players and policies in other countries is an important direction to offer a comparative perspective at the global level.

Chapter 6 Directionality of innovation at the firm level: a descriptive analysis

6.1 Introduction

In Chapter 5, the empirical analysis at the sectoral level has pointed out the importance of the complex yet not accidental interactions and feedback loops in the SSIP as an open system. Because it is business firms that undertake activities of innovation and production aggregating to that feedback, the role of green industrial policy and causal mechanisms could not be fully captured unless the responses of firms in terms of their innovation strategies and activities are systematically understood and that firm heterogeneity is properly addressed. It is therefore the objective of the remainder of empirical analysis to unpack the dynamics of state-business interaction at the actor level. This chapter zooms in to the level of firms (OEMs) to disaggregate how directionality of innovation under green industrial takes shape and changes overtime. It works as a preparatory chapter and lays the foundation for chapter 7 and chapter 8 that explain firm-level patterns in response to state intervention.

Recall that directionality of innovation in "era of ferment" consists of two intertwining processes. The first process relates to the normative dimension of system change, that is, regime shift from a polluting one to a greener, cleaner one. The second process relates to the positive and material dimension of system change. The open systemness of SSIP under transformation features technological multiplicity, and each technological trajectory and configuration along the possibility spectrum bears implication for the type of product architecture and design, production network, value chain and inter-firm relationships that are involved in. Eventually these form the specific assets, resources and capabilities for sectoral change through firms'

choice and implementation of their innovation strategies. The specification in this second dimension reflects the selectivity of green industrial policy that aims to drive competitiveness and sustainability. The concept is operationalised at the level of firms and a 2 by 2 matrix is presented to characterise four types of firms that make systematically different decisions on directionality of innovation. This is further operationalised and measured based on the compilation of various sources of empirical data.

The empirical analysis primarily focuses on incumbent firms. They are already large corporations with multiple businesses and complex supply networks, and face the common problem in face of technical change for green transformation that presents both opportunities and challenges. To perform the empirical analysis, a multiple case study is conducted on 12 OEMs that share common features: they are domestic firms in China's automobile industry or the domestic branch under a large automobile industrial group, have indigenous passenger car brand(s), and have made exploratory and experimental efforts in EV manufacturing. These 12 OEMs cover the majority of major incumbent, indigenous-brand OEMs in China's electric car sector, while not exceeding the ideal limit of multiple case study suggested by Robert K. Yin (2013).

A longitudinal perspective is adopted to examine firm heterogeneity and its change over time. The four-phase division of time (Chapter 4) would be too fragmented to examine firm-level innovation strategies and activities. The analysis from the current chapter to chapter 8 draws a rougher distinction in order to best present case studies and their findings: a line is drawn between the years before 2015, when firms mainly engaged in technological exploration and experimentation of electric mobility under pilot schemes; and the period since 2015, when green industrial policy support was reaffirmed and became nationwide, and firms engaged in larger scale deployment and diffusion of EVs.

The rest of the chapter proceeds as the follows. Section 6.2 offers the definition of directionality of innovation at the level of firms and presents the typology in the 2 by 2 matrix. Section 6.3 introduces the operationalisation and measurement of these parameters. Section 6.4 presents the analysis at the level of firms and firm groups, before and after the year 2015. Section 6.5 summarises the findings and discusses them with reference to the open systemness of SSIP and firm embeddedness, which eventually leads to the explanatory analysis in the next two chapters.

6.2 Conceptual framework: a typology of directionality of innovation at firm level

The analytical framework chapter has laid out an integrated definition of "directionality of innovation" in era of ferment of green transformation at the sectoral level. Diving into the level of incumbent firms, directionality of innovation is concerned with strategic choices of technological innovation and related activities regarding (1) **technological substitution**, i.e., whether to engage the greener regime's technological and product development and market deployment; and if so, to what extent. The latter denotes the relative importance of incumbent regime and greener regime technologies at the certain time conjuncture, as an incumbent firm needs to make trade-offs given limited resources and time window. Put it another way, it concerns how aggressive or active firms are pursuing new technologies, assets and networks that inevitably erode existing ones to a certain extent. (2) **technological variation**, i.e., facing technological multiplicity, the specification of technological trajectories and configurations within the scope of the greener technological regime. It is possible that firms would like to keep the breadth of exploration in order not to miss out future opportunities under uncertainty. In other cases, firms instead are more willing to concentrate on certain technological solutions to cultivate their expertise and competitive edge. In addition, firms may also adjust the scope and specification dynamically as the sectoral change unfolds.

Now it is possible to categorise incumbent firms into different types based on the 2 x 2 dimensions. In terms of technological substitution, firms differ between those who actively pursue green technologies and divert resources and cultivate capabilities to develop and deployment them, and those reluctant to engage in technical change. In terms of technological variation, firms differ between those embark on multiple technological configurations within the possibility scope of the green regime, featuring a diversity of product system designs, and those focus narrowly on very limited technological configurations, typically one, or at most two, in the green regime. To the extent that the degree of technological substitution is active or reluctant, and the scope of technological variation is broad or narrow, incumbent firms can be categorised as four types (Table 6-1).

Table 6-1 A typology of directionality of innovation at the firm level[46]

		TECHNOLOGICAL SUBSTITUTION	
		Active	Reluctant
TECHNOLOGICAL VARIATION	Broad	Type I Firms	Type II Firms
	Narrow	Type III Firms	Type IV Firms

Type I Firms are active in technological substitution and maintain a broad scope of technological configurations of green technologies. They embrace the new technological regime that is prospectus of replacing the existing one in their technology and business strategy.

[46] Author's elaboration.

To achieve that, they invest considerably in R&D and production capacity in green technologies whilst the incumbent regime business is still important.

Type II Firms are reluctant in technological substitution, which means that they act only as a technological follower in the green regime. They see green transformation as a very long process and a distant future, and hence are very cautious in making R&D and product investment decisions in green technologies. To get prepared for the perceived far-away future, however, it is possible that they keep a wide scope of technological exploration as no single technological solution has proved to be the best option in "era of ferment".

Type III Firms are active in technological substitution but keep a very narrow scope of technological variation. In terms of developing and commercialising green technologies and products, they are early movers. But they choose to concentrate on almost only one, at most two, technological configurations of the green product system.

Last, Type IV Firms are neither active in pursuing green technologies nor exploring them in diversified technological trajectories. They concentrate almost all resources and capabilities to make profit from the incumbent regime technologies, and only invest a minimal level of resources in green technologies. Moreover, they do so only with a focus on the most cost-efficient way, instead of exploring different technological solutions in parallel, which would be too risky and costly from their standpoint.

These patterns do not remain unchanged. As the sectoral change unfolds, firms' position in the quadrant may change overtime as they adjust their strategies and the competitive landscape changes. For example, those previously reluctant to develop and commercialise green technologies increasingly feel the pressure to do so. Those keeping a narrow focus in the greener technological regime seek to diversify their business and product portfolio, or

otherwise those maintaining a wide range of exploration decide to narrow down to sharpen their competitive advantage, reduce costs or avoid locking-in.

6.3 Research method

6.3.1 Multiple case study

The objective of this chapter is to characterise firm heterogeneity in directionality of innovation and evolutionary dynamics. Hence a multiple case study design is an ideal choice. The criteria of inclusion and exclusion is first based on the focus of this research, i.e., only automobile manufacturers that are already incumbent in the ICEV regime, have indigenous brand (instead of pure JVs with global brands) and have embarked on innovating electric cars and their market deployment are selected. A further specification is that I only look at the business of passenger vehicles as technological challenges and market demand are very different between passenger versus and commercial vehicles. Third, a firm should be directly affiliated to the corporate group, and I do not include remote subsidiary companies. Otherwise, it would be misleading to draw comparisons between firms of strikingly different scales and organisational structures.

This results in twelve firms in total. I keep this list of cases in order to maximise the between-case variation in locations, histories, sizes and many other aspects, in the reasonable range of multiple case study sample number (Robert K. Yin, 2013). This allows for enough diversity for generalisation and maintains the external validity of this study. A summary of these firms' demographic information is presented below in Table 6-2.

Table 6-2 Background information on selected business firms in the EV sector[47]

Firm	Location	Ownership type	History of JVs with global brands in ICEV regime
Changan	Chongqing City	SOE, affiliated to the central government	Yes, with brands from the U.S., Japan and France.
SAIC	Shanghai City	SOE, affiliated to the local government	Yes, with brands from the U.S. and Germany.
JAC	Hefei city, Anhui Province	SOE, affiliated to the local government	No
Chery	Wuhu city, Anhui Province	SOE, affiliated to the local government	Yes, with a brand from France.
Zotye	Jinhua city, Zhejiang Province	Private	No
Geely	Hangzhou city, Zhejiang Province	Private	No
GAC	Guangzhou city, Guangdong Province	SOE, affiliated to the local government	Yes, with brands from Japan and France.
BYD	Shenzhen city, Guangdong Province	Private	No
BAIC	Beijing City	SOE, affiliated to the local government	Yes, with brands from Germany and Korea.
FAW	Changchun city, Jilin Province	SOE, affiliated to the central government	Yes, with brands from Germany.
Dongfeng	Wuhan city, Hubei Province	SOE, affiliated to the central government	Yes, with brands from France and Japan.
GWM	Baoding city, Hebei Province	Private	No

[47] Author's compiling from open access data.

6.3.2 Operationalisation and measurement

There is no absolute value to denote the activeness of technological substitution, which is instead empirically determined and is a relative term among incumbent firms. Guided by the conceptualisation, I ask structural questions on-firm level data. Regarding the degree of technological substitution, I ask the following questions: how active a particular firm is in developing EV technologies and products, and bring them into market? How much emphasis is put on EV while continuing with its ICEV business? Degree of technological substitution is hence first read from firms' business and technology strategies released in their annual report, major strategic announcements and media communications where their top executives speak up. For example, some firms set ambitious goals for electrification, while others express more concerns and say they should be cautious[48]. However, aware of the "words-deeds gap", I pay close attention to how and to what extent firms actually *implement* these strategies. *Active engagement in technological substitution* can be qualitatively judged from the following facts: ambitious goals for electric mobility transition are set; the establishment of EV R&D branch/centre, accompanied by heavy investment and specialised personnel; the number of launched EV models that can be properly functional in the hands of individual consumers - instead of prototypes. If a firm announces ambitious plans but the efforts are mediocre, then it should still be said to be *reluctant* in *technological substitution*. The same can be said about firms who even do not have dedicated business and technological strategies to embark on e-mobility.

Switching to scope of technological variation, I ask the following questions: how many technological trajectories and configurations does a particular firm adopt in its EV product development? Do these products only involve battery-based competences, or still ICE-based

[48] The ratio between EV and ICEV business and investment is sometimes explicitly stated, but not for every firm.

competences, or both of them? This is also examined based on the strategy statement by the firm and its actual EV product information. Technological multiplicity is reflected in the number of technological trajectories chosen by a firm, for example, HEV, BEV, FCEV, PHEV, and other alternative fuel vehicles. Thus, if a firm rolls out EV models of no more than two technological configurations, then its *scope of technological variation* can be said to be *narrow*. Technological developments pursued along no fewer than two trajectories and cover core competence in the two regimes (ICE, battery) can be said to be *broad in scope*. For firms that diversify in EV technological configurations, detailed attention is paid to what specific configuration(s) is/are prioritised in their strategies and activities.

6.4 Directionality of innovation among incumbent firms: heterogeneity and the evolutionary dynamics

6.4.1 Firm-level patterns before 2015

A comprehensive examination of the twelve firms' technology and product innovations and their implementation concerning electric mobility (Table 6-3) confirms and validates the typology developed in Section 6.2.

Table 6-3 Patterns of directionality of innovation among firms before 2015[49]

		Technological substitution	
		Active	Reluctant
Technological variation	Broad	**Type I Firms** (BYD, SAIC)	**Type II Firms** (Changan, Geely, GWM)

[49] Author's elaboration.

	Narrow	**Type III Firms** (BAIC, JAC, Chery, Zotye)	**Type IV Firms** (GAC, FAW, Dongfeng)

In the period before 2015, most of these incumbent automobile manufacturers engaged in developing and producing EV products to varied extent. Only one special case is Dongfeng, whose BEV model was still under development and only released to the market after 2015. This overall pattern shows that they all acted in *de facto* "compliance" to the green industrial policy, specifically, the "Pure Electric Drive" strategy. However, they varied a lot in terms of the degree of technological substitution and scope of technological variation, and in the "words" and "deeds" of their innovation strategies. In the period of technological exploration and small-scale deployment of EV, the concrete patterns of technological substitution and variation by each firm group is presented in the table below.

There are only two Type I Firms in this period (Table 6-4), i.e., BYD and SAIC. BYD is a leading actor in the e-mobility. Before 2010 it was already determined to develop ICEVs, HEVs (mainly PHEVs) and BEVs in parallel. It did not participate in 863 Major Project, which mostly involved SOEs, but started to develop market-oriented EV models as early as 2003, and launched the first PHEV model F3DM and BEV model F3e in 2006. Since 2012, its PHEV model based on Dynasty series became one of the bestselling PHEVs in China's domestic market. SAIC is a local SOE in Shanghai. It participated in national and municipal level R&D projects to develop HEV and BEV models, and since 2010 Shanghai Expo started to roll out PHEV and BEV models for market deployment. SAIC insisted on multiplicity of technological trajectories. By announcing the "Double Core" technology Strategy, it put major emphasis on "Blue Core" (high performance ICE power system) strategy and at the same time actively

implemented the “Green Core” (“new energy vehicle”) strategy. Its PHEV model Rowe 550 was a strong competitor to BYD’s Qin PHEV.

Table 6-4 Directionality of innovation, Type I firms[50]

Firm	Tech-substitution and tech-variation	Before 2015	Since 2015
BYD	Technology and business strategies	Develop three technological trajectories in parallel: ICEV, HEV (including PHEV), and BEV); “Pure electric drive" strategy; start deployment from public transport and then to consumer market.	Develop three technological trajectories in parallel (ICEV, HEV including PHEV, and BEV); "Whole market strategy" covering all application scenarios; Gradually stop producing and selling ICEVs.
	Product models in electric mobility regime	Two BEV models in A0 class segment; the 1st and 2nd generations of PHEV models indigenously developed.	Two generations of BEV models in A0/A00 class market segments and A/B class market segments; the 3rd and 4th generations of PHEVs covering all market segments. Launched new BEV brand and product series.
SAIC	Technology a nd business stra tegies	From “multiple technological trajectories in parallel” to “Pure electric drive”; Technology strategy “Double Core Strategy” (Blue Core - high performance ICE powertrain; Green Core - e-mobility)	The “CASE” strategy (Connectivity, Autonomous driving, Car-Sharing and Electrification); "Core-driven" technology strategy (in this version, "green core" is emphasized more). New brand and independent EV firm is established after 2020.
	Product models in electric mobil ity regime	1 HEV model (later suspended); 1 BEV model; 2 PHEV models (one of them sold very well). All adapted from ICEV product platforms.	2nd and 3rd generations of BEV and PHEV models. BEV models cover A0/A/B class market segments. PHEV models cover A/B/C class segments. Launched new luxury BEV brand and product series based on a newly developed platform.

In this period, Type II firms include Changan, Geely and GWM Motor (GMW). Their efforts in the EV regime were only explorative, without much input in commercialising EV models (Table 6-5). None of them make e-mobility as a formal part of their corporate strategy before 2014. Though they also had EV models deployed, for example, Changan’s E30 in 2011, this was not primarily the result of the firm’s indigenous efforts, but incorporated from third parties and mainly used for demonstration in Beijing. However, these firms kept technological exploration and small-scale demonstration along multiple technological trajectories, ranging from most incremental solutions (HEV) to radical ones (BEV), including not only options

[50] Author’s compiling from existing data.

within the industrial policy support realm but also outside from it (for example, methanol vehicles by Geely).

Table 6-5 Directionality of innovation, Type II firms[51]

Firm	Tech-substitution and tech-variation	Before 2015	After 2015
Changan	Technology and business strategies	No formal business strategy or technology strategy on electric mobility is put forward. Annual reports only mentioned its importance. In technology strategy, change from multiple technology trajectories to the establishment of "Pure electric drive" at the end of 2014.	Announces "581" technology strategy in 2015; in 2017 launches "The Third Innovation and Entrepreneurial Scheme"; in 2021 "New Mobility Ecosystem Strategy". Established independent EV company in 2018; In 2021 launched independent EV brand.
	Product models in electric mobility regime	1 HEV model (later suspended); Two BEV models in the A00 and A0 class segments.	2 generations of PHEV models covering A0/A/B class segments; 2 generations of BEV models covering A00/A0/A/B class segments; 1 generation of high-end BEV model based on newly developed platform; 1 generation of REEV, MHEV and 48V HEV under development.
Geely	Technology and business strategies	No formal business strategy or technology strategy on electric mobility is put forward. Annual reports only mentioned its importance. Regarding to e-mobility, it emphasizes multiple technological trajectories developed in parallel.	In 2015 announces the "Blue Geely Plan"; In 2021, it becomes two "Blue Geely Plan" in parallel, one in high-performance ICE and HEV, the other in BEV; In 2021 launches "Intelligent Geely Strategy".
	Product models in electric mobility regime	2 BEV models in A00 class segment (in collaboration with other firms); 1 methanol vehicle model; 1 HEV model.	2 generations of BEV models in A0/A class segments; two PHEV models in A/B class segments; 1 generation of MHEV in B class segment; continued with methanol vehicle.
GWM	Technology and business strategies	No formal business strategy or technology strategy on electric mobility is put forward. Annual reports only mentions it but does not emphasize its importance.	Announced in 2015 that it will increase investment in EV and autonomous driving. Establishes new EV brand in 2018. In 2021 it announces "2025 Strategy" focusing on multiple technological trajectories.
	Product models in electric mobility regime	1 HEV model; 1 BEV model in A0 class segment; 1 PHEV model.	1 generation of BEV model under independent brand, covering A00/A0 class segments; 1 generation of HEV and PHEV models in A0/A/B class segments in different product series.

Type III firms include BAIC, Chery, JAC and Zotye (Table 6-6). Compared to most other incumbent automobile manufacturers, they were very active in embracing electric mobility, not only in words" but also "deeds". BAIC sticked to the "Pure Electric Drive" strategy and

[51] Author's compiling from existing data.

announced its first version of "Blue Sky Guardian Plan" to cultivate the entire EV value chain. JAC announced its own "Pure Electric Drive" technology strategy as early as 2009 and rolled out the first market-oriented BEV model iEV shortly after that. This model went through four rounds of renewals towards 2013. Zotye took an even more active stance in doing EV business, practicing what it called "SUV+EV" strategy, i.e., selling ICEVs in the SUV segment and using the revenue to support BEV production and diffusion. Towards 2015, it had four product series in the BEV trajectory. Chery was slightly more conservative in its technological strategy, emphasising more on technological exploration in the mainstream automobile market (where ICEV dominated). But it did roll out the very popular QQ model which was driven by lead-acid batteries, not covered by "Pure electric drive" industrial policy subsidy scheme, but proved lucrative.

Table 6-6 Directionality of innovation, Type III firms[52]

52 Author's compiling from existing data.

Firm	Tech-substitution and tech-variation	Before 2015	After 2015
BAIC	Technology and bu siness strategies	"Blue Sky Guardian Plan" in 2011. Pure electric drive.	2015 "Blue Sky Guardian Plan 2.0"; 2017 "Open and Sharing" strategy, and launches a new BEV brand thereafter; In 2021 announces its "2029 Strategy".
	Product models in electric mobility regime	1st generation of BEV model in A0 segment; 2nd generation of BEV models in multiple product series, mainly in A0 segment.	3nd generation of BEV models in increased product series, expanded to A and A00 class segments. The 4th generation of BEV model added an independent luxury new brand in the A class segment.
JAC	Technology and business strategies	Establishes "Pure electric drive" strategy at the firm level established as early as 2009.	2015, renews the "iEV+ Strategy", aiming for 30% EV sales in its total vehicle sales. In 2017 openly announces that EV is its "strategic core business".
	Product models in electric mobility regime	4 generations of BEV model in A0 class segment.	Expanded to two product series, both are BEVs. One in the A0 class segment, the other upgraded to the A/B class segment.
Cherry	Technology and business strategies	Makes it clear that it insists on "indigenous development" and focused on "technology research and development" in EV regime.	Announces EV as its third corporate strategic field in 2015, and publishes "whole series, 457" EV technology strategy. Launches a new EV brand in 2022.
	Product models in electric mobility re gime	1 HEV model (later suspended) in A0 class segment. 2 generations of BEV model in A00 class segment.	The 3rd generation of BEV model in A0/A/B class segments. 1 generation of PHEV models in multiple product series covering multiple market segments.
Zotye	Technology and business strategie s	Puts forward "SUV (ICEV)+EV" dual business strategy. Pure electric drive in e-mobility.	Continues with "SUV (ICEV)+EV" business strategy with a focus on pure electric drive. In 2019 announces the "Green Future" strategy.
	Product models in electric mobility regime	2 generations of BEV models. To the 2nd generation, 4 BEV product series mainly in the A00/A0 class segments.	Increased BEV product series, covering the A00/A0/A/B class segments, but mainly A00/A0 class.

Type IV firms include GAC, FAW and Dongfeng. Before 2014, they were very reluctant to engage EV technology and product development, and their limited efforts were made on no more than two types of technological configuration (Table 6-7). Though FAW and Dongfeng participated in 863 Major Projects very early, they only lingered around the prototype and demonstration stage and did not treat e-mobility as a formal part of their corporate strategy (FAW did have a "Blue Path Strategy", but it was very vague and rarely put into practice). Marketised models were very rare. GAC did not participate in national R&D program until 2011, when it joined an R&D program to develop REEV supported by MOST. Up to 2015, it only had one model in this trajectory used for demonstration in the Pearl River Delta cities. The rare EV models launched by some of these firms were mostly BEVs in A00 or A0 segments,

where required product system integration capabilities not as sophisticated as of larger vehicles and hybrid solutions.

Table 6-7 Directionality of innovation, Type IV firms[53]

Firm	Tech-substitution and tech-variation	Before 2015	After 2015
GAC	Technology and business strategies	No formal business strategy or technology strategy on electric mobility is put forward. Only mentions its importance in annual reports.	Wants to accelerate EV development in its 13th five-year plan. Establishes an independent EV brand in 2020 and announces its "2025 Strategy" in 2021.
	Product models in electric mobility regime	1 REEV model in A0 class segment.	3 generations of BEV models: the 1st generation in A0 class segment; the 2nd generation based on a new platform in the B class segment; the 3rd generation based on updated new platform in A/B class segments. 1 generation of PHEV models in A0/A/B class segments. Also HEV and MHEV products under development.
FAW	Technology and business strategies	In 2011 announces the "Blue Path Strategy" and in 2014 further announces the "New Energy Vehicle Strategy".	Continues with its "New Energy Vehicle Strategy". In 2021 announces "15333" EV strategy in its 14th five-year plan.
	Product models in electric mobility regime	1 BEV model in the A0 class segment under development but not on sale.	2 BEV product models in the A0/A class segments. Under an independent brand, rolled out 1 HEV product model and 1 BEV product model in the B class segment.
Dongfeng	Technology and business strategies	No formal business strategy or technology strategy on electric mobility put forward, but mentions "scale production of EVs during its 12th five-year plan".	Launches an independent BEV brand in 2018. Announces "New Energy Vehicle Leap Action" in 2021.
	Product models in electric mobility regime	1 BEV model in the A00/A0 class segment.	3 BEV models in the A00/A0/A class segments. The 4th BEV model was launched under a new, independent luxury BEV brand in the B class segment.

6.4.2 The evolutionary dynamics of firm-level patterns from 2015

Firms' choices of directionality of innovation changed over time after 2014 and 2015 as the sectoral change dynamics unfolded. Overall, two important trends can be observed. First, there was growing convergence in firm's degree of activeness in technological substitution. Second, in terms of the scope of technological variation, some made successful diversification efforts while others not. As a result, the gap is widened between firms that are narrowly specialised

[53] Author's compiling from existing data.

and those with a broad array of technological configurations. The changes in technologies and business strategies and actual EV product innovation in each firm group are presented in detail in the right column of Table 6.4-6.7 above. These changes can be summarised as convergence in technological substitution and divergence in technological variation.

With respect to the degree of technological substitution, either early movers or laggards in the first period, were then increasingly proactive in launching and implementing e-mobility strategies. The most radical one, BYD, foresaw to totally phase out ICEV production during the 2030s[54]. SAIC aspired to reach its "carbon peak" in around 2025, with EV sales taking up no less than 32% of its total vehicle sales. BAIC renewed its Blue Guardian Plan in 2015 and in 2021, and declared to roll out over 40 EV models in its "2029 Strategy". JAC, Chery and Zotye, the early movers in the earlier phase, also took more active steps, whereas they were plagued by their own problems.

More dramatic strategic turn in technological substitution is seen among the reluctant movers such as Changan, Geely and so on. For example, Changan was almost indifferent to electric mobility before 2014. Only in the turn of 2014 to 2015, when national policy reassured continued support for the "Pure Electric Drive" strategy towards 2020, that Changan was finally determined to consider it seriously. In 2015, Changan set a "518" target[55] that focused on the specific technological parameters of its EV products. This soon proved to be still too conservative, and hence in 2017, Changan announced to embark on its "Third Innovation and Entrepreneurship Plan"[56] by transforming itself from an automobile manufacturer towards a "intelligent mobility technology company". Other late movers showed similarly growing

[54] This is alleged to be achieved in March 2022 by BYD.
[55] "5" refers to 5-second taken for acceleration to 100 km/hour. "1" refers to average fuel consumption of 1 litre/100 km by its hybrid vehicles. "8" refers to 8 kWh electricity consumption/ton of vehicle by weight by battery electric cars. These targets are all set for the year 2025.
[56] This is a group level strategic turn. The first turn was made to transform from a military machinery manufacturer to vehicle manufacturer, and the second turn was made to shift to passenger vehicle manufacturing.

activism, not only manifested in ambitious electrification strategic plans but also a fast-growing number of EV models in various market segments.

The scope of technological variation saw growing divergence over time. Earlier firms insisting on technological multiplicity further broadened the scope, and EV models were seen in more nuanced market segments, e.g., Changan, SAIC, BYD, Geely. Some diversified in the process from a narrow "specialist" to a "generalist", for example, Chery, GAC, GWM and FAW were all able to roll out PHEVs, HEVs and others apart from the single technological solution they specialised in earlier. However, the rest of incumbent firms were locked-in to a narrow focus. BAIC, JAC, Zotye and Dongfeng had only BEV models in the market even until 2020. Except BAIC that was able to incorporate A and B sized segments, others had rather limited selection of EV models (mostly in A0 segment and smaller, and most recently SUVs). This pattern seems to get consolidated overtime, resulting in a divergence in scope of technological variation in the selection process.

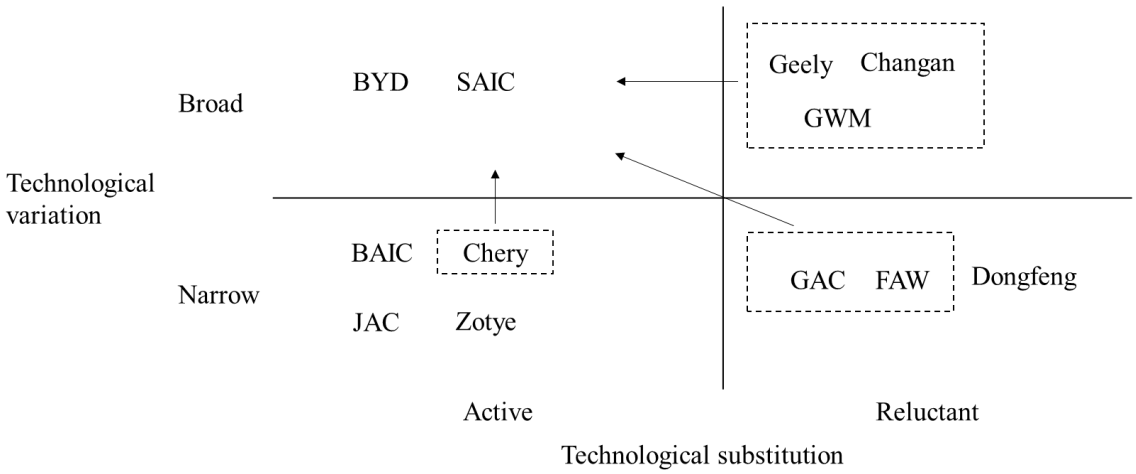


Figure 6-1 Change of directionality of innovation among firms since 2015[57]

[57] Author's elaboration.

To visualise the pattens and their change over the two periods, I illustrate the movement of firms' position in the 2 by 2 matrix via Figure 6-1 above. The convergence in degree of technological substitution marks the migration of firms leftwards from their previous position (original Type I stay unchanged), while the divergence in scope of technological variation leaves some firms in the lower quadrant and prompts other firms to the upper quadrant. These heterogenous patterns and their dynamics overtime will be explained in the two chapters that follow (chapter 7 and 8), and their implications for their performance and transformative role will be discussed in further later chapters.

6.5 Conclusion and discussion

In this chapter, I operationalise the concept of "directionality of innovation" at the level of firms and develop a typology, denoted by a 2 by 2 matrix, to characterise the different behavioural patterns among incumbent OEMs. There is also a temporality aspect – the evolutionary dynamics of firm heterogeneity in direction of innovation can also be examined using the matrix.

A multiple case analysis is conducted on twelve indigenous incumbent OEMs in China's automobile industry that have more or less developed and deployed EV models (passenger cars) in domestic market. I categorise them according to empirical data against the 2 by 2 matrix specified in 6.2. To look at the dynamics over time, I use the year around 2014 and 2015 as a time juncture to study the two periods.

It is found that the twelve OEMs, despite all being incumbents, are highly heterogeneous in terms of both activeness of technological substitution and scope of technological variation. All four types of firms co-existed before 2015. Overtime, two trends are apparent. First, the is a convergence towards more active and radical technological substitution, be they early movers or followers in the first period. Second, the is growing and consolidating divergence between

firms of broad technological variation and those of narrow technological variation. On one hand, some OEMs such as Chery, GAC and FAW have joined BYD, Changan, SAIC, Geely and GWM in engaging multiple technological trajectories spanning both ICE-based and battery-based configurations. On the other hand, some other OEMs such as BAIC, JAC, Zotye and Dongfeng have remained to roll out only BEVs, without any other technological configurations that utilise core competences in the ICEV regime. This gap seems to have enlarged and consolidated during the course. Considering the overall dynamics throughout the past decades and more, I call the former group of firms as ***"generalists"*** and the latter group of firms as "***specialists***". This distinction is important for the analysis in the next two empirical chapters.

As such, this thesis puts forward a conceptual approach to disaggregate the homomorphism and isomorphism of organisations in the same sector when they experience transformative changes. However, it is unknown why they adopt certain direction of innovation differently and why it changes over time differently. Given the significant consequences of directionality of innovation on competitiveness, development and sustainability, it is important to understand why and how such directionality of innovation is shaped in the open sectoral system in different ways.

Existing literature falls short of answering this question. It is true that green industrial policy has certainly provided certain incentives, for example, in the form of subsidies that directly reduce the costs of green technologies significantly, and market creation for EV models by restricting customers' access to ICEVs. But all these could not explain why firms differ or converge, and under what conditions, in terms of their innovation strategies and activities as a response. Certain institutional thinking would consider state ownership as a potential explanation (Lin et al., 2020; Lin et al., 2021; Rong et al., 2017). However, in effect some SOEs are reluctant to engage in EVs (e.g., FAW), while other SOEs are very active (e.g., JAC).

Among private firms, such difference also exists. For example, think about how Geely acts slowly in developing in-house EV competences compared to BYD's proactiveness in deploying EVs in the market. Because all these firms are OEMs in the automobile industry, it is not totally convincing to apply the incumbent-versus-new-entrants argument either (Anderson & Tushman, 1990; Christensen, 2013; Eggers & Park, 2018). Some would argue from the perspective of business and management studies that larger corporations may suffer stronger path dependence than smaller firms, whereas both BYD and SAIC are pretty large in scale and size, and active in technological substitution, while Changan, FAW and Dongfeng, also large firms, were indifferent to electric mobility before 2015.

It can be seen that none of existing literature and theories could offer a satisfactory, comprehensive explanation on firms' different strategic responses to green industrial policy in terms of directionality of innovation. It is hence the objective of the next two empirical chapters to fill this gap based on the empirical background laid out in this chapter.

Chapter 7 Understanding firms' different responses to green industrial policy: Multiple case study on China's EV manufacturing firms (prior to 2015)

7.1 Introduction

Business firms in the focal sector are the major entities of innovation that turn the supply side of green technologies into market diffusion. In the previous chapter, the descriptive analysis on twelve OEMs in China's automobile industry has shown how directionality of innovation takes shape at the actor level, and how the pattern changes over time. Therefore, only by probing into the concrete strategies and processes of innovation of firms could the effectuation and outcome of green industrial policy be sufficiently understood. The objective of this chapter is to unpack the nature and source of firm heterogeneity in their strategic responses to green transformation heavily affected by state intervention.

(Green) Industrial policy literature has so far paid little attention to the object of policy intervention (Zylberberg, 2017). A state-centred or policy-centred analysis prevalent in industrial policy literature looking at the aggregate level dynamics sheds little light on the "micro-structures" of system transformation, i.e., how artifacts, linkages and assets are allocated and formed undertaken by firms. Innovation management literature and business studies provide rich insights into innovation strategies and processes and their antecedents. Whereas the neoclassical assumption of firms and market transactions takes agency away from firms and does not fully consider the implication of firm heterogeneity (Shapiro & Shapiro, 1976). By contrast, the evolutionary and capability theory of the firm (Montgomery, 1995; Teece, 2017) remedies this deficit and seeks to open the "black box" of firms. However, this literature has not paid enough attention to firm behaviour in times of transformative change,

especially under heavy policy intervention. It is true that management and organisation studies look at the interaction between the firm and its external environment, including policies (Cashore & Vertinsky, 2000; Dibrell et al., 2015; Kotter, 1979). Whereas public policy is often treated as one of the elements as part of the "environment" or context external to the firm (Cook & Barry, 1995). The nature of firms' embeddedness and how this shapes the interaction between firms and the external environment are not well understood yet.

Therefore, this chapter seeks to fill the gap by developing an inter-disciplinary framework to explain firm heterogeneity in innovation strategies in the context of policy-driven green transformation. It adopts a political economy perspective and brings (green) industrial policy literature and innovation management and organisational studies together to understand the dynamics and forces of change in the early sectoral transformation.

What critically bridges the two literatures (and disciplines) is the notion of firm-centric *incentive structure* (Chapter 3) embedded in the SSIP as an open system. Firm centric incentive structure mediates green industrial policy incentive to the immediate decision-making environment of firms, and looks at how, the incentive structure as a whole, affects innovation strategies concerning direction of innovation. It is also recognised that environmental factors are not determinative, and firm-level factors play an important role, too. From an extended resource-based view and capability theory of the firm (Armstrong & Shimizu, 2016; Teece, 2017), the moderating and conditioning effect of two firm-level variables are examined: a) the technological capability of the firm in the incumbent technological regime, and b) the overall resource portfolio possessed by the firm.

Based on this analytical framework, empirical analysis is conducted upon the twelve OEMs and the patterns identified in Chapter 6. Because the analysis involves both between-firm comparison and cross-firm synthesis, the unit of analysis includes both the firm and firm groups. Data analysis is based on various data sources specified in Chapter 4. Again, I adopt a

longitudinal perspective to look at the co-evolutionary and interaction dynamics between system-level and firm-level factors. In the analysis, a division of time is drawn between the period before 2015 and after, as there is important incentive change[58]. This chapter looks at the former period to enable in-depth analysis and ensure that complexity is sufficiently addressed while the patterns can still be observed and explained. The next chapter (chapter 8) continues to focus on the political economic understanding of between-firm convergence and divergence after 2015 until around 2020.

This chapter makes a number of contributions to literature. First, it provides an understanding of directionality of technological innovation at the level of firms, hence fills an important void in innovation studies concerning firm innovations strategy in times of transformative change. Second, this chapter presents a novel framework to explain firm heterogeneity in this regard. The framework looks at the interaction between system-level and firm-level factors and emphasises the combination of these factors and the contingency that bears strong explanatory power. As such, it contributes to both innovation system and innovation management literature. Third, by looking at firm-centric incentive structure, this chapter creates the space where different disciplines that examine different levels of innovation phenomenon, i.e., green industrial policy, industrial dynamics and strategic management of innovation, could communicate and be connected to understand firm innovation in system change.

The remainder of this chapter proceeds as follows. Section 7.2 elaborates on the analytical framework integrating multiple strands of literature. Section 7.3 introduces the research method and analytical steps. Section 7.4 presents the case studies of OEMs before the year 2015. Section 7.5 conducts the cross-case comparison and synthesis, which leads to more generalised

[58] The rationale for this operation is also outlined in Chapter 4 and 6.

findings. Section 7.6 summaries the main findings, and concludes and discusses with relevance to policy and managerial implications.

7.2 Analytical framework

7.2.1 Variegated incentive structure in the open SSIP: a firm-centric concept

Incentives guide the flow of capabilities and resources towards certain ends (Fu, 2015; Lundvall, 2007). They are closely related to directionality of innovation because they are concerned about the extent to which actors are motivated to get involved in green transformation and the guidance of (or prevention thereof) innovative efforts toward specific technological solutions.

This thesis interprets the firm-centric incentive structure as being composed of multiple incentives stemming from different building blocks of the SSIP under green transformation, yet qualitatively not equalised to the simple adding-up of each incentive. Instead, this concept emphasises how incumbent firms make sense of their incentive environment in an integrated and interactive way. Recall that in the open systemness described in Chapter 3, the incentive structure is not unified, single-layered and unequivocal, but is inevitably ***variegated***, due to multi-layer, multi-source of incentives in the open system and their ambiguity in early stage of system change. Moreover, because of the heterogeneity of firms, even the same incentive can have drastically different implications for different firms.

The content of firm-centric variegated incentive structure embedded in the open SSIP is disaggregated as follows.

(1) Technological regime incentives: Appropriability conditions and technological opportunities

Appropriate conditions in its original meaning refers to the extent that technology knowledge can be protected from others (Becker & Dietz, 2004). Despite that sectoral specificity plays a role, from the perspective of firms, it concerns the profitability of firms' involvement in green technologies and the challenges in maintaining innovation rents and competitiveness. Compared to the incumbent, mature technological regime, the appropriability conditions in green technological regimes are inferior due to high costs, limited economy-of-scale and network effects in the value chain. This is additionally affected by the under-development of complementary assets (Malerba & Orsenigo, 1997). Taking these together, if the appropriate conditions are improved in the green technology, then the incentive to engage green innovation by incumbent firms would be higher.

Technological opportunity is a related but different aspect of technological regime characteristics. It reflects the easiness of innovating for any given amount of resource invested in search. Greater technological opportunity incentivises firms to engage in exploration in a certain direction that promises to yield innovative benefits, and in this regard, its implication is similar to appropriate conditions. If the innovation challenge is too high, e.g., the green technologies are too complex in their configuration, then technological opportunity perceived by firms would be lower compared to the mature technological regime. Another aspect of green technology to think about is the ambiguity and uncertainty of it, for risk-aversion firms that perceive high uncertainty would be discouraged from engaging in green technology development. If it does so, then they are inclined to keep technological multiplicity to avoid pre-mature lock-in.

(2) Market regime incentives

Market regime incentives include the ***size of the market segment*** that corresponds to certain position in the technology-product matrix (Malerba, 2002), cost-efficiency and the degree of product market competition. For green technologies, the initial market demand is undoubtedly

small. The size of the market is of great importance for green technology diffusion. In a multi-tech product, multi-component sector, market preferences are often heterogenous, and some technological solutions and products cater for a larger population than others.

Cost-*efficiency* is a critical factor that affects both the purchasing decision of consumers and firms' strategy about products and technologies. Customers normally pay for the functions of the products and services, not primarily for the environmental performance. When the green technologies are immature, they are often more costly while functionally inferior to mature products in the incumbent regime. Similarly, in the face of technological multiplicity, some solutions in the technology-product matrix are more cost-efficient than others that are more costly. This element is especially important for developing countries and emerging economies where a considerable proportion of the population is price sensitive. An improved status of cost-efficiency of green products would incentive incumbents to make more innovation efforts.

Besides, ***product market competition*** is yet another critical factor that strengthens or weakens the extent that firms are willing to engage in green technologies. In the early phase of green transformation, green product market competition is very weak and incumbent firms are preoccupied with incumbent-regime technology improvements. However, an increase in the level of product market competition in the green regime will significantly increase the incentive to innovate in green technologies and their market diffusion. For example, when early movers in green technologies have established some edges in certain market segment(s), technological followers will soon realise that they have to "catch up", or they will risk missing the time window to narrow the gap with early movers.

(3) The multi-faceted institutional incentives

a. Green industrial policy

A definition of green industrial policy for the purpose of this thesis, and its conceptual elements, has already been documented in Chapter 3 and reiterated in Chapter 5. While it is important to acknowledge its architecture as a portfolio of multiple-level specifications (from strategy level to instrument level), it is beyond the purpose of this thesis to tease out and add up the incentives by each of them. Instead, I focus on the nature of green industrial policy and the incentive created by it. That is, its *selectivity* in the policy design to push for certain structural change in the industrial sector. This is important because green industrial policy has its dual objective to facilitate competitiveness and sustainable development. Given technological multiplicity, selectivity lies in the core of discrimination among different material means to achieve the sustainability objective. Here, I take over from previous chapters and continue to focus on the "Pure Electric Drive" technological strategy and its supporting policies, that aim at both competitiveness and transformation towards sustainability. The selectivity is reflected in the policy preference that electric mobility is encouraged, and in electric mobility, battery-based solutions are further encouraged. With this strategic intention, concrete financial incentives and demand conditions are put in place to facilitate the structural change. This deals with, but is not confined to, rent management (Schmitz et al., 2015), such that certain innovation activities are encouraged over others. As such, it can directly change the price incentive and cost structure of green technologies from the perspective of producers (firms). It can also affect incentive structure indirectly by altering other elements in the system. For example, regulation on market entry/exit can affect the competitive structure in the industry, hence (dis)motivating firms to get involved.

b. Firm-level institution: ownership type

Ownership type is a firm-level institution that affects the incentives to innovate in green technologies. For many countries, state ownership is a type of corporate governance to manage the strategic sectors in the economy where market failures may be present (Minetti et al., 2015).

In addition, they are expected to assume corporate social responsibility because of the public nature of their ownership (Córdoba-Pachón et al., 2014; Zhu et al., 2016). In green transformation that is highly policy driven, SOEs are particularly relevant in taking the initiatives in investing in and experimenting with green technologies. However, SOEs themselves may lack the incentive to do so because of the classical principal-agent problem and the pursuit of their own interests. In addition, their market performance is questioned because of policy burdens (Lin et al., 1998), and information asymmetry at multiple levels of corporate governance (Qian, 1996; Xu et al., 2005), and the potential contradiction between the controlling shareholder (the state) and other minority shareholders (Lin et al., 2020). It therefore remains to be seen how state ownership affects SOEs' incentive to engage in green technologies given the unsettled debates in literature.

c. The importance of subnational institutions

The above-mentioned two aspects of institutional environment can be deeply affected by the way government power is vertically organised. It has been widely agreed in economic geography and political economy literature that as long as certain forms of decentralised/delegated governance are involved, local government is motivated to pursue its own interests and tailor policies to fit local conditions (Segal & Thun, 2001a; Zhong, 2015). The role of subnational institution in innovation and structural change therefore warrants close examination (Sun et al., 2018; Sun et al., 2011). One mostly common and explicit government incentive is to maximise (the retainment) tax revenue and fiscal resources at the local level. This is not unique to developing countries but countries of fiscal decentralisation in general (Lin & Liu, 2000; Oates, 1993)[59], which is exacerbated by the peculiarity of political economy model in China (Li & Zhou, 2005; Zhang & Peck, 2016). Therefore, local government has

[59] The incentive can be strengthened when political mobility is associated with economic performance, as is typical in China.

justified inclination to support emerging industries and attract more investments. However, it has to make trade-offs between growth opportunities and the negative consequences of "creative destruction" brought about by green structural change. Some regions rely heavily on polluting sectors for income and employment, while others less. Therefore, it is important to understand the implementation gap (Ran, 2017) at the local level in the context of green industrial policy.

The implication of multiple level governance for state ownership is no less ambivalent. SOEs can be institutionally differentiated as some report to the central government, while others report to governments at the sub-national and local level. It is therefore understandable that local government counts on a centrally affiliated SOE for (part of the) economic and employment growth but does not have the equal political authority to exercise command and control. Local government has stronger say and concern over SOEs affiliated to itself in terms of capital relation. The implication for institutional structure is well illustrated in Thun (2006).

In sum, the tension between the level of authority and ownership affiliation, and its combination of local government incentives to specify and implement green industries can lead to very different institutional structures faced by business firms on the ground. Note that local governments differ as well due to historical and cultural conditions, which is also taken into consideration in data analysis.

7.2.2 The moderating role of firm-level factors

(1) Technological capabilities in the incumbent technological regime

That technological capability as an important factor that affects innovation performance is well established in business and management literature (Coombs & Bierly III, 2006). In times of technical change, the strength of technological capabilities in the existing technological regime can be both constraint and enabler at the same time (Eggers & Park, 2018). On one hand, strong

technological capabilities mean that such firms have the necessary "absorptive capacity" to pick up new technologies, adapt to technical change and establish competitiveness (Cohen & Levinthal, 1990; Teece, 2017). On the other hand, other things being equal, strong capabilities often imply good performance in the existing technological regime and established interests, and this can be a strong force of path dependency (Mueller, 1997) and source of incumbent dilemma (Christensen & Rosenbloom, 1995; Hill & Rothaermel, 2003).

Strong technological capabilities in the incumbent regime also imply the capacity to do different designs and solutions. Often technical change in a complex sector is not totally competence-destroying, and some technological capabilities remain important, for example, design and product development, system integration and mass production. Moreover, incumbent firms are more capable of hybridisation between old and new technologies when completely new technologies lack maturity and feasibility. Therefore, highly capable firms feature "creative accumulation" in technical change in a multi-tech, multi-component sector (Bergek et al., 2013).

(2) Overall resource portfolio

The resource-based view of the firm (and its extended version) predicts that the resources a firm has – both tangible and intangible – affects its innovation performance (Bakar & Ahmad, 2010; Barney, 1991; Verona, 1999). This applies to both innovation in non-disruptive times, and matters even more when green transformation requires vast investment into technological developments with few short-term economic returns, and if a firm engages in new technological regime along multiple trajectories (Wan et al., 2011). For large corporations, I define the overall resource portfolio possessed by the focal firm, which consists of different types of resources, including financial, technological, and human resource, etc. From an extended perspective, it is important to differentiate between internal resources and external

ones that are *immediately* accessible and usable through external linkages (Lavie, 2006; Sun et al., 2010).

7.3 Research method

Chapter 4 has outlined research design, case selection and data collection and analysis. What is added here is the use of *structured, focused comparison* within the same group and across groups (George, 2019; Sivesind, 1999) against the analytical framework elaborated above. The data analysis is iterative until a satisfactory and saturated explanation is reached. In this chapter, the analysis focuses on the period before 2015.

The operationalisation and measurement of those analytical elements and variables are provided below.

Firm-centric incentive structure. This is an integrated decision-making environment for incumbent firms embedded in the open SSIP. The reference point should be the directives of green industrial policy, in this chapter, the "pure electric drive" strategy and its supporting regulatory and policy specifications. Ownership type and sub-national institution are both very explicit and straightforward. With the implications of "Pure electric drive" strategy in mind, the other various incentives vary in degree or extent in terms of motivating firms to engage in technological substitution/variation. Because they are firm-centric, relative perceptions, they do not have an absolute or object value, but are assigned certain levels such as strong, moderate or weak (see the comparison and synthesis in Section 7.6). I am aware that this inevitably causes ambiguity in the measurement, but the data analysis process that looks at the same content for exactly the same list of incentives ensures the feasibility of cross-firm comparison.

Firm-level factors. *First, technological capabilities in the incumbent (ICEV) regime*. Voluminous studies measure technological capability using different indicators, not limited to input or output of innovation, leading to very different results in empirical studies (Coombs &

Bierly III, 2006). Many of these indicators are argued to not well capture the tacit and intangible side of technological capability (OECD & Eurostat, 2018). In this chapter, the number of patents is used as the basis, searched from Google Patents website. The number of patents granted in China (CN) and the U.S. is recorded separately, as scholars believe that US patents reflect stronger technological capability (Wang et al., 2015). I additionally look interviews and contextualised evaluation of firms' relevant capabilities in the case study.

Second, the overall resource portfolio of firms. Given that data for each resource component – financial, technological, human – is not always accessible, I lay out several specifications here. First, I do not measure each of them, but take them as a whole, which can be proxied by the size of a firm. That firm size as a proxy for resources is well documented and frequently adopted based on a Schumpeterian notion of innovation and organisation (Kumar & Siddharthan, 1994), measured by total assets (Amato & Amato, 2007), and the number of employees (Arvanitis, 1997). Second, I differentiate between internal and external resources. While firm size functions as an indicator of internal resource, external resource is also critical for large corporate groups (Demirkan, 2018; Freel, 2003). Here I focus on external resources that are accessed, and/or can be accessed by *institutionalised mechanisms*, e.g., state ownership, JVs with MNEs (Sun et al., 2010). By emphasising institutionalised access, it does not equalise to any open innovation strategies themselves. However, when necessary, in the analysis of each firm I also mention the role of certain type of resources that proved to be critical enabler or constraint of shaping directionality of innovation at the organisational level.

This firm level data is collected from 2010-2020. I compile the data and make iterative comparison on them, and evaluate and rate technological capabilities and resources respectively, both referring to numerical data, as well as case studies in context to make sense of the importance of these indicators. They are rated in relative terms from high, medium to low (reflected in the stars, see section 7.4). To improve the quality and validity of the rating, I

consult key insights from interviews (with managers and experts), and a variety of data sources to triangulate. Due to the number of OEMs studied and the limited space here, I only report the findings in the chapter, and put firm-level data in the appendix for reference (see Appendix B. Firm-level variable measurement (2010-2020) supplementary data)[60].

7.4 The variegated incentive structure, firm level moderators and direction of innovation in the electric mobility transformation: before 2015

7.4.1 Type I firms

BYD is a private firm, and does not have obligations to central or local government in institutional terms. Seeing the great business potential in China's passenger car market, BYD entered the automobile manufacturing sector in around 2003 by purchasing a licensed car manufacturing company Qinchuan. ICEV had been a backbone business given China's booming consumption. As a latecomer, BYD highly valued the technological opportunities of electric mobility. BYD insisted on the paralleled development of ICEVs, PHEVs and BEVs in the beginning, and attached considerable importance to electric mobility in the early 2000s. This incentive was strengthened by its pre-history in 3C battery technology and outsourced manufacturing for leading mobile phone MNEs such as Apple and Samsung. This formed its unique advantage in the most critical complementary assets for EV. Therefore, BYD was very proactive in technological development and market experimentation of EVs in the early 2000s, when many SOEs were still doing small experiments under the 863 Major Project. Based on the available ICEV model F3, BYD developed its first BEV model F3e and PHEV model F3 DM in around 2006, and through the process it cultivated an R&D team professional in EV product design and development.

[60] Note that firm-level data compiled in the appendix is only supplementary.

Shenzhen is in the southern region of China and the forefront of "reform and opening up", hence political intervention is significantly weaker compared to Beijing and Shanghai. Though BYD is not a SOE, it won great attention and support from Shenzhen city government. This is because Shenzhen, an export processing city, lacked manufacturing industries especially in complex products, and it was eager to catch up in this regard. One policy maker in Shenzhen city government explained:

> "*The automobile industry in Shenzhen started very late, in 2004. We were a blank paper...we wanted to do something, and thought about how to narrow down the gap in the sector, because we did not have JVs like Beijing Benz. The automobile industry has a long industrial chain, some of it is higher end. So we wanted to use this to development Shenzhen's automobile industry. It would not have been possible if we did not choose this technological path (EV, author's note)*." (Interview P3-01)

At the time when almost all OEMs had landed in other cities, Shenzhen decided to take a different path by combining the ambition to strengthen manufacturing base with its competences in IT, electronics and 3C batteries, resulting in its strong interest in BYD, which was also seeking a place to invest. Hence the two actors perfectly aligned with each other in their strategic focus on electric mobility. As there was no such thing as "disruptive" because no prior ICEV existed here, Shenzhen government supported BYD with intensive supply and demand side measures.

In the beginning, BYD was very confident about the prospect of BEVs hence deploys e6 to run in the market. However, it turned out that few people were willing to pay for it because it was not mature and relied heavily on charging infrastructure that was almost absent in the beginning. BYD switched its priority to PHEVs after this market backlash. F3 DM model proved to be more commercially mature and less demanding of charging infrastructure. With this adjustment,

BYD decided to maintain a ratio of 7:3 in deployment of PHEVs and BEVs in the short run. To circumvent the patent barriers erected by Toyota, BYD worked out the Dual Mode (DM) configuration of the hybrid electric powertrain, which became the core subsystem of its Dynasty series PHEV models. The model named Qin was very popular among available EV models in domestic market.

The early success of BYD's exploration and experimentation with EVs, with the strong support from Shenzhen city government, strengthened the position of policy makers at the national level to support electric mobility transformation as a window of opportunity for China to catch up and cultivate competitiveness. Several interviewees indicated how BYD's exploration influenced policy making in the central government:

> "*Back then we did LiFePO.4 battery because it had good safety conditions. Earlier during 863, we could not do better in power batteries, then the dominant technology was NiMH. Later I went to Shenzhen to go on a survey tour, and the Shenzhen government told me that the battery firm (BYD) was doing good. It opened my eyes: in the past we did batteries in small workshops…here it was highly automated, and I realised that good technologies were here. Then I reported it to related ministries.*" (Interview P1-07)

> "*BYD was the earliest in China to commercialise EV, though many big corporations (SOEs, author's note) did R&D even earlier*." (Interview P1-08)

SAIC is faced with a different incentive structure. As an industrialised and economically developed city, Shanghai had the urgent task to solve air pollution and transportation problems. The technological opportunity of EV perceived by SAIC was not quite attractive compared to the growing, lucrative passenger ICEV business through JVs with GM and VW. Through early exploration of EV technologies (esp. HEV) in the 863 Major Projects, SAIC accumulated

certain level of product development and engineering capabilities, with the potential to turn EV prototypes into products. Given this basis, Shanghai was selected as one of the six pilot cities to implement the private purchase subsidy scheme in 2010, and this task naturally landed at SAIC, the local SOE reporting to Shanghai SASAC. For both Shanghai Municipal government and SAIC, the political pressure to deliver something in the EV regime was acute. In 2009, Shanghai Municipal government held a working meeting on EV industrialisation, and to implement that, SAIC group soon organised a corporate-level meeting to express its determination to industrialise EV and made up a leadership team. It aimed to deliver HEVs, PHEVs and BEVs to the market by 2012[61]. At the same time, to meet the demonstration requirements ordered by Shanghai municipal government for the 2010 Shanghai Expo, SAIC needed to deliver BEV models.

To the extent that the obligations to implement the state industrial policy at municipal level were eminent, SAIC developed both BEV and PHEV models for small-scale deployment. Compared to BEV, SAIC was more comfortable about hybrid solutions as the latter were more mature on its own and the firm had previous experience in national R&D project. However, neither the city nor the firm acted as mere passive recipients of industrial policy's preoccupation with batter-based solutions, but exhibited strong manoeuvrability. SAIC had good reason to stick to ICE-bases solutions, as it had been building capability through JVs and earned a lot in the passenger car business backed by a localised, high-quality supply networks in Yangtze River Delta. Shanghai along with its satellite cities was almost the most competence automobile industrial cluster in China, hosting best-selling German and US JV brands in the region. It hence had the incentive to preserve the strong incumbent industrial base. At an NEV development conference in 2009, local government confirmed the "focus of support on hybrid

[61] http://news.sohu.com/20090505/n263784283.shtml "SAIC's new energy vehicle industrialization 'accelerated'", accessed on 11/18/2020.

electric vehicles and high-performance battery electric vehicles". Though these presided the formal launch of the "Pure electric drive" strategy, it can be seen that the local government in Shanghai and SAIC were jointly more inclined to pursue a less disruptive, a more pragmatic trajectory while taking care of industrial policy preferences. Hence the industrialisation and commercialisation focus was put on PHEVs. Rowe 550 plug-in model, adapted from ICEV model Rowe 550, was the flagship of SAIC's early efforts in the e-mobility regime. BEV was only attended as a minor part before 2015. The only BEV model delivered to the market was E50, which eventually terminated due to unsatisfactory performance and poor consumer acceptance.

A senior technology manager in SAIC EV development recalled the rationale for the choice on PHEV as the commercialisation and industrialisation focus: *"Then the group CEO insisted that battery function was not good, and price was high. Though 'pure electric drive' was national policy trend, but the competitiveness (of BEV, author's note) was not comparable to PHEVs".* (Interview B3-02)[62] He advised the group to work on deep hybrid solutions like Toyota, but the group CEO commanded to look to GM Volt. *"We debated a long time, and eventually we decided on PHEV, and there was no way back."* (Interview B3-02)

This strategy of technological multiplicity with selective focus was maintained in the "Dual Core" power system technological strategy announced in early 2015. Mr. Xiaoqiu Wang, then the manager of SAIC passenger vehicle company and chief director of its technology centre, openly explained:

[62] This is a historical interview conducted by an EV-focused media in 2016, https://www.d1ev.com/news/renwu/47210 . The original question was: "When it comes to new energy vehicle technology, there are different routes. At present, although SAIC Motor has layouts in the three routes of pure electric, plug-in hybrid and fuel cell, the Roewe e550\e950 plug-in hybrid models are mainly introduced to the market. How did such a technical choice come about?"

> "*For an enterprise, national regulation is very important, but we should not develop solely referring to national regulations. After all, for the moment NEV product costs are high, and we cannot quit traditional automobiles (ICEVs) simply because of NEVs" … "… in a rather long period of time, the ratio between traditional and new energy vehicle is probably 8:2, this is the reason why SAIC publishes 'Blue Core' strategy alongside the 'Green Core' strategy"*. (Interview B3-03) [63]

Shanghai city government made concrete efforts to support the deployment of SAIC's EV products. Apart from encouraging other SOEs to purchase EV models and utilising Shanghai International Automobility city to do demonstration, it also had measures to protect local market niche to assist Rowe's deployment and diffusion. Though not officially acknowledged, it is observed that Shanghai's local subsidy scheme prescribed a 40 L fuel tank size and 1.6 L engine capacity threshold for the highest amount of subsidy[64]. This excluded BYD's model Qin but enabled SAIC to qualify it, making Rowe e550 5,000 RMB cheaper than Qin. Many local buyers shifted to Rowe e550 upon the price change.

What enabled SAIC to experiment with multiple technological trajectories is its growing indigenous technological capabilities and rich resources. SAIC Group has built up a technology centre as the R&D platform for its own brand (Rowe and MG[65]), which was a rich technology resource pool for the entire industry in China. In 2009 it established a subsidiary tech-centre especially for the R&D of EVs, Shanghai E-propulsion Auto Technology CO.[66], LTD. with 2-billion-RMB investment. It recruited overseas returnee engineers to conduct sub-system and core component development for EV. Especially worth mentioning is Dr. Zhujun, who once

[63] This is a historical interview on SAIC Auto Expo, 2015. Source: https://www.sohu.com/a/11864220_115822 Accessed on 01/01/2021.
[64] Subsidy Standards for Promotion and Application of New Energy Vehicles in Shanghai (2016-2017).
[65] MG was purchased from UK. However, after several years, MG models were mainly based on technologies developed in SAIC group.
[66] Also called Shanghai Jieneng Auto Technology Co., Ltd.

studied and worked in Singapore, and joined Pan Asia Technical Automotive Centre (PATAC) in 2004 to work on GM's hybrid model LaCrosse. When Shanghai E-propulsion was established, Zhujun went to take a lead as the general manager and chief director.

At the same time, product system and sub-system level knowhow of EVs benefited from SAIC's close interaction with GM's explorative efforts in PHEVs and integrated system and sub-system global suppliers[67]. Financial resources came from SAIC group as one of the four largest automobile groups in China, as well as capital back up from municipal government, needless to say the various supply-side and demand-side policy support mentioned above. These resources enabled SAIC to experiment with different EV configurations relatively carefree, including costly BEVs. This is why SAIC declared in its five-year plan that the short-term target was not about EV sales volume, but continuous efforts of technological development, experiment with product deployment and building up of indigenous value chain.

7.4.2 Type II firms

Type II firms, including Changan, Geely and GWM, were not active in technological substitution of ICEVs for EVs before 2015. For simplification and to reduce necessary repetition in the analysis, I present the three cases altogether where the incentives are similar and discuss some of them individually when needed.

From the perspective of technological opportunities and appropriability, the three of them did not value EVs much given the burgeoning ICEV business in China's domestic market. Changan and Geely were two of the dominant incumbent players in the automobile industry in China, each of them topping China's best seller list for at least three consecutive years with over 1 million sales/year in the 2010s. Facing intensified competition pressure from JV brands after China's accession to WTO, primary attention was paid to improving ICE powertrain

[67] For example, the development of hybrid electric powertrain had important help from Ricardo.

performance, cost-performance and product quality in the ICEV regime. Changan established a Chongqing-based, globalised R&D network involving nine cities in five countries to build up and gradually improve its indigenous technological competence. Geely achieved this somehow differently through the acquisition of Volvo. Regardless of this difference, both firms could develop (internally) competitive ICEV models in medium-sized sedan market segment (Typical for Changan was the EDO series, and Emerald series for Geely) and the SUV market segment (e.g., Changan's CS series and Geely's GE series). Therefore, they enjoyed high sales revenue and competitive advantage in domestic automobile industry. For Changan, this was further aided by JVs with Ford and other global brands[68]. That said, the technological opportunities in ICEV regime and appropriate conditions were far better than the EV regime (especially batter-based solutions).

In terms of technological configurations, Changan kept the options open. Mr. Xu Liuping, the CEO, commented that for Changan, the technological trajectory in the future ten years would be diverse, with the co-existence of various technological solutions, and Changan were to adopt a gradualist approach by rolling out HEVs first and then BEVs (and FCEVs) according to "*degree of difficulty and commercialization feasibility*"[69].

Switching to the external incentives, despite Changan and Geely have different corporate governance structures, neither of them faced heavy pressure from the state. Changan was a SOE financially responsible to the central government SASAC. However, it was only a second-tier subsidiary of a gigantic state-controlled group, China South Industries Group Corporation (CSGC) and based in Chongqing Municipal city, a traditional industrial city in Southwestern China. Therefore, local government did not have the authority to impose industrial policy

[68] As a matter of fact, JV brands sales make up a significant share of Changan group's vehicle sales before 2017. However, its indigenous brand (Changan Auto) sales are still voluminous.
[69] https://auto.sohu.com/20090715/n265220817.shtml "Changan VS BYD, two cities compete for new energy vehicles"

commands on Changan. The firm's parent group CSGC had many other priorities to serve and was very cautious in using state capital to make investments in uncertain, risky new technologies. Nor was Chongqing motivated to replace its incumbent automobile industrial cluster with new ones that might affect local value chains, GDP growth and employment, as the automobile industry ranked first among its five "pillar industries"[70]. In 2010, automobile and motorcycle industries generated a GDP of over 278 billion yuan, representing 30.6% of the gross output value of industrial enterprises above designated size that year.

Under such circumstances, both Chongqing Municipal government and Changan were not very enthusiastic about EVs' fast industrialisation – under the "pure electric drive" strategy –in local market in the short run. They however did see opportunities in the broad electrification trend, albeit in the most incremental direction – HEVs. Following technological exploration in HEV R&D in the 863 Major Projects, in 2009, Changan was almost the first to commercially launch its HEV model Jiexun. This soon proved to be a failure, as few people would pay for it given the high costs and flawed products[71]. This did not help Chongqing enter the first round of pilot city list for the private purchase subsidy scheme as well. Without local subsidies, it was impossible that Changan's EV models could sell well in the market. At the same time, Changan was still very sceptical about the prospect of EV even after 2012. As many other incumbent firms, it assumed a "wait-and-see" attitude. In its 2014 corporate plan, Changan still adhered to the principle of "*broad spectrum, great depth and multiple trajectories*" in the e-mobility regime, prioritising HEVs over PHEVs and then BEVs. It was not until 2015 that Changan realised it was really the time to shift to "pure electric drive". One technological director commented:

[70] This is a heuristic word, 支柱产业, meaning that an industry is the backbone of an economy, just like a pillar to a house, and without it, the supported entity would be unstable, unsustainable, and even collapse.
[71] This is not only due to the immaturity of EV itself, but also the under-development of ICE powertrain technology at that time.

"*Changan was doing the best in HEV back then in the country. We sticked to our course and worked hard, but once government subsidy faded, we lost the opportunity. Changan was had no choice but to shift to BEV and PHEV*." (Interview B1-01)

"*We chose HEV for two reasons. First, our company had much technological accumulation. Second, at that time battery technology was immature, and difficult. Therefore, we invested a lot of money on HEV, and just followed NEVs (by NEV, the interview meant 'pure electric drive', author's note)*" (Interview, B1-01)

Geely made slightly more efforts on EV product deployment, but overall, its indigenous efforts on technological development and product commercialisation were very limited. In the turn of 2010, it was almost fully occupied with acquisition of Volvo and technological and product upgrading afterwards in the ICEV regime. In 2010, private subsidy scheme pilot landed in Hangzhou, which hosted a certain scale of automobile industrial cluster and early experiments in small EV models (e.g., by Zotye). Regarding this, Geely's CEO Mr. Shufu Li insisted: "*Geely will not give up the original strategy of 'advancing in multiple trajectories', because the market is far more important than subsidy. Relying on subsidies is a short-sighted practice. It is more important for companies to understand market demand and regularity of new energy vehicle technology development*."[72]

Geely's strategy on electric mobility was also based on the integration with Volvo. One insider disclosed in an interview: "*Compared with Volvo's brand value, its advanced technology is a resource that Geely values more"*[73]. As manifested in CEO Mr. Shufu Li's remark in a media interview: "*Ford and Volvo have spent tens of billions of dollars to conduct research new energy technologies in the past ten years, which will be an inexhaustible wealth for Geely*." [74]

[72] This is Mr. Li's remark in 2010 at an open event at Geely University. https://www.china5e.com/news/news-106462-1.html
[73] Media coverage, https://auto.sina.com.cn/news/2010-04-20/0728591809.shtml
[74] The same source as above.

Apparently, the approach Geely took was to secure its place in the future electric mobility competition based on Volvo's technological competence, and this would not take place immediately. Even in March 2014, Mr. Li re-iterated the company's strategy by being a follower, pointing out the fact that the prospect of EV was still unclear. He explained why Geely explored along multiple trajectories:

> "*Different EV technological trajectories have shared technologies. For example, there is a lot in common between fuel cell battery, lithium battery, and hybrid technology; electric motor and BMS are also common. We increase our input in these aspects, and we will be safer. We will not be caught in a situation where one day one technology is disrupted, and we do not have any other technologies. Preparing several technologies makes Geely's survival and development in a stable status*." (Interview B5-01)[75]

However, this does not mean that Geely totally stayed away from e-mobility, given the fact that Hangzhou was selected as one of the first-round pilot cities to implement the "Pure electric drive" strategy and policy support was abundant. Hangzhou was eager to build up the EV sector because its industrial structure was biased towards digital technologies and E-commerce but weak in manufacturing sectors. As a private firm, while there was no obligation for Geely to comply to the industrial policy, the offer of 1:1 local subsidy and the related polies that encouraged EV uptake were still attractive. In presence of some already very active early movers, Geely collaborated with them to follow the technological and industrial development in the EV. Up to 2014, a small-sized, A00 segment BEV model called Zhidou was already very popular in Chinese nascent EV market. This belonged to Xindayang Machinery & Electrical Group Co., Ltd., a company outside of the sector which already done years of R&D on mini

[75] This is a historical interview, when Geely CEO Mr. Li answered media interview. https://www.evlook.com/news-16158.html

and small BEVs. Because Xindayang lacked enough factories and financial resources to proceed to mass production, Geely seized this opportunity to tap into electric mobility. Therefore, together with Xindayang and Jinsha River Investment Co., Ltd., the three of them invested 1 billion RMB and established Xindayang Electric Vehicle Technology Co., Ltd. to embark on EV deployment. At the same time, Geely invested 50% share with another EV manufacturer Zhejiang Kangdi Technologies Group to form the JV Kandi Technologies Group and rolled out mini-EV and A00 segment EV in Hangzhou. The Panda model was very popular in local market. Through these two JVs, Geely was involved in e-mobility as a follower and minimised its input and risk in technological development and manufacturing.

GWM presented a case that is more similar to Changan. It is a private firm based in Baoding, a small city in Hebei province[76]. GWM was almost the sole automobile manufacturing company and hence the economic backbone in the region. Baoding was not among the pilot cities to implement the "Pure electric drive" policy. While the city government did not have capital control over GWM, neither did it actively use policy instruments to promote EV adoption due to its limited fiscal resources and industrial incumbency status. GWM was similarly not motivated to engage EV at that time. Having transformed from a truck manufacturer, its experience in passenger vehicle manufacturing was shorter than many others such as FAW, Dongfeng and SAIC. With limited financial resources and political backup from central or local government, it targeted at SUV segment to carve out its own competitive advantage, when the sedan market saw an ongoing race-to-the-bottom game and pickup truck was not a mainstream market segment. GWM was best known for the large-size, cost-efficient and practical SUV model Haval, which was extremely popular among consumers with several

[76] Though Hebei is geographically next to Beijing, GWM does not strictly belong to the Beijing-based industrial cluster, but a more stand-alone automaker.

family members and a tight budget. It took up over 70% of GWM's total vehicle sales. In 2014, the single model Haval 6 created a 31,5854 sales record.

The period before 2015 was critical for GWM to build up its own technological capabilities, competitiveness and brand image in domestic market, hence it paid little attention to the scale production and development of EV. Only three models were announced but saw nearly ignorable market deployment. However, they covered three different technological configurations including HEV, PHEV and BEV thanks to the company's indigenous capabilities in ICE power system.

7.4.3 Type III firms

BAIC, JAC and Zotye were also very active in technological substitution but focused only on BEV. In terms of indigenous brand, they were all in a less competitive status in China's domestic market. BAIC had JVs with German brands (Mercedes Benz) and Korean brands (Hyundai), and its indigenous commercial vehicle brand Foton performed well. Whereas its indigenous passenger car brand Senova only started in around 2012 through acquisition of the then outdated Saab vehicle platform from a Sweden company. BAIC's indigenous technological capability in passenger car was hardly built up as its time spent on even reverse engineering was very short. In 2007, BAIC group established the Beijing Automotive Research Institute New Technology Department to specially develop EV technologies. Like others it started with hybrid solutions supported by 863 Major Projects, MOST and Beijing Science and Technology Commission. This was not fruitful, though.

In 2009, national industrial policy became biased towards battery-based solutions. Beijing Municipal government viewed this as a strategic opportunity for an alternative path of automobile industrial development, because the city did not have a strong industrial base in the ICEV regime; its only SOE, BAIC, had very weak technological capability in this regard

(especially passenger cars). In 2009, Beijing New Energy Vehicle Technology Industrial Park was established in the city's industrial suburb to host BAIC New Energy Vehicle Co., Ltd. In the inaugural, Mr. Qi Liu, Secretary of the Beijing Municipal Party Committee, declared that: "*The unveiling of 'One Park, Two Companies[77]' opened the prelude to Beijing's new energy vehicle development strategy. We will take pure electric vehicles as the strategic and industrial direction of leapfrog development*."[78]

Local government in Beijing exerted strong pressure on BAIC to adopt the "pure electric drive" strategy and take timely action. "*Back then Beijing Municipal government decided to specify battery electric car as the future direction of NEV, and after we made up our mind, in 2009 we quickly embarked on R&D of battery electric cars*" (Interview B6-01) [79]. Apart from this pressure, for BAIC itself, technological opportunity presented by electric mobility was also important. BAIC also had no competitiveness in domestic market in ICEV passenger car business. Most of Senova's ICEV models operated as taxi fleet in the city, while private purchase was rare due to inferiority in quality, function and brand image compared to domestic competitors. Therefore, for BAIC, e-mobility was the inevitable choice it should readily embrace. Mr. Zhan explained the situation very clearly: "*For BAIC, firstly we needed to set a strategic orientation, that is, the transformation from traditional manufacturing towards manufacturing-service. Therefore, we viewed new energy vehicle as a strategic sector in BAIC's transformation, and it is an important pathway that BAIC could keep growing sustainably*." (Interview B6-02) [80]

[77] Two companies refer to BAIC New Energy Vehicle Co., Ltd. and Beijing Pride New Energy Battery Technology Co., Ltd.
[78] https://www.most.gov.cn/tpxw/200911/t20091119_74291.html , "Minister Wan Gang and the leaders of Beijing inspected the research and development of new energy vehicles in Beijing".
[79] This is a historical interview with Mr. Zhan. Zhan Wenzhang: 16 years' experience in China's NEV. https://nev.ofweek.com/2020-04/ART-71011-8610-30437283.html
[80] This is a historical interview, an open speech made by Mr. Zhan. https://m.gasgoo.com/news/60358478.html

In the view of decision makers, the challenge they faced in pushing forward electric mobility was not about technology itself, but more about market deployment and to seize the first-mover advantage. With the strategic alignment between Beijing Municipal government and BAIC – though the local government exerted strong pressure on BAIC as well, intensive measures were in place to foster the market deployment of BAIC's EV models. Model EV150 was the first commercialised BEV developed by BAIC in cooperation with value chain partners. It entered the market as taxi running in Beijing city. This marked the tangible implementation of BAIC's "Blue Sky Guardian Action Plan" in transformation of e-mobility. In the years that followed, BAIC enriched product models based on EV150, mainly upgrading technologies and extending electric drive ranges to 200km, 300km and so on.

Due to limited technological capability in ICE power system and product system integration, BAIC did not develop PHEVs. Beijing Municipal government's policy also aligned: it specified "pure electric drive" as vehicles that were only driven by power batteries, almost equalling BEV. This had something to do with its capital city's status in the forefront of emission reduction and structural adjustment to industries to phase out heavy and polluting sectors. When the central government launched the "pure electric drive" strategy, Beijing forcefully lobbied decision-makers into including it as the sixth pilot city in the first round, in order to get the policy rents to rejuvenate its growth and foster structural transformation. Therefore, it adopted a radical approach that no longer involved ICEs. Apart from this openly claimed reason, another important factor underlying this specification was that BAIC lacked competitiveness in ICE-related solutions and capacity to develop a HEV prototype. If Beijing rolled out subsidy scheme exactly the same as the national policy, then much of the money would go to other EV manufacturers, for example, BYD[81]. Out of these combined factors, in

[81] Mr. Wang Binggang (1938.03 -2021.08), the former leader of the National New Energy Vehicle Innovation Engineering Expert Group, once commented openly: "The Beijing Municipal Government nominally

Beijing's implementation of the "pure electric drive" industrial policy, PHEV was excluded from receiving the 1:1 local subsidy. Both Beijing Municipal government and BAIC NEV were exclusively focused on the promotion of BEVs since the beginning.

The choice of JAC on BEV was also dominated by firm-level incentive and the support from local government, in a less protectionist and statist approach. JAC was a SOE in Anhui province in central China, reporting to the SASAC of Hefei city government, the capital city of the province. Economic development and industrialisation here was relatively backward and smaller in scale compared to first-tier cities in China, hence Hefei had been catching up ambitiously aiming at high-tech sectors, with some initial successes[82]. Historically the economic governance in this region was not interventionist. Local government did not impose electrification on JAC. Considering that Hefei had not reached the stage that environmental problems became particularly urgent, the city was more motivated to pursue industrialisation. Overall, the political pressure faced by JAC to embark on technological substitution was very low.

Instead, both Hefei city government and JAC themselves had strong incentive to promote EVs. JAC only stepped into passenger vehicle manufacturing in 2006 as a small truck manufacturer, and without strong technological and business basis in the ICEV regime, saw great potential in the EV regime. JAC started following EV technologies as early as 2002 when world-wide exploration was going on. It tapped into various vehicle configurations: BSG, ISG, BEV, etc. Due to its weakness in auto transmission technology, it did not apply for R&D projects on

emphasises the need to control pollution and smog, but more people think that it is because Beijing does not have hybrid products. The Beijing Municipal Government will not admit it, and BAIC BJEV also said that 'the government has no protection for us'. However, objectively people have their own views on this." https://chejiahao.autohome.com.cn/info/1510010/

[82] It is known for localising BOE's 6th generation LCD panel production line through a joint investment of 17.5 billion RMB. At that time, BOE was at the brink of bankruptcy while Hefei city government had only 16 billion RMB's annual revenue. This risky move proved to be extremely successful and laid the foundation for Hefei's reputation as "the best venture capital city".

hybrid vehicles under the 863 Major Project framework because of the limited commercial value perceived by JAC. In its own exploration, the R&D team figured out that HEV would offer JAC no advantage; nor was PHEV practical in the short run because it required capabilities in battery and transmission technologies that JAC were in lack of. Therefore, when some early voices about the "pure electric drive" strategy in policy debates reached JAC, it swiftly decided to go this way. In 2009, JAC confirmed the "pure electric drive" technological trajectory at the firm level, intending to start from BEV and then tap into PHEV when auto transmission technologies were mastered[83]. Hefei city government also had the intention to seize this opportunity to strengthen its manufacturing industries and secure a new engine of economic growth. When the private subsidy scheme was launched, the Science and Technology Bureau in Hefei city government urged JAC to accelerate their pace in order to qualify the first-round pilot, and JAC did not disappoint it. Thanks to early accumulated competence and concerted efforts on product development, JAC was able to roll out BEV models to meet the demonstration requirements. The first batch of EVs consisted of impressively over 500 vehicles, and the inauguration ceremony even attracted Mr. Gang Wan to attend. One manager commented: "*Back then it is not like Hefei's nowadays. Hefei was not that developed then, and it did not have much influence. For what did they give the pilot city to Hefei? Mainly because of JAC*." (Interview B3-01)

However, due to relatively small group size and limited resources, it had to use all of its resources economically. According to Mr. Xia Shunli, the head of JAC's EV R&D department, "*adhering to the consistent philosophy of JAC, he told his team from the very beginning that they must produce things that can be produced quickly, and the products produced must be*

[83] JAC also explored REEV technologies during the 2000s. iREV, a REEV model based on Heyue ICEV product platform once appeared in an exhibition, but it never entered market. Hence this technological configuration was excluded for analysis because it did not commercially exist.

things that consumers like"[84]. Following this product market positioning, the first BEV model adapted from ICE vehicle platform Tongyue came into being in 2009. This model was upgraded in 2010 to the second generation, formally named as iEV series. Up to 2013, iEV model was upgraded to the 4th generation after solving many product-related problems, and had rather good performance compared to other BEV models available at that time in domestic market.

Chery's decision-making was dominated by firm-level incentives. It was a SOE based in Wuhu city, a small and less developed one, in Anhui province. As a latecomer in domestic automobile industry, Chery thrived in China's passenger car market through industrious R&D efforts from reverse engineering to indigenous technological development on cost-effective, affordable ICEV models that met customers' needs, hence widely known as the "Technology Chery"[85]. Although it was a SOE, around only 20% of its share belonged to Wuhu city SASAC. Objectively local government had very limited sway over the decision-making process at Chery, not to mention the non-interventionist governmental style in the region. Hence Chery's technology and business strategies had been quite market oriented. Since 2002, Chery had made success through cost innovation through a combination of low-cost, economic models such as QQ, Ruihu, and Fengyun, etc. Popular ICEV models were QQ and Fengyun. In 2010, Chery became the first indigenous brand automobile manufacturer to reach a 2-million accumulative vehicle sales record.

Chery's first EV model was A5 BSG as a result of active participation in 863 Major Projects. This configuration was based mainly on ICE solution combined with start-stop function; a common solution seen worldwide. Once national industrial policy shifted its course to "pure

[84] This is a historical interview conducted by China Industry News http://www.cinn.cn/headline/jzdc/201801/t20180122_161378.html.
[85] This is an endorsement in the industry on Chery for its concentrated, unmoved efforts on technological development.

electric drive", hybrid solutions based on ICEs proved to be unfavourable in the market without subsidies. Chery refocused on cost-effective electric cars, which boiled down to its QQ3EV model. This did not target the mainstream market segment as those JV brands models, and many observers and policymakers called it "low speed electric vehicle (LSEV)". These were small, frugal and cheap vehicles propelled by lead acid battery which did not support high speed drive or long drive range. One important advantage was that it did not require additional charging infrastructure other than 220 V household use electricity. QQ3 EV was very popular among price-sensitive, low-income groups in China, selling over 15,000 models up to October 2014. Though not classified as "new energy vehicles" by the industrial policy, QQ3 EV made up the largest proportion of single-model EV sales in China's domestic market. In order to qualify for the private subsidy scheme, Chery subsequently modified QQ3 EV into eQ using lithium batteries. This helped it gain the essential financial resources to keep growing and expanding, as the scale of Chery group was not comparable to other giant groups (e.g., FAW, SAIC) and local governmental fiscal support was also scarce.

It can be seen that what attracted Chery in its product innovation and commercialisation of EV was the technological and business opportunities specifically in the A00 size segment through cost innovation. However, as one of the few economic backbones in the city, Wuhu did want Chery as a SOE to protect economic development, local industry and secure jobs. The eQ series targeting frugal innovation, which did not belong to mainstream market (small to medium size segment) enabled Chery to keep a balance between preservation of local industries and pursuing and exploiting emerging technological opportunities.

There was no doubt that Chery possessed the technological capability to develop PHEV solutions, but this did not translate into tangible product innovation in the short run due to resource constraints. It did not earn much following low-cost strategy despite selling many cars. The financial conditions at one time got worse because of its multiple-brand strategy in the

ICEV regime which led to the cannibalization among its different product models, resulting in an alerting shrink in its market share. Given these difficulties, Chery adopted a gradualist approach to first concentrate on BEVs and then tap into PHEVs, and this was to some extent similar to the approach that JAC adopted. However, JAC was comparatively more proactive as it targeted EV deployment at the A0 segment, one of the mainstream sedan market segments in domestic market.

Zotye chose BEV as the sole technological configuration in the EV regime and actively participated in product launch and market deployment. This was driven by a combination of firm-level incentive and local governmental motivation to support the emerging sector. As a latecomer firm from the private sector, it had no JVs with global MNE brands, nor financial backup from local government (via state capital) to secure its survival. Eager to grow and build up competitiveness, it hence saw great opportunity in the emerging EV regime. In 2005 it started working on BEV and four years later delivered its first model 2008 EV, which was then put into local demonstration in Hangzhou city. As a matter of fact, this model was the first to receive NEV licence plate in China, and both Zotye and local policy makers were quite optimistic about it. Though there was no political pressure for Zotye to execute industrial policy, Hangzhou city was highly motivated to support this emerging manufacturing sector [86]. As Hangzhou entered the first-round pilot city list, Zotye could receive central and local governmental subsidies for EV deployment.

Without sufficient technological competence in ICEs, Zotye chose BEV as the entry point. It entered the automobile manufacturing only after China's accession to WTO. In 2003, the headquarter was established in Yongkang city, Zhejiang province, and later its R&D centre landed in Hangzhou. The first ICEV model called 2008 was launched in the year 2005. In face

[86] This has been discussed in Geely's case earlier and will not be repeated here in detail.

of massive market demand, constraint in financial resources and lack of pre-history and capabilities in ICEVs, it chose to target the highly profitable SUV segment in a quick pace. Through purchasing vehicle platforms (e.g., Fiat) and production line from other EV manufacturers (e.g., Toyota's production line in Taiwan), Zotye soon expanded its product series and rolled out new models. However, this was achieved through adaptation and turnover of existing vehicle models by prestigious brands[87] that were then sold at an attractively affordable price. During the years when the market was not that crowded, this strategy worked and generated much revenue. Much of this money was then spent on supporting its active experimentation and deployment of BEVs. This was officially called by its decision makers as "interactive development" between SUV (ICEV) and BEV. "*Zotye now adhere to a strategy of interactive development, traditional energy vehicles[88] and new energy vehicles' interactive development, because at present we are still a young enterprise, to expand the market we still use traditional energy vehicles. We need to do well on this*." (Interview B12-01), explained Mr. Jianzhong Wu, chairman of Zotye, in 2010. However, the opposite side of the quick expansion and turnover at Zotye was the very limited efforts and investments in building up its own technological competence and R&D capabilities in automobile[89]. Therefore, Zotye had to concentrate on BEV as the sole technological trajectory that it could manage working out. This was additionally justified by the fact that BEV received far more subsidies, which meant a lot for a resource-constraint enterprise. In times of technological immaturity, Zotye and Hangzhou city were both enthusiastic about innovative business models to make BEV models run in the market. They undertook many pioneering projects back then, for example, learning that Better

[87] One example is Zotye's adaptation of Porche. It is reported that at an automobile expo, when the chair of Porche saw a vehicle model by Zotye that looked extremely similar to Porche, he seemed very unhappy about this.
[88] This refers to ICEVs.
[89] For example, its ICE was based on Mitsubishi' old version.

Place tried battery swapping in California to solve the charging problem, they worked with State Grid to experiment with this solution[90].

7.4.4 Type IV firms

Both FAW and Dongfeng were SOEs affiliated to central government SASAC and among the "Big Three" that received national industrial policy support to nurture "national champions" in the automobile industry since the 1980s. FAW group formed JV with most popular German brand VW (including Audi) and Japanese Toyota, and enjoyed an important share in domestic market. The central government also looked to them to carry out technological explorations in the EV regime in the early 2000s. FAW was one of the first SOEs to participate in the 863 Major Projects, but this only resulted in vehicle prototypes for demonstration, for example HEV model B70 and B50 adapted from indigenous brand Benteng. Hybrid solutions were also tested on ICEV model under another indigenous brand Hongqi (in Chinese language this means Redflag, 红旗). In 2010 when the private subsidy scheme came into force and Changchun was selected as one of the first-round pilot cities, FAW sedan company further rolled out BEV model Benteng B50 and Weizhi B50 and established an NEV subsidiary.

In 2011, FAW published its "Blue Path Strategy" [91] in response to the "Pure Electric Drive" industrial policy. It announced to invest around 9.8 billion RMB for EV product development, vehicle platform development and building up of production capacity. 13 EV product models were in the plan and 4.3 billion RMB was said to be invested in EV factory and production line construction in Changchun industrial cluster. In 2014, it further published the "New Energy Strategy" aiming for 15% domestic market share in the EV regime. However, these announced strategies sounded quite ambitious and vague, but are hardly put into practice and take effect.

[90] This turned out to be unsuccessful and stopped at a very initial scale, though. However, Zotye continued with small BEVs that had limited drive range and very low price, which were still attractive to many commuters.
[91] This is also called "low carbon and energy saving technology strategy" by FAW.

At that time, FAW group was undergoing an important strategic adjustment in its businesses. On one hand, the group decided to get rid of several subsidiary companies and concentrated resources to build up its own indigenous brands. However, its indigenous sedan sales declined 24%, among which sedans under Benteng brand fell by nearly 30%. This reduced its net income from 2,170 million RMB in 2011 to minus 8,000 – 5,000 million RMB in 2012. This situation continued ever since except an increase in 2013, which did not help FAW sedan recover from shrinking. Reduced financial resources added difficulty to FAW's implementation of EV strategy which would not be profitable in the short term. Therefore, though the EV production site was planned to put into use by 2014, it was eventually abolished in 2017 without ever being accomplished. Up to then, around only 24.15 million – 0.56% of the total investment – was actually made. According to the decision reached in the board meeting, "*based on the principle of benefits maximisation, the company plans to adjust the implementation site of new energy products in the future and terminate the construction of new energy factory technical transformation projects … improve the efficiency of capital use, and protect the interests of the company and all shareholders*."[92] FAW chose to use existing production capacity for EV development instead. On the other hand, the top leadership at FAW group had always desired to build up the Hongqi brand, which was not simply a sedan brand, but bored political implications[93]. When China's automobile industry made moderate progress in the 21st century, FAW's leaders wanted to rejuvenate this program, which would also be an important political asset for corporate leaders once the brand succeeded. Therefore, much financial resources and technological competence were devoted to the Hongqi brand[94], leaving less space for exploration and experiment in the nascent EV regime.

[92] "Announcement on Adjusting the Implementation Site of New Energy Products in the Future and Terminating the Construction of New Energy Factory Technical Transformation Projects".
[93] In the 1950s, the early FAW started manufacturing Hongqi sedan model as a prove of accomplishment after the establishment of PRC. This was not fruitful, however. For a more detailed description, see
[94] The company plans to do it first in the ICEV regime and then tap into EV models.

On the side of local government, though Changchun was selected as one of the pilot cities to implement green industrial policy, the local government lacked the institutional authority to command a centrally affiliated SOE. FAW group, on the other hand, had many other priorities to serve, and shareholder interests to take care of, as has been discussed above. From the perspective of Changchun city government, in the short term it was more important to preserve and strengthen the ICEV regime to sustain GDP growth and secure local employment in presence of popular JV brands. This fitted more with FAW group's own economic and financial benefits.

As a result, before 2015, only B50 BEV was seen in the market for sale. FAW did not roll out PHEV models despite its declared accomplishment of Hongqi PHEV prototypes. A lack of indigenous technological capability in the ICEV regime was another important factor. There was little incentive to invest in technological development when JV brands sold very well. Limited technology transfer through JVs left FAW with weak absorptive capacity to master core technologies or develop new technologies. Without enough competence in ICEs and only half-hearted engagement in BEVs, it was difficult to launch market-oriented PHEV models.

The story of Dongfeng was similar in many aspects, especially its incumbency status and lack of local governmental incentive to push for green structural change. It was renamed from Second Automobile Works to Dongfeng and moved headquarter from Shiyan, an old industrial cluster to Wuhan, the capital city of Hubei province in Central China by the middle segment of the Yangtze River. Its JVs with French brand Peugeot/Citroen and Japanese brands Honda and Toyota were highly profitable. Another important source of income was generated by commercial vehicle business (e.g., heavy trucks and military-purpose vehicles), similar to Jiefang of FAW. This took up nearly 50% of Dongfeng group' income[95]. In the passenger

[95] In some years, the ratio is even higher than 50%.

vehicle business, while technology transfer via JV was not so successful, its efforts on indigenous brand did not go well, either. The sedan business unit of Dongfeng was established in 2007 shortly after its movement to Wuhan, and in 2011 it published indigenous brand development plan "Qian" (乾) D300[96] that targeted 1 million passenger vehicle sales towards 2016. This partly included two sub-brands, Fengshen and Fengxing, both targeting the mainstream automobile market segments in China. With only limited experience in passenger vehicle technology and product development, ICEV models under these brands were hardly competitive in the market, and as a result, the D300 target was not met. However, Dongfeng even aimed for higher-end market segment seeing other automakers do so. It started its so-called "No.1 Project" on A9 model in 2012, and three years and a half later, this model was launched. Whereas it was built on mature vehicle model PSA no. 3, a vehicle platform provided by French partner, yet another sign of lacking indigenous technology capability itself.

This bottleneck was due to a lack of experience and technological capability in the ICEV regime (passenger car), which further constrained Dongfeng's ability to develop functionally good EV models. Moreover, when financial resources and R&D efforts were concentrated on implementing the D300 plan, the resources that could be used for EV development – which was costly, risky and unprofitable – were even more tight. This was exacerbated by the fact that Fengshen brand did not bring revenues to the group, but financial loss[97]. Under such circumstances, before 2015, there was no available EV model developed by Dongfeng deployed in the market. The only model Fengshen E30 was still under development and

[96] The corresponding Chinese character is 乾, which refers to the first trigram of The Eight Trigrams of Zhou Yi. The entire plan denoted Dongfeng's aspiration to pursue leadership status in the industry and targeted for 3 million sales in indigenous brand towards 2016, among which passenger vehicle would sell 1 million models.
[97] In fact, several sub-brands under Dongfeng's "Great Autonomy Strategy" to build indigenous brands, including Fengshen, Fengxing, Fengguang, Yulong, Zhonghua and others, were heavily invested but did not earn money. The more Dongfeng invested, the more financial loss this resulted in. Therefore, the financial condition faced by Dongfeng's indigenous passenger vehicle business was not encouraging.

launched in 2015, with a short drive range of 170km, lagging behind its domestic competitors in key technological parameters.

From the perspective of local government, because automobile industry was the strategic industry to not only Wuhan city but also Hubei province, local authorities did not want disruptive changes; nor could they impose industrial policy directives on Dongfeng as the latter reported to SASAC in the central government. Though selected as a first-round pilot city, without enough functional EV models developed by Dongfeng, there was very little space for Wuhan city government to provide policy support to deploy and diffusion them.

GAC was a local SOE based in Guangzhou city, the capital city of Guangdong province. The region had been the forefront of market economy reform and opening up to FDIs, hence local government was not interventionist at all. The way that local authority interacted with GAC group and how economic activities were coordinated was characterised by Eric Thun as *laissez faire* model in China (Thun, 2006). Guangzhou was quite late to invite global automobile manufacturers to form JVs with local firms, hence missed several North American and European OEM giants and had a relatively small scale of automobile industry compared to regions such as the Yangtze River Delta dominated by SAIC group and its partners. For a long time, GAC group's revenue was mainly contributed by JVs with Japanese brands Toyota and Honda after 2002, and was later joined by Fiat, another international brand to form JV with GAC. Even in 2010, GAC was still focused on new JVs and the expansion of its production capacity. The strategic focus was undoubtedly in the ICEV regime and its upgrading.

In 2010, GAC group established its indigenous brand Trumpchi that positioned itself in the middle and higher end of the market. This marked the first step of the group's corporate strategy shifting to the parallel development of JV brands and indigenous brands. In the 2010 annual report, ranking first among the to-do lists was to ensure that Trumpchi ICEV passenger cars

could be successfully accepted in the market and form an excellent brand image through high-quality customer service. Both Guangzhou city government and GAC group provided much support for this work, including the establishment of GAC Research Institute and GAC Components R&D Centre, and investment of a new industrial base. Like other indigenous brands, Trumpchi gained initial market success via SUV model, i.e., the GS series.

During 2010 to 2015, the bulk of GAC's income came from JV brands and Trumpchi's share gradually increased. In face of fierce competition in China's domestic market, Toyota and Honda intensified their product innovation efforts and improvements on high-performance ICEs. For GAC, JVs were expanding quickly and Trumpchi was in the critical period of capability building, therefore the resources that could be allocated to EV were very limited. GAC also perceived the technological opportunities in this emerging regime negatively. In its 2012 annual report – when the first round of EV demonstration almost concluded – it insisted that "*The state (Chinese government) highly valued the development of energy saving and new energy vehicles. Though our company is also working on…however, new energy vehicle technologies are not mature, and cannot entirely replace traditional fuel vehicles*[98]*. There is considerable uncertainty regarding the future prospect and direction of these technologies*[99]." [100] With rich income from selling ICEVs, there was also not enough financial incentive to invest heavily in EVs.

Therefore, GAC's involvement in the EV regime was mainly in technological exploration and prototype development, and its choice was informed by Japanese partners. The established competitiveness of Toyota and Honda in HEV convinced GAC that hybrid solutions were more practical and should be the strategic focus in industrialisation of EVs. At that time, Toyota and

[98] This refers to ICEVs.
[99] This refers to EVs.
[100] GAC 2012 Annual report.

Honda were about to launch their HEV models at a large scale in Southern China market. For example, the iconic Toyota Camry model was launched in 2012, the only model with engine capacity below 2.5 L and was very popular among consumers. The two brands also planned to localise core hybrid system technology development and power system production in Guangdong, which would be an invaluable asset for the region. Therefore, Guangzhou city government was very interested in HEV solution lead by JVs and far less interested in battery-based solutions that no firm was good at. As a result, both Guangzhou city government and GAC showed only half-hearted reception of the "pure electric drive" strategy.

This does not mean that Guangzhou dismissed national industrial policy entirely. The only pressure is said to come from inter-governmental competition, in the sense that other cities with their SOEs had more or less EV models for demonstration under the "pure electric drive" strategy, it would make Guangzhou's governmental officials under political stress if they did not have at all. One manager told:

> "*Guangzhou city government asked GAC to work out EVs. Later the city government was open, in the case that GAC did not do, then it introduced BAIC to Guangzhou. Now you can still see many BAIC's EVS, this is because it acquired a factor in Zengcheng district. By doing this BAIC was able to network with Guangzhou government. Then you see, this had pressure on GAC. Even BYD's EVs were here. At this moment GAC had to do something. You yourself is the largest SOE in Guangzhou, if you do not do it, then you are not living up to your responsibility*." (Interview B7-01)

> "*So, we first adopted a following strategy, several thousands' vehicle every year, at least we had something. (But once we really made up our mind, in 2017 we did it very quickly and in a large scale.)*" (Interview B7-01)

It was only then that GAC started to put more emphasis on the battery-based solutions. Insisting that BEV was far from technologically and commercially mature, and seeing the fact that its own HEV technology was not as mature and competitive compared to Japanese brands, it eventually undertook an R&D program sponsored by MOST focusing on REEV configuration. This became a stepstone through which GAC could master product system development involving power batteries and still utilise its past experience in hybrid technologies. Only until 2014 that GAC had formed the initial system integration capability in EV through this project, and there was a limited number of models are demonstrated in the Pearl River Delta region mainly in the public transport sphere.

7.5 Cross-case comparison and synthesis

7.5.1 Cross case comparison: stylised facts

Secon 7.4 has applied the analytical framework to analyse and explain the different strategic choices on directionality of innovation among twelve incumbent OEMs in China and shown how the interplay between firm-centric, variegated incentive structure and firm-level factors contribute to the heterogeneity among firms. Based on the case studies presented above, I now summarise the interplay between analytical elements and variables for each firm in the tables below. To make it easier to navigate, several clarifications are made here.

First, national industrial policy is used as the reference point for understanding the working direction of other incentives. It is denoted by "+", meaning that it works in the same direction as national industrial policy. This applies to political pressure from local state, local industrial structure and governmental incentive, and perception of tech-opportunities in the EV regime. If there is no political pressure, or the political pressure proves to be *de facto* minimum, then it is assigned "Null".

Second, moderating factors vary in degree, signalled by the "*" mark. ***means technological capability is very strong, **means moderate and * means weak. The same applies to the evaluation of overall resource portfolio of firms.

Third, direction of innovation at the firm level is again explicitly shown in the right column. Forth, both the first and this second point emphasise that there is no absolute value, but empirically assessed status, based on the triangulation of multiple sources of credible data. Because they are firm-centric, they are naturally a relative term depending on which firm is compared to which others.

Based on these specifications, the structured comparison between the four firm groups and within each group is presented in the tables below (Table 7-1-Table 7-4).

Table 7-1 Incentive structure, firm-level factors and direction of innovation – Type I firms

	National industrial policy	Political pressure from local state	Local industrial structure and governmental incentive	Perception of tech-opportunities in the EV regime	Technological capability in the ICEV regime	Overall resource portfolio	Directionality of innovation
BYD	Pure electric drive, with a focus on battery-based solutions. +	Private firm, no political pressure from Shenzhen city government. Null	Shenzhen is a latecomer city in manufacturing industries, esp. automobile. Government eager to support. +	Highly valued, due to its latecomer status and unique competence in battery technologies. +	Strong ***	Rich and expanding, through both vehicle and ICTs business. Active local governmental support of EV diffusion. ***	Active in technological substitution and a broad scope of technological variation; in e-mobility, priority is hybrid solutions.
SAIC	Pure electric drive, with a focus on battery-based solutions. +	SAIC is a local SOE. Shanghai Municipal governmental pressure is strong (transportation, demonstration, pilot city, etc.). +	ICEV regime is important but the city is also keen to support emerging and indigenous industries. A balancing strategy is sought. - +	Moderately valued, with a long-term view. -	Strong ***	Rich, esp. rich revenues from the group's JV brands and has Shanghai governmental back up. Tech-resource from JVs as well. ***	Active in technological substitution and a broad scope of technological variation; in e-mobility, priority is hybrid solutions.

Table 7-2 Incentive structure, firm-level factors and direction of innovation – Type II firms

	National industrial policy	Political pressure from local state	Local industrial structure and governmental incentive	Perception of tech-opportunities in the EV regime	Technological capability in the ICEV regime	Overall resource portfolio	Directionality of innovation
JAC	Pure electric drive, with a focus on battery-based solutions. +	Hefei is a pilot city, and JAC is the local SOE. But political pressure is very low. Null	Hefei is a less developed city and keen to catch up in the automobile industry and support emerging industries. +	High, due to a latecomer status in the ICEV regime. +	Moderate**	Limited to moderate. Vehicle revenue is limited but has city and provincial governmental back up. **	Proactive in technological substitution but a narrow scope of technological variation, solely focusing on BEV models.
Chery	Pure electric drive, with a focus on battery-based solutions. +	Wuhu is not a pilot city. Cherry is a local SOE but governmental share is only 20%. Political pressure is very low. Null	Automobile industry is Wuhu's economic backbone. Government feels obliged to protect jobs but also welcomes new investments. - +	Overall sees opportunities in the long term. But LSEVs are highly attractive in the short term. - +	Strong ***	Moderate. Vehicle revenue is good but local state capital is very small in scale. **	Active in technological substitution but a narrow scope of technological variation – only LSEVs (later BEV)
Zotye	Pure electric drive, with a focus on battery-based solutions. +	Hangzhou is a pilot city but Zotye is private. not a SOE – Political pressure does not exist. Null	Hangzhou is keen to catch up in the automobile industry and strengthen its manufacturing base apart from ICTs. +	EV is highly valued due to latecomer status. +	Weak *	Limited. Limited ICEV sales; no governmental back up. *	Proactive in technological substitution but a narrow scope of technological variation, solely focusing on BEV models.
BAIC	Pure electric drive, with a focus on battery-based solutions. +	Beijing is the capital city and a pilot city, and BAIC is the local SOE. Political pressure from local state is very high. +	Beijing hosts JVs, but is more motivated to catch up with leading regions, keen to push for structural change in local industries toward high-end, high value-added. + -	Mixed. The group has rich income from JVs and not willing to take risks, but the indigenous brand is a latecomer in ICEV. - +	Weak *	Moderate to rich. JV brands earn much and has local governmental back up, but not comparable to the "Three Big". **	Active in technological substitution but a narrow scope of technological variation, , solely focusing on BEV models.

Table 7-3 Incentive structure, firm-level factors and direction of innovation – Type III firms

	National industrial policy	Political pressure from local state	Local industrial structure and governmental incentive	Perception of tech-opportunities in the EV regime	Technological capability in the ICEV regime	Overall resource portfolio	Directionality of innovation
Changan	Pure electric drive, with a focus on battery based solutions. +	Chongqing is not a pilot city. Changan is a SOE affiliated to central government SASAC. Political pressure is very low. Null (de facto)	Automobile industry is one of the pillar industries in the region. Government seeks structural change, but is more inclined to preserve industrial base and jobs. - +	Low, only valued in the long term. -	Strong and enhancing. ***	Rich. Is a large group. Massive vehicle business income from JVs and increasingly from indigenous brand, and has state capital as back up. ***	Passive in technological substitution; moderate broad scope of technological variation (BEVs and PHEVs).
Geely	Pure electric drive, with a focus on battery-based solutions. +	Hangzhou is a pilot city but Geely is a private firm. Political pressure does not exist for Geely. Null	Hangzhou is keen to catch up in the automobile industry and strengthen its manufacturing base apart from ICTs. +	Low, overall only valued in the long term. In short term, only interested in market diffusion of mini BEVs. - +	Strong and building up. ***	Rich. Massive vehicle sales income. Good access to finance. Technology resources from M&A of Volvo. ***	Passive in technological substitution; broad scope of technological variation (BEVs, PHEVs, methanol, etc.).
GWM	Pure electric drive, with a focus on battery-based solutions . +	Baoding is not a pilot city, and Greatwall is a private firm. Political pressure does not exist. Null	Mixed. Baoding is a small city and welcomes investments and industries, but also needs to secure jobs in the short term. + -	Low, only valued in the long term. -	Moderately strong and building up. **	Moderate. It only transforms from truck to passenger vehicle business recently and small in scale. No governmental back up. **	Passive in technological substitution; moderate broad scope of technological variation (BEVs and PHEVs).

Table 7-4 Incentive structure, firm-level factors and direction of innovation – Type IV firms

	National industrial policy	Political pressure from local state	Local industrial structure and governmental incentive	Perception of tech-opportunities in the EV regime	Technological capability in the ICEV regime	Overall resource portfolio	Directionality of innovation
GAC	Pure electric drive, with a focus on battery-based solutions. +	Guangzhou is not a first-round pilot city. GAC is a SOE, but political pressure is very low. Null (*de facto*)	Guangzhou seeks to strengthen its manufacturing base, mainly through enhancing the ICEV regime and develop HEVs dominant by Japanese JVs. - +	Low, only valued in the long term. -	Very moderate in indigenous brands. *	Moderate to rich. Group size is moderate. Growing sales from JV brands and has governmental back up in a highly developed region. Tech resource from the group. **	Passive in technological substitution and has a very narrow scope of technological variation)
FAW	Pure electric drive, with a focus on battery-based solutions. +	Changchun is a first-round pilot city but FAW is an SOE affiliated to central government SASAC. Political pressure is de facto very moderate. Null (*de facto*)	Automobile industrial cluster is a regional economic backbone, and government inclined to preserve incumbent industrial base. -	Low, only valued in the long term. -	Weak in indigenous brands. *	Rich. Massive sales from JV brands and central government back up. ***	Passive in technological substitution and has a very narrow scope of technological variation (BEV).
Dongfeng	Pure electric drive, with a focus on battery-based solutions. +	Wuhan is a first-round pilot city but Dongfeng is an SOE affiliated to central government SASAC. Political pressure is de facto very moderate. Null (*de facto*)	Automobile industrial cluster is a regional economic backbone, and government inclined to preserve incumbent industrial base. -	Low, only valued in the long term. -	Weak in indigenous brands. *	Rich. Massive sales from JV brands and central government back up. ***	Passive in technological substitution and has a very narrow scope of technological variation (BEV).

7.5.2 Incentive compatibility

When taking the four groups of firms together, it can be observed that they diverge in terms of how their incentives *in combination* work in line with/against the priority of national industrial policy, and to what extent. I hereby inductively develop the concept of ***"incentive compatibility"*** to characterise the nature and aggregate effect of the incentive structure on firms' choice of direction of innovation. It is defined as the *de facto* status that firms' overall incentive structure, i.e., the integrated environment where various incentives from the SSIP interact with each other, works in line with the selective green industrial policies.

Incentive compatibility is a firm-centric strategic context that varies in degree. To determine when it is higher and when lower, however, does not a mere counting method, nor looking at the mere presence/absence of a certain factor. Because incentive differs in nature and type, firms make sense of each of them in very distinct ways. This is why the incentive "structure" matters. Hence only by examining their interaction and the implication for innovation strategies could the degree of incentive compatibility appropriately captured.

The data analysis leads us to conclude that a *high level of incentive compatibility* is present when the majority of other incentives encourage the same or similar direction of action given national industrial policy preferences, and there are not substantial, decisive counter-acting incentives at work. A *low level of incentive compatibility* describes the incentive structure faced by firms where the majority of other incentives work in the direction against the national industrial policy preferences, and there are no substantial counter-acting incentives at work that imposes industrial policy preference on firms. Other status stands in between.

In aggregate, the level of incentive compatibility explains firm's varied activeness in technological substitution and specification within the EV regime. More active engagement in

electric mobility, with a commercialisation focus on BEV is associated with a higher level of incentive compatibility in the incentive structure of an embedded firm. Otherwise, firms are reluctant to allocate resources to develop EV, and are indifferent to the "pure electric drive" strategy when incentive compatibility is low.

There are still further nuances that need to be explained. Given a high level of incentive compatibility, the specific components and contents of it could differ, and this shapes the concrete mechanisms and pathways that lead firms to formulate their innovation strategies. Specifically, it is found high incentive compatibility differs between one that is overwhelmingly dominated by political and institutional forces, and one where such overwhelming institutional and political incentive is weak or absent. In the latter situation, the incentives from local government and firms themselves to pursue technology and market opportunities play a more dominant role in determining the characteristics of the incentive structure. Now we unpack each of these situations by referring to the case study results.

There is the situation where high incentive compatibility of a firm's incentive structure is overwhelmingly dominated by political and institutional forces. Other incentives may go in line with or against this factor, but none of them are decisive. This situation characterises SAIC and BAIC. To meet the 2010 Shanghai Expo demonstration target, Shanghai Municipal government put strong pressure on SAIC to bring EV to the "industrialisation" (commercialisation and scale production) stage. Moreover, as one of the first-round pilot cities, Shanghai felt the pressure to roll out BEVs because some other cities had already done so (e.g., JAC in Hefei, BYD in Shenzhen) under the watch of the central government.

The political pressure felt by BAIC from local government was even stronger. As the capital city, Beijing stands at the forefront of executing state policy. Moreover, the city itself is in need of structural transformation and industrial upgrading as it had not excelled in automobile

industry compared to leading clusters. Therefore, it was Beijing Municipal government that lobbied to obtain the pilot city opportunity and required BAIC to work on electric mobility. Without strength in ICEs, the focus on "pure electric drive" was exclusively dedicated to BEVs. It can be seen that the political and institutional force faced by BAIC is more characterised by the intentionality from local state that strategically complied to national industrial policy for regional benefits, while the political pressure faced by SAIC and Shanghai Municipal government was more exogenous. Therefore, while both acted very early to bring EVs into commercialisation stage, SAIC was more inclined to keep multiple technological trajectories while responding to the requirements to deliver BEVs. Of course, firm-level factors also influence the outcome, and this will be explained in later subsections.

High incentive compatibility in a firm's incentive structure can also occur when there was no strong political and institutional pressure, but more dominated by the concertation between local government and firm-level motivation to exploit the technological opportunities presented by electric mobility. This explains the cases of BYD, JAC, Zotye and Chery. Their incentive compatibility still varied in degree but overall remained at a high level. BYD took a most aggressive strategy towards phasing out ICEVs while developing and deploying EVs. A latecomer in domestic market, it aimed to take advantage of its technological competence in batteries to become a leader in the emerging EV regime. Shenzhen had little prior basis in automobile industry. It aspired to become a manufacturing centre by mobilising local competences in ICTs and batteries. This strategic resonance between Shenzhen city government and BYD resulted in very early market deployment of EV models locally, even prior to and informs the framing of national industrial policy. Similar activeness, albeit not as strong as BYD, can be found in JAC-Hefei and Zotye-Hangzhou in terms of firm-local state strategic interaction. Chery's approach to electric mobility can be understood as a weaker

version of incentive compatibility. It found attractive technological opportunity specifically in the low-speed, small-sized, frugal market niche.

The option of low incentive compatibility characterised by strong political and institutional pressure in the case studies does not exist. All firms that were reluctant to embrace electric mobility were driven by the concertation between local government and firm-level incentives to maintain status quo, i.e., the path-dependency produced by local state-business interaction. For private firms, there was a lack of political or institutional force, hence their innovation strategies were more oriented towards technological and market opportunities. This is why Geely and GWM overall showed very little interest in in-house efforts to develop and deploy EV models. Geely did deploy a considerable number of EV models in the market, but how it achieved this was not through in-house efforts, but cooperation with other firms in the most cost efficient small-size BEV segment. Besides, Hangzhou's incentive to facilitate the deployment and diffusion of EV models was comparably higher than those old industrial clusters. Therefore, Geely's innovation strategy should not be seen as an exception, but only a weaker version compared with other OEMs in the same group.

For SOEs that show limited interest in EVs, despite their various forms of institutional embeddedness with the state sector, the political pressure to execute industrial policy was *de facto* weak. FAW, Dongfeng and Changan are similar in this sense. All of them were affiliated to central governmental SASAC, hence local state did not have the authority to have forceful directives to implement the "Pure Electric Drive" strategy. Moreover, both local government and the firm were more inclined to preserve their highly profitable ICEV industrial base, given the rich revenue earned by JV brands and numerous supply networks. GAC was affiliated to local governmental SASAC, but it felt weak political pressure for the reasons explained in the case study.

7.5.3 The relation between firms' technological capability and resources

It is a rather straight forward finding that both strong technological capability in the incumbent (ICEV) regime and rich resources have a positive influence on firms' ability to develop and deploy EV technologies and diversify technological solutions. One important side-finding drawn from the multiple case studies is that the two factors work ***in complementary*** to each other, not mutually substitutive. This means that the lack of either of them could preclude technological multiplicity in firms' exploration and experimentation of green innovations or disabling a firm from diversifying technological configurations in a later stage if it is unable to do so earlier. This will be further validated in the empirical findings after 2015 in the next chapter.

This helps understand the single focus of Chery (LSEV) and GWM (BEV) due to limited financial resources and scale before 2015, that of GAC (REEV) when its indigenous brand Trumpchi was just starting in 2010, and of Dongfeng when it was struggling to build up capability in ICEs. By comparison, BYD, SAIC, Changan and Geely maintained a diversity of technological solutions early on. This is attributed to the coupling of both technological capabilities and the upgrading efforts in ICEs, as well as rich financial resources as the backup. Moreover, firms like Changan and SAIC were able to build on their earlier accumulation of HEV technologies during the 863 Major Project.

7.5.4 Synthesis: the interplay between incentive structure and firm level factors

Then firm level factor – technological capabilities in the incumbent regime and overall resource portfolio – come into play as important moderating factors. It is found that firm level factors strengthen the influence of incentive structure in *the same direction* with the degree of incentive compatibility. This means that whether strong technological capabilities and rich resources work as path dependency or enabling change, is *contingent upon* whether the incentive

compatibility faced by firms are high or low. To this stage, how firm-centric incentive structure, characterised by the degree and nature of incentive compatibility, interact with firm-level factors to shape the patterns of directionality of innovation can be generalised below (Table 7-5) and explained in the following paragraphs.

Table 7-5 The interplay between incentive structure and firm-level factors and the result

Incentive structure		**Firm-level factors**	**Directionality of innovation**
Incentive compatibility: Degree	Incentive compatibility: Type and content	Technological capability in the ICEV regime and overall resource portfolio	Firm innovation strategy
High	Dominated by political pressure mediated by local state	Both are strong	Leading with strategic balancing (SAIC)
		One strong and the other moderate or weak	Selective leading (BAIC)
	Dominated by firm-local governmental incentive	Both are strong	Versatile leading (BYD)
		One strong and the other moderate or weak	Selective leading (Cherry)
		Both are weak	Selective leading (JAC, Zotye)
Low	Dominated by firm-local governmental incentive	Both are strong	Versatile following (Geely, Changan)
		One strong and the other moderate or weak	A weaker version of broad following model (Greatwall)
		One strong and the other moderate or weak	Selective following (FAW, Dongfeng) (GAC is a weaker version of this model, it is just starting)

Where there is a high level of incentive compatibility in a firm's incentive structure, and the firm has strong technological capability in the ICEV regime and rich resources, then it is able to comply to national industrial policy preferences (electric mobility in the "pure electric drive" direction) while putting commercial emphasis on more mature solutions (PHEVs). This

explains the case of SAIC and BYD. While BYD's short-term priority on PHEV and exploratory efforts on BEV were almost entirely based on technological and market considerations, SAIC's commercialisation focus on PHEV also reflected the inclination to preserve existing ICEV competence by both the group and local government. Despite that the concrete reasons were different, they led to the same result. This is called "***leading with strategic balancing***", where "strategic" reflects the contingency in firms' directly faced decision-making environment.

When there is a high level of incentive compatibility in a firm's incentive structure, but the firm has either weak technological capability in the ICEV regime, or limited resources, or the lack of both, then firms are found to respond actively to national policy preferences with narrow specialisation. This explains the case of Zotye, BAIC, JAC, and the temporary case of Chery in the early period. For Zotye, BAIC and JAC, the lack of technological capability in the ICEV regime prevented them from developing hybrid solutions and putting them into market. However, with strong motivation to exploit the technological opportunities, they chose to actively focus on BEV that relied less on the core competences in the ICEV regime. Chery was technologically competence but met financial constraints temporarily, hence focused on BEV as the starting point. This resulted pattern is called ***"selective leading***".

In the situation where incentive compatibility is low in a firm's incentive structure, strong technological capabilities and rich resources instead contribute to firms' path dependence in the incumbent regime (ICEV). This is because both the firm and local government are motivated to preserve the existing industrial base, and continue to exploit the opportunity from the still-upgrading ICEV technologies they are good at. Rich resources enable them to explore EV technologies and commercialisation, but to a lesser degree that brings limited risk and threat to the firm's financial performance. However, technological multiplicity is maintained because of the uncertainty and ambiguity of future technological opportunities and trajectories

perceived by the firm. This explains the case of Changan, Geely and GWM. Notably GWM was a weaker version as its size and resources are at a smaller scale compared to Changan and Geely, and its passenger car technologies were still upgrading at that time. This resulted pattern is called "***versatile following***".

In the situation where incentive compatibility is low in a firms' incentive structure, it is impossible that a firm is in lack of technological capabilities and resources, for if it were the case, then the firm would be highly motivated to pursue the technological opportunities of EV, which with be in contradict with the precondition. This is because that the system level and firm-level factors are to some extent correlated. If I rule out this option, then a firm could be constrained in either of the organisational level factors. First, the firm has weak technological capability in the incumbent regime, but is in no lack of resources (especially financial). It is possible that the firm could earn a lot of money not based on indigenous technological efforts. For example, FAW and Dongfeng before 2015. However, because they themselves were not technologically competent, they could not roll out hybrid solutions, hence only had minimum efforts on BEV to nominally respond to industrial policy call. GAC's technological capability was also weak in the beginning, despite rich resources from the group, JVs and Guangzhou city. Hence it only focused on REEV it had already made some accumulation and was most familiar with, at a minimum level of commercialisation efforts to reduce financial costs and risks. This resulted pattern is called "***selective following***".

7.6 Conclusion and discussions

In this chapter, I have continued to investigate the object of green industrial policy -- innovation strategies of business firms in the focal sector in terms of direction of innovation. Based on the typology of firm-level innovation strategies in response to green industrial policy described and analysed in chapter 6, I explain firm heterogeneity and its change overtime in this current

chapter. I put forward the notion of variegated incentive structure, which is a firm-centric concept and denotes the nature and type of incentives that combine to guide innovative activities undertaken by incumbent firms. I argue that firm heterogeneity should be better understood through the interaction between system-level dynamics and actor-level factors. Therefore, an inter-disciplinary framework is developed to examine the interplay between the variegated incentive structure firms are embedded in, and the technological capabilities and overall resource portfolio firms possess. Multiple case studies are conducted on twelve OEMs in the period before 2015, and data is analysed through structured, focused comparison.

The comparative and longitudinal case studies lead to several major interrelated findings. First, the heterogeneity of firms in their choice of directionality of innovation is explained by the interplay between the variegated incentive structure and important firm-level characteristics, i.e., technological capabilities in the incumbent regime, and overall resource portfolio.

Second, with state industrial policy as the reference point, key to understand the implications of incentive structure is the degree and type of the incentive compatibility. The higher the degree of compatibility within a firm's incentive structure, the more active the firm is in technological substitution and inclination to focus on selectively supported technologies. Strong technological capabilities and rich resources can raise the intensity of these firms' innovative efforts in the green regime. However, given a certain degree of incentive compatibility, firm-level characteristics are found to play a more decisive role in shaping the scope of technological variation and its specification. Firms with weaker technological capabilities and limited resources lead to selective focus on specific niches in the EV technologies, while firms with strong technological capabilities and rich resources keep a broad scope of exploration and commercial experimentation.

Third, a logical conclusion from the above two findings lead to another point that, the interplay between the system level and actor-level variables explains the behavioural patterns of the four groups of incumbent OEMs before 2015.

Fourth, a supplementary finding is that the role of technological capabilities in the incumbent regime and overall resource portfolio is mutually complementary instead of substitutive. And among these two, the former is more decisive especially when time window for incumbent firms to take action is restricted.

The findings of this chapter bear important implications on literature. The study contributes to our understanding of the driving forces and dynamics of transformation of innovation system (at the sector level), hence distinguishes itself from the more or less static analysis of innovation system structure and agency. It also differs from industrial catch-up or co-evolutionary literature that focuses less on rather radical transformation of systems. The study not only demonstrates the contemporary relevance of the innovation system concept on its own (Weber & Truffer, 2017), but also takes an experimental step to show how cross fertilisation of multiple disciplines could fruitfully achieve stronger explanatory power. While this thesis examines industrial sectors, the focus on incentive structure implies the potential to be generalised to transformative change in other innovation systems.

Besides, this study bears important implications for rethinking the role of institution and the new institutionalism perspective in such a context. The core message is that the link between institutions and actors' innovation strategies and behaviours should be understood through the mediation of the incentive structure firms are embedded in, and its interaction with organisational properties. I argue that it is not possible to truly make sense of the impact of institutions without looking beyond institutions themselves and examining the incentive structure as an integrated context. As has been shown from the empirical analysis, institutional

factor does not work in a deterministic way; nor is it playing out individually and mechanically. In the variegated incentive structure, neither institutional embeddedness in the format of multi-level governance nor state ownership has a decisive and explicit influence over the innovation strategy of business actors. Instead, they are highly contextualised, and contingent on the existence of and interaction with other incentives; only through these interdependencies and interactions do they take concrete effect. It is therefore important to make sense of how they interplay and what stands out as the most prominent force. Taking state ownership as an example. SOE is expected to play an active role in strategic fields and public purposes, but it also well documented in literature that SOE has its own agency and can exhibit strong risk aversion and resistance to change. How it plays out, however, is activated by the existence, nature and degree of other incentives, especially local government and firms' own perception of technological opportunities and status of incumbency, and the organisational properties of the firms.

In addition, this chapter also adds to innovation management literature from the resource-based and capability-based view of firms (Armstrong & Shimizu, 2016; Lavie, 2006; Teece, 2017). It not only validates the two perspectives, but also makes two further contributions. The first aspect concerns the dual role of technological capability in times of technology regime shift in a multi-tech, multi-component sector. Its concrete role can be better understood when it is activated by the incentive structure firms are embedded in. Therefore, it may be oversimplified to claim "creative destruction" or "creative accumulation" over incumbent firms (Bergek et al., 2013). In this sense, this chapter also sheds light in incumbent response to technical change scholarship (Eggers & Park, 2018) by emphasising the important role of incentive structure in transformation towards sustainability. Regarding the second aspect, I find that the role of technological capability and resources are complementary to each other and mutually reinforcing, not substitutive, in shaping incumbent firms' innovation strategies. Both

theoretical perspectives hold, but they are not stand-alone explanations. Among the two, technological capability stands out as more decisive of firms' ability to engage in technological multiplicity.

Admittedly there are limitations to this study which warrants further research. First, I only include incumbent firms due to their scope and volume. The next step should examine how new entrants, such as those EV start-ups from the ICT and IT background, make sense of and navigate their embedded incentive structure. Further, a comparison between incumbent OEMs with those new entrants would shed light on firm heterogeneity from another angle and contribute to the classic debate in industrial dynamics literature. Third, in methodology I use structured comparison to look at how different incentives and organisational factors interact with each other. In the future, with the availability of more open-access and high-quality indicators, it is possible to use configurational approach such as QCA to address the similar set of research questions. Last, the evolutionary dynamics has not stopped here, and the "era of ferment" would persist for a long time. Longitudinal study for a longer time frame is invaluable to reflect on the analysis and findings in this study.

Chapter 8 Understanding firms' different responses to green industrial policy: Multiple case study on China's EV manufacturing firms (since 2015)

8.1 Introduction

Chapter 7 conducts a systematic investigation of the different strategic choices on directionality of innovation by incumbent OEMs facing state intervention into green transformation through the multiple case study on twelve OEMs until the year 2015. This period is characterised by technological exploration and experimental, small-scale deployment of EV models in the market subsidised by central and local government under the "pure electric drive" strategy.

The effectuation of green industrial policy – characterised by the "pure electric drive" strategy and supporting policies – at the actor level can only be sufficiently understood by looking at the incentive structure faced by firms, and its interplay with firm-level characteristics. The incentive structure faced by OEMs has been shown to be highly variegated, complex and variant. Through the data analysis, I have inductively developed the notion of "incentive compatibility" to denote the nature and content of the firm-centric incentive structure and found that the higher incentive compatibility is, the more proactively technological substitution an OEM engages and the more possible that technological variation is specified in line with policy preferences. Moreover, firm-level characteristics, including the technological capability in the incumbent regime, and overall resource portfolio, play a contingent moderating role. Their influence on the link between incentive structure and firm innovation strategy depends on the

content of the linkage itself. Put it another way, the two sets of factors mutually activate each other in the same direction to take effect.

In this chapter, I continue to examine the interaction between firm-centric incentive structure and organisational level factors and how it shapes OEMs' configuration of directionality of innovation in China's EV sector since 2015 until around 2020. The year 2015 marks a shift between small scale, experimental deployment of EVs to large-scale deployment and diffusion of EVs, with important policy and regulatory changes. The analytical framework developed in Chapter 7 can be used to analyse the same set of twelve OEMs. It will be shown that both convergence towards active technological substitution (from ICEV to EV) and divergence in terms of the scope of technological variation (the consolidated demarcation between "generalists" and "specialists") can be explained by the same framework. Theoretical and managerial implications are discussed at the end of this chapter.

8.2 The variegated incentive structure, firm level moderators and direction of innovation in the e-mobility transformation: 2015-2020

8.2.1 Evolving incentive structure and convergence to active technological substitution

The incentive structure faced by firms changed both endogenously and exogenously during the early process of sectoral transformation, which was mainly pioneered by several firms that were proactive in technological substitution in replacement of ICEVs. This process led to several important aspects of change in the building blocks of the evolving sectoral system, and as a result, alternating the concrete incentive structure where each firm was embedded in.

The direct outcome of pioneering firms' efforts under the influence of/coinciding with the "Pure Electric Drive" industrial policy was the improvement of EV technologies and product quality and function. In the process, the costs of the green technologies and products gradually

dropped down, despite still incomparable to highly mature ICEVs. With the initial diffusion of EV models, complementary assets such as power battery and charging facilities were also developed to some extent. These all led to the improved appropriate conditions and technological opportunities in the EV regime compared to the earliest stage of system change. Of course, the continued existence of policy rents still played a role, but the phase-out of private purchase subsidy began to made room for more market-based competition.

An accompanying outcome is the increased product variety and enhanced product function in the market, which contributed to heated product market competition in the EV regime. This was significantly affected by two factors. First, regulatory change in the institutional regime. Seeing that many incumbent automobile manufacturers, especially big SOEs that were supposed to take a lead were reluctant to roll out market-oriented EV products, NDRC in the central government revised the investment entry regulation in the automobile industry to lower the entry barrier in this sector. Specifically, it began to allow firms without competences in ICEs and previous experience in automobile manufacturing to embark on EV manufacturing, under the condition that these new entrants shall only develop EV models that were purely driven by power batteries. This attracted several start-ups with a strong background in the IT sector, such as NIO, XPENG and Li, and many others. These firms were established soon around or after 2015. Instead of rolling out product families like incumbents do in the ICEV business, they chose to concentrate on one single product series/model. By integrating state-of-the-art ICTs with electric vehicles and making great efforts in user service and experience, they gained much attention from consumers and media coverage. In effect, such a strategy reflected the aspiration to be the “Tesla” in China.

This led to the second factor, the entry of Tesla, a disruptor in the global incumbent automobile industry, into China. The early success of Tesla in combining autonomous driving and electric car in Model S inspired Chinese start-ups, and the latter posed increasing competitive pressure

on technological followers in China. What's more, a regulatory change in automobile industry FDI opened door to international brands in order to incentivise domestic incumbents. The first concrete step was the launch of Tesla's Mega factory in Shanghai without requirements to form joint ventures with Chinese SOEs. Benefiting from lower manufacturing and production costs, Tesla's BEV model soon became the most popular one in the consumer market. At the same time, previous JVs gradually participated in the competition as well, whose parent companies had decades of technological exploration in electric cars (e.g., Audi's MEB platform, BMV's i3, GM's E series, etc.), and recently decided to embark on more active electric mobility transition.

In sum, the heightened product market competition brought about by both endogenous and exogenous changes became the dominant incentive that drove all firms to get significantly more aggressive in engaging in electric mobility. For example, Changan had been enjoying domestic success in producing and selling ICEV models in China, hitting a sales record of over one million vehicles per year during its peak days during the mid-2010s. It dismissed electric mobility as immature and was very conservative in business strategies related to EV. "*Initially we looked down upon these startups, but later we had to acknowledge that they had something, and we need to learn from them*." (Interview B1-02)

However, just after 2014, it realised that there might be no choice but catching up with first movers, or it would be too late. Hence in 2015 it announced the "518" technology strategy, which soon proved to still be too conservative, and therefore in 2017, it launched "The third innovation and entrepreneurship plan" to make the transition to electric mobility another milestone of corporate development[101]. In subsequent years, it invested heavily in the whole

[101] In the history of this business group, the first milestone was its entrance into automobile manufacturing in non-passenger vehicle business and the second milestone was its decision to focus on passenger vehicles, establish indigenous brand and develop its own R&D system.

value chain of electric mobility. As one of its bold steps, Changan launched an independent high-tech, luxury BEV brand AVATR based on brand-new developed original BEV product platform to compete with IT-based new entrants. Similarly, such strategic moves are also observed among other domestic incumbents after 2015.

At the subnational level, the initial political pressure under which some local governments and OEMs kicked start the technological and commercial exploration gave way to heated local governmental competition. This reinforced the convergence in active technological substitution among firms. Previously some regions with long-established automobile industrial clusters as their engine of industrialisation and economic growth only responded to national industrial policies half-heartedly, hardly moving beyond fulfilling the demonstration targets, typically those hosting SOE together with JVs, e.g., Chongqing, Wuhan, Changchun, Guangzhou, etc. With early-moving regions becoming the hub of EV system integration and manufacturing capabilities as well as preliminarily formed battery supply networks, late-moving regions were weakening to the competitive pressure. They mobilised various resources to attract investments from OEMs, power battery firms and automobile electronic suppliers. Chongqing city, where Changan was located, established the New Energy Vehicle Industrial Park in its Liangjiang New District, a national-level district that pooled resources to support strategic industries. Similar EV and IT focused industrial parks/districts were launched in Changchun, Wuhan, Guangzhou, Hangzhou and so on. Early mover regions also intensified their policy measures in a similar way. At this stage, local governmental policy not only supported technological upgrading in high-performance ICEVs and product system integration, but also the formation of supply networks with competent battery manufacturing firms, and the co-location between OEMs with IT suppliers. In the demand side, more efforts were made to expand the construction of charging facilities by providing subsidies whereby utility companies were

incentivised to cooperate with EV makers and service providers to deliver packaged charging solutions.

8.2.2 The moderating role of firm-level factors

Firm-level factors continue to play an important moderating role since 2015. In this period, as section 8.2.1 indicates, the degree of incentive compatibility has significantly risen and converged to a twin process: increasing between-firm competition in EV product market and inter-regional competition for new technologies, investments and value chains. The strength of technological capabilities and size and quality of overall resource portfolio had a positive influence on the linkage between high incentive compatibility and active technological substitution. In particular, strong capabilities and rich resources supported OEMs' commercial production and deployment of various EV models in the market when they lacked cost-efficiency. This again validates and supports both the extended resource-based view and capability view of the firm.

In terms of the scope of technological variation, which is a major point of divergence between incumbent, indigenous brand OEMs in China's EV sector, a further finding is that the two firm level factors together determine whether OEMs were eventually able to maintain or expand to technological multiplicity in the EV regime. The two factors are mutually and necessarily complementary to each other. The enhancement of technological capability and expansion of resources led to the successful broadening of the scope of technological variation; on the contrary, the absence of either of these two factors led to the failure in attempts to diversify technological trajectories. The movement of each of the four types of firms can therefore be unpacked and explained below.

Type I firms had stayed in their quadrium and continue to be important player in electric mobility. BYD and SAIC benefited from their steady revenue growth, strong financial backup

and continuous technological upgrading efforts in high-performance ICE power train (and related hybrid power systems). They tapped into more nuanced technological configurations and more diversified product architectures and market segments, for example, SAIC's ei5 (a compact, battery electric SUV but more similar to sedan in its outlook), and BYD's enriching Dynasty series EV models.

Some Type II, Type III and Type IV firms migrated towards Type I firms, successfully, including Changan, Geely and GWM from Type II, Chery from Type III and GAC and FAW from Type IV. Changan and Geely had kept good financial performance in selling ICE sedans and SUVs, and their group size was quite large. They had also worked hard on technological capability building in high-performance ICE system, though the approach differed – Changan rolled out NE power platform through the combination of indigenous efforts and international cooperation (especially power system research team in Birmingham, UK), and Geely gained a lot, both technologically, financially and brand-wise, after M&A of Volvo. Both firms were able to invest a huge amount of money into various hybrid solutions and bring them into market, for example, MHEV, HEV and others that were not covered by the subsidy scheme.

Chery was financially constrained before 2015. After it made adjustment by "Going Back to One Chery" to cut off various sub-brands and concentrate R&D efforts on the upgrading of ICE product system integration and application of advanced ICTs, it regained good financial performance and revenue growth. This made it possible for Chery to develop PHEV solutions apart from BEVs (eQ models), and further launch the Kunpeng hybrid power system. Similar to Chery was GWM, whose ICEV business was boosted by a concentration of efforts in the SUV segment represented by its phenomenal Havel model. As the corporation grew up, GWM had more resources to be spent on developing its hybrid powertrain system, the Dedicated Hybrid Technology (DHT) and diversify technological solutions into HEV and PHEV covering three different market segments. Despite only moderate success, FAW also managed to roll out

its hybrid power system through continuous efforts on technological capability building for its indigenous brand Hongqi[102]. Despite that the market competitiveness was still unclear, HEV models under Hongqi brand (e.g., H9) were at least successfully launched in the market. GAC also transformed itself from a specialist to a generalist in EV technological configurations. This was supported by business success in scaling up of its indigenous Trumpchi brand ICEV models, with a product strategy focusing on A segment compact sedans (e.g., GA series) and SUVs (e.g., GS series). At the same time, its capability building efforts in ICE power system and hybrid power system benefited from the parental group, the newly established GAC Components R&D Centre, and the examples set by JV partners Toyota and Honda that were extremely competent in developing hybrid power systems. GAC launched its own hybrid power system Julang after 2018.

For some other firms in Type II, III, and IV, the failure to build up indigenous technology capability in the core competence in the ICEV regime, and/or a constraint in financial resources, prevented them (Dongfeng, JAC, BAIC and Zotye) from diversifying into technological solutions other than BEVs. Dongfeng had not strengthened its indigenous ICE powertrain and system integration capability in passenger vehicle, and one of the group's core businesses, Jiefang brand truck manufacturing, encountered market backlash in mid-2010s. This reduced the group's investment into NEV project and made it become even more cautious, which was delayed and eventually abolished. JAC was constrained by both factors, too. Its passenger car core technologies only sustained moderate vehicle sales in the low-cost vehicle segment, but it was very hard to upgrade to a more complex, integrated and sophisticated level. With other OEMs raising the bar in the high-performance sedan and SUV segment, JAC became less competitive. In addition, the group's truck business also ran into difficulty as the market

[102] The strategic emphasis was put on Hongqi instead of Benteng for good reasons. This is strongly driven by the political implication of the brand as representing the national image of China since the mid-20th century. Leaders at FAW are highly motivated to rejuvenate this brand, which will add to their political promotion.

demand for commercial vehicles was not as vast as passenger cars. Although Anhui provincial and Hefei city governments lent a hand to JAC, for example, financial assistance via various governmental programmes, this constituted a very obscure amount of money in contrast to the huge investment required for an automobile manufacturer to upgrade its core technologies and developing EV technologies. As a result, JAC had to stick to BEV, only expanding product categories from the iEV series to an additional E series, and its R&D efforts in hybrid solutions were eventually not brought to the market. BAIC's lack of indigenous ICE powertrain technological capability also prevented it from diversifying. Although Beijing city government offered *de facto* protection by excluding PHEVs from local subsidy, it revised the rules after 2015 by adding REEV as one of the technological configurations that qualified the "pure electric drive" strategy, hoping that BAIC could work out this solution through cooperation with partner BMV to strengthen firm-level and regional competitiveness. However, the weakness of BAIC in ICEs and system integration capability led this plan to nowhere. Until 2020, BAIC's EV subsidiary firm still focused on BEVs only and did not have any other solutions available. The indigenous ICEV brand performed so poorly that it was ultimately merged with BAIC-EV altogether. Zotye faced an even more dire situation. Entering into Chinese automobile industry quite late, it was not able to cultivate indigenous technological capability to perform product design, development and system integration. Instead, it was stuck in imitating and modifying international brands' vehicle models and made them available at a low cost in the market. This might have worked well for a while, but when other domestic OEMs were making great efforts to improve product quality and functions, Zotye soon lost competitiveness in 2017, with ICEV sales dropping by 50%, and had not recovered ever since. Because its small size, the development of BEV models was feed by ICEV business, and without backup by state capital like SOEs, the big backlash brought its EV business to an end as well.

8.2.3 The relation between the technological capability and resources of firms

This dynamics again confirmed the finding in Chapter 7 that both strong technological capability in the incumbent (ICEV) regime and rich resources have a positive influence on firms' ability to conduct technological substitution and diversify technological solutions. It is confirmed that these two organisational level factors work in complementary each other. This means that the lack of either of them could pose tremendous challenge to diversifying technological solutions or maintaining technological variation in later stages, which proves to be a source of consolidating gap between generalists and specialists.

This helps understand the fact that Chery, GWM, GAC and Dongfeng were able to tap into various hybrid solutions after 2015 once filling the capability and/or resource gap (Table 8-1). The failure of JAC, BAIC, Zotye and FAW to broaden their scope of technological variation was mainly due to the lack of indigenous technological capabilities in the ICEV regime, which was exacerbated by a relative smaller size of overall resource (Table 8-2). The effect was accumulative. BYD, SAIC, Changan and Geely started as a generalist with at least BEVs and PHEVs, and further diversified their profiles in the later stage (Table 8-1). This benefited from the cultivation or upgrading of a certain level of technological capabilities in the ICEV regime and ample financial resources to draw from while their automobile business is expanding steadily.

Table 8-1 Firm-level factors and successful diversification of technological solutions

Firm	Tech- capability upgrading in the ICEV regime	Resource portfolio change	Tech-substitution	Tech - variation	Change after 2015
BYD	Yes, 1.5T motor and 4 generations of DM power system	Increase in revenue, financial resources from the stock market, R&D more internationalized.	Radical, increase of EV volume, phase-out of ICEVs.	BEV, PHEV, far more product segments.	Unchanged, consolidated in Type I
SAIC	Yes, CUBE-TECH 1.0 and 2.0	Increase in revenue (esp. JVs), technology cooperation with GM, state capital backup and capital market finance	Active, increase of EV volume.	BEV, PHEV, more product segments.	Unchanged, consolidated in Type I
Changan	Yes, NE power platform 1.5 and 2.0	Increase in revenue, technology cooperation with overseas R&D centre, state capital backup and capital market finance	Active, increase of EV volume.	BEV, PHEV, REEV, MHEV, 48V EV, more product segments.	From Type II to Type I
Geely	Yes, based on Volvo technologies	Increase in revenue, absorption of Volvo technologies, capital market finance, worldwide M&A to acquire technologies and assets.	Active, increase of EV volume.	BEV, PHEV, REEV, MHEV, 48V EV, more product segments.	From Type II to Type I
Greatwall	Yes, enhancement of ICE power systems	Increase in revenue, expansion of scale, cooperation with BMW.	Active, increase of EV volume.	BEV, PHEV, HEV, more product segments.	From Type II to Type I
Cherry	Yes, cooperation with Roover and product system upgrading.	Yes, revenue increase after brand strategy adjustment.	Active, increase of EV volume.	BEV, PHEV, HEV, more product segments.	From Type III to Type I
GAC	Yes, development of Julang hybrid power system	GAC research institute and components R&D centre, local government support, state capital backup and capital market finance	Active, increase of EV volume.	BEV, PHEV, HEV, more product segments.	From Type IV to Type I
FAW	Yes, moderate progress in Hongqi brand ICE powertrain	ICEV sales is steady; state capital backup.	Active, moderate increase of EV volume.	BEV, PHEV, HEV, slightly more product segments.	From Type IV to Type I

From the deepening divergence from specialists and generalists, it can be concluded that the strength of technological capability and resource portfolio are mutually reinforcing, rendering firms such as BAIC and JAC in a “vicious cycle”: weak technological capabilities in ICEs – lack of competitiveness in the incumbent regime – financial income is constrained –

insufficient investment into technological upgrading due to both lack of absorptive capacity and resource constraints. This is especially problematic as the system transformation goes on, because the scaling up of the EV regime growingly require more technological and value chain efforts and resource commitment. The vicious cycle is not easy to break when time window is very short, because capability building in a complex product regime requires committed efforts and heavy investment. The success of GAC, GWM, Chery and to a lesser extent, Dongfeng to diversify all depended on the continuous technological upgrading in the ICEV regime, which brought revenue and the product integration capability for EV as well (Table 8-1). BAIC, JAC and Zotye failed to do so due to the inability to cultivate a certain level of indigenous technological capability in vehicle design and system integration (Table 8-2).

Table 8-2 Firm-level factors and technological lock-in to BEVs

Firm	Tech-capability upgrading in the ICEV regime	Resource portfolio change	Tech - substitution	Tech - variation	Change after 2015
BAIC	No, still weak in ICE (passenger vehicle)	JV and indigenous ICEV brand revenue dropped, despite state capital backup.	Active, whereas EV volume declined at later stage.	Only BEV, with more product segments.	Unchanged, locked-in to Type III
JAC	Obscure, still weak in ICE (passenger vehicle)	Indigenous ICEV business and truck business shrank, despite state capital market backup.	Active, whereas EV volume declined at later stage.	Only BEV, with slightly more product segments.	Unchanged, locked-in to Type III
Zotye	No, weak in ICE	Indigenous ICEV business dropped sharply and no state capital backup.	Active, whereas EV volume declined at later stage.	Only BEV, with slightly more product segments.	Unchanged, locked-in to Type III, later exit from the market
Dongfeng	No, weak in ICE (passenger vehicle)	ICEV sales and truck business dropped, despite state capital backup.	Active, whereas only moderate increase in EV volume.	Only BEV, with slightly more product segments.	From Type IV to Type III and is locked in to Type III.

8.3 Conclusion

This chapter has focused on twelve Chinese automakers' innovation strategies concerning directionality of innovation after 2015 until around 2020. This second period features large-scale deployment and diffusion of EVs in the sector. At the level of firms, the period sees convergence in active technological substitution, and consolidated divergence on technological variation between some "generalists" and "specialists", while some "specialists" successfully diversifying into "generalists". This is explained using the analytical framework in Chapter 7, by examining in detail the interplay between firm-centric incentive structure and important firm-level properties including technological capabilities and resources.

The applicability of the analytical framework is validated again in this chapter. In the period after 2015, the degree of incentive compatibility raised for all incumbent OEMs. Those incumbent automakers that were reluctant to engage in electric mobility faced intensified competition in the emerging regime, which was amplified by inter-regional competition. This co-movement in the market structure and sub-national institutions made competition the dominant force in firm-centric incentive structure. Hence convergence in technological substitution was seen among all incumbent automakers. It is worthwhile to mention that this change in incentive structure could be exogenously driven, through regulatory and policy change that proactively altered the market structure.

However, while having the incentives, not all firms previously as specialists could diversify into generalists. Again, technological capability in the incumbent regime, and overall resources, played a mutually complementary and reinforcing role. The lack of either of them prevented firms from expanding the scope of technological variation. This not only validates the resource-based view and capability theory of the firm, but also highlights their combination as a

necessary condition for incumbent firms in a multi-tech, multi-component sectors to pursue technological multiplicity in times of radical change.

Chapter 9 System building of indigenous EV manufacturing firms: strategies and processes

9.1 Introduction

In prior chapters I have examined the role of green industrial policy at the sectoral level from a more top-down perspective. This is complemented by a detailed examination of the *ad hoc* heterogeneous strategic choices of direction of innovation made by firms shaped by the variegated incentive structures in their embedded innovation system, and firm-level capabilities and resources. While these steps have elucidated on the meso-level interactions over direction of innovation in the selection process, the strategies and activities of innovation undertaken by those incumbent firms that concretise and materialise the chosen direction of innovation, and how these activities and processes translate into system level outcomes, remain unknown.

Existing literature has voluminous accounts of innovation strategies and processes in general, which can be widely found in fields of innovation and technology management, organisational learning, evolutionary economics and socio-technical system approach, to name a few. However, very few have shed light on the strategic innovation of firms systematically and comprehensively in the context of early-phase green transformation, nor how firm-level activities interact with and translate into system-level dynamics, leading to the con-constitutive organisational and sectoral outcomes.

The conceptualisation and operationalisation of innovation strategies is ambiguous and unspecified in the first place, depending on the theoretical lens and different levels of

aggregation. At the meso level, the industrial catch-up literature implicitly interprets innovation strategy and process as pathways leading to the achievement/loss of industrial leadership, for example, path-following, stage skipping or path creation(Keun Lee & Franco Malerba, 2017a, 2017b; Mathews, 2002). In certain sectoral systems where technological innovation plays a critical in narrowing the forerunner-latecomer gap, specific mechanisms of learning and capability building are inherently included in the analysis as occasional micro-constituents of catch-up strategies (Joo et al., 2016; Majidpour, 2016; Malerba & Nelson, 2011). But from a more general point of view, innovation processes and activities undertaken by firms are rarely examined in detail or depth. Moreover, these analyses are often conducted at the country and sectoral level, except for highly concentrated industrial structures where only a limited number of firms exist, for example, complex product systems (CoPS) and heavy capital goods sector (Kim & Lee, 2008; Kwak & Yoon, 2020; Nam, 2015). Apart from this, a high level of abstraction tells very little about the concrete innovation activities and processes at the organisational level.

In contrast, management of innovation and technology literature in business studies have rich and eclectic discussions on firm-level innovation strategies and processes, focusing on intra- and inter- firm level activities that affect bear organisational consequences on performance and competitiveness. Innovation strategy and process can empirically refer to very different kinds of things, mainly including a) organisational learning (Lavie et al., 2010; Stata, 1989; Weick & Westley, 1999), b) modes of innovation, that is, science, technology and innovation (STI) versus doing, using and interacting (DUI) (Fitjar & Rodríguez-Pose, 2013; Parrilli & Heras, 2016), c) incumbent adaptation to technological discontinuity (Bergek et al., 2013; Eggers & Park, 2018; Jenkins, 2010), and d) the strategies and means of knowledge acquisition and capability building, which concerns the classical “make-or-buy” decision (Leiblein et al., 2002; Veugelers & Cassiman, 1999), and there has been wide recognition of the importance open

innovation paradigm (Chesbrough, 2006; Drechsler & Natter, 2012; Huizingh, 2011). While open innovation is not a panacea and it is recognised that indigenous efforts are necessary to form the "absorptive capacity" (Fu & Gong, 2011; Fu & Zhang, 2011; Spithoven et al., 2011), this paradigm is proved to be unprecedentedly important for survival and competitiveness in light of radical change and emerging technologies, especially for firms in developing countries facing resources and institutional constraints. Nevertheless, these studies are almost silent on the concrete innovation activities and processes of firms undertaken in early phase of green transformation and dynamics leading to systemic change.

To understand innovation processes in such transformative change, it is not enough to focus on any single element of the strategies and activities mentioned above. A few innovation management researchers do recognise the necessity to overcome existing fragmentation and piecemeal examination of firm innovation. Especially, in the claim to "match your innovation strategy to your innovation ecosystem", Adner (2006) advances that innovation strategies should consider where, when and how to compete and comprehensively manage different types of risks arising from interdependency. Decisions and activities of innovation hence are an integrated and coherent set of choices and actions. While the ensuing studies point to the potential of activating industrial architecture and innovation ecosystem literature to offer more systemness (Jacobides et al., 2006; Pisano & Teece, 2007), there is still substantial limitation to this strand of literature. First, the examination of industrial or ecosystem level variables is concerned with organisational performance. The system or ecosystem firms are embedded in is the external environment that firms draw resources from or try to strategically leverage in order to gain a competitive edge. It is less concerned with how firm-level activities shape the dynamics of system change, and much less with firms' role in navigating green transformation. Therefore, a more comprehensive and systemic approach is needed to add our knowledge on how firms act as the agent of sectoral change towards sustainability through innovation.

In this chapter I attempt to fill this gap by investigating how incumbent firms driving system change in early phase of green transformation from the perspective of "system building" (chapter 3). Specifically, this chapter explores how they act as agents of sectoral transformation through innovation processes and activities that span and bridge the supply side and demand side of green technologies along the industrial value chain. The objective of this chapter is hence to zoom in to the organisational level, taking a firm-centric perspective, to investigate in detail what types of innovation activities are pursued, how assets, networks and division of labour are reconfigured and consequently, how firm-level activities translate to system level dynamics.

The analytical elements of "system building" (see Chapter 3, also in the analytical framework of this chapter) provide the "focus device" to analyse the concrete strategies, processes and activities of innovation. Notably, the directionality of innovation at firm level is treated as given in this chapter based on the differentiation drawn between generalists and specialists in Chapter 8. To gain an in-depth, systemic and holistic understanding of the change dynamics, I conduct a longitudinal case study on each category of firms: Changan as a generalist and BAIC as a specialist. Based on the in-depth case studies, this chapter further inductively formulates a process-based model of system building that characterises and explains the process of change.

This chapter proceeds as the follows. Section 9.2 revisits core concepts and presents the analytical framework. In Section 9.3 introduces the research method. Section 9.4 presents the in-depth case studies of two EV manufacturers representing "generalists" and "specialists". Section 9.5 further introduces and explains the generalised process-based model of system building. Section 9.6 summarises the findings and closes with discussion in reference to literature, managerial implications and directions of future research.

9.2 Analytical framework

9.2.1 System building

Recall that in the analytical framework (chapter 3), firms in the focal sector under green transformation are viewed as system builders and their innovation strategies, activities and processes as an integrated whole are defined as ***"system building"***. It integrates the narrow and broad versions of system integration into a firm-oriented concept that connects firm level and system level resources, assets and dynamics. The definition can be revisited as follows: It refers to *a dynamic portfolio of innovation processes and value chain activities, drawing and integrating resources within and outside of the existing sectoral boundary, that aim for the emergence of a new system along the desired direction*. System building consists of four interrelated conceptual elements: a) direction of innovation; b) design rules and knowledge integration; c) dynamic positioning along the industrial value stream; and d) sources of technology and resources. A detailed explanation of each element can be found in Chapter 3 and hence not repeated here. In this chapter, I further elaborate on the inherent links between those elements in the system building activities by incumbent firms.

From a longitudinal perspective, it has been demonstrated the there is growing convergence in active technological substitution, and divergence in terms of technological variation. Hence, in this chapter I take directionality of innovation at the firm level as given and compare two types of firms: generalists, i.e., those with a broad scope of technological variation covering core competences in both old and new regime, and specialists, i.e., those specifically focus on core competences in the new regime. The basic assumption that how incumbent firms perform "system building" from a longitudinal perspective differ between "specialists" and "generalists".

Design rules and depth of knowledge integration (within and beyond the product system hierarchy) reflects the content and degree of technological and product innovation conducted by system integrators, hence constitutes the "supply side" of innovation for green transformation. This analytical element in a sense concerns the nature of innovative activities, i.e., to what extent existing design rules of product is changed, and in what ways, as well as the knowledge boundary of the firm. Firms' dynamic positioning along the industrial value stream, or value chain, additionally touches upon the demand side of green innovation, i.e., aftersales activities. This element concerns the boundary of firm in terms of activities in innovation and production from a value chain perspective. The last analytical element lists the variety of knowledge and technology sources that support the development, production, deployment and diffusion of green innovations within and outside of the sectoral boundary, and at multiple geographical levels.

9.2.2 The bridging role of business model innovation in firms' system building

In this chapter, the importance of business model (BM) and business model innovation (BMI) in firm's system building is highlighted in early phase of green transformation, in the sense that it stands at the critical juncture between the supply and demand side of green innovation and hence plays a bridging role in system building by incumbent firms that transcends and redefines boundary of the firm.

Existing literature in business and management studies has well documented the rationales and benefits of BMI. Because technological innovations do not automatically materialise and guarantee economic success, business models are important for "outlining a contingent approach with respect to how to organise the production system/value chain, taking into consideration the 'appropriate regime' and the innovator's prior asset positioning" (Teece, 2010, p. 183). While the conceptual understanding of business model is fussy partly because

of the different analytical scopes specified in different empirical research, I adopt its iconic definition as "the rationale of how an organisation creates, delivers and captures value" (Osterwalder & Pigneur, 2010, p. 14). This shares the conceptual core with Teece's perspective of BM as conceptual model of a business that "articulates the logic and provides data and other evidence that demonstrates how a business creates and delivers value to customers" (Teece, 2010, p. 173).

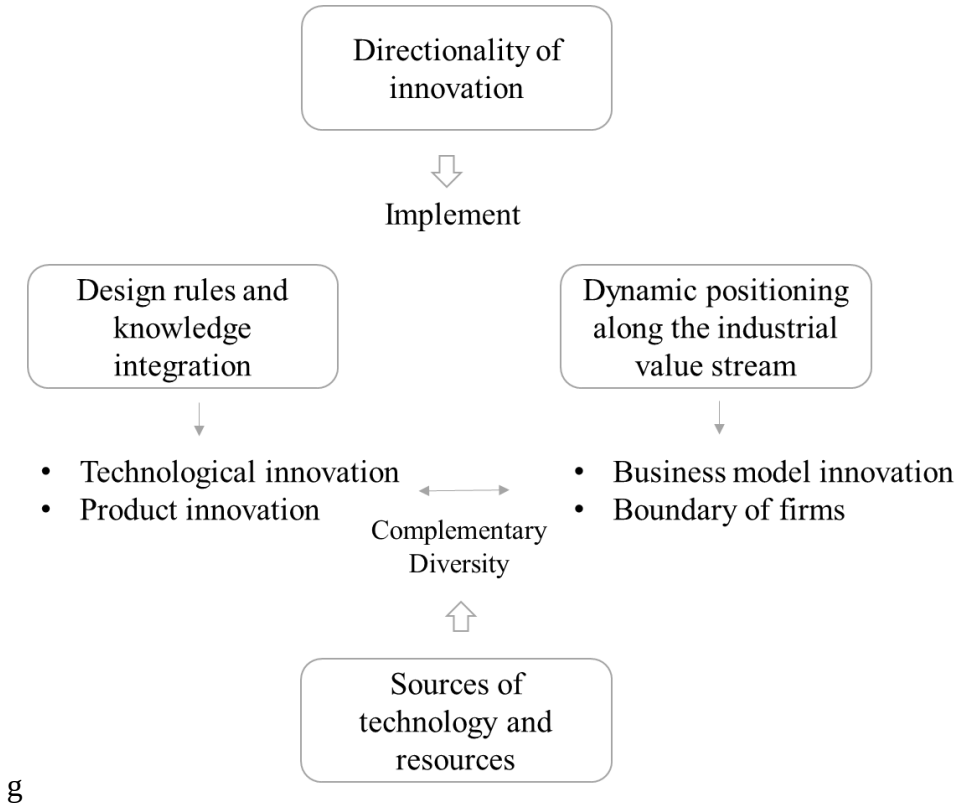
BMIs are critical to successful innovation management (Chesbrough et al., 2013), and are important for firms and sectors in green transformation, too. First, just as new technologies in general do not automatically lead to market demand, green technologies need to meet the same prerequisite to convincingly articulate their value to users. Second, green sectors featuring "infant industry" often have room for improvements in terms of quality, function and performance, as well as maturity and stability in their design and services, compared to their counterpart mature technologies and products (Oltra & Saint Jean, 2009). This makes green innovations disadvantageous in terms of cost-performance. Moreover, the positive environmental externalities created by the adoption of green technologies and products are often not reflected in market price (Lanoie et al., 2007). The existing market is inclined to make purchase decision on more conventional criterion, e.g., price, function, quality, taste, etc., therefore green technologies do not justify themselves to be accepted merely because they are "green". An alternative value proposition is therefore very much needed to compensate for this deficit in commercial value and function. Third, different from technologically and commercially mature innovations, the value proposition of green innovations is often ambiguous in the beginning. There is also the need to educate consumers about green technologies to create the awareness and shape market preference. Hence, besides commonly held benefits of BMIs in general, BMIs for green transformation additionally create the space

for experimentation, user education and demand elicitation (Boon & Edler, 2018; Thøgersen & Zhou, 2012).

Therefore, BMI is an important part of innovative activity in the early phase of green transformation. Furthermore, beyond the basic rationales drawn from management and environmental innovation literature, it is argued in this thesis that BMI assumes a bridging role in aligning system building activities and processes. Green technology is a prerequisite for green transformation, but it is not sufficient unless it is successfully commercialised, manufactured and diffused in the market, resulting in the modification and re-organisation of system of production and consumption. While design rules and knowledge integration, together with the production of green products forms the supply side of green innovation, the system integrator's activities and processes to materialise these strategic decisions are expressed in its dynamic positioning along the industrial value stream and coordination of upstream and downstream resources and capabilities. The downstream activities necessary to bring product systems to market adoption and diffusion naturally connect with the demand side of green innovation. BMI, through innovative methods of value creation and capture where system integrators coordinate upstream and downstream activities (Figure 9-1), modifies the industrial architecture through activities of innovation, production and deploying green technologies.

Therefore, business models are an inherent part of system building that accompanies technological and product innovations. According to the logic of equi-functionality, to the extent that BMIs complement technological and product innovations and bridge product system with the broader socio-technical system, the multiplicity of technological configurations and design rules in means that BMIs do not manifest and work in a singular way across all the possibilities. Instead, they complement technological and product innovations in different ways according to the desired functions and market segments under the overall strategic framing of green transformation of a system integrator (Figure 9-1). For example, for

technological configurations that have inferior appropriability conditions and/or less mature technologically and commercially, then the role of BMIs might be more prominent. By contrast, for technological configurations that are less demanding in novel competences and complementary assets, or that target lower-end market segments, then the BMIs would be more addictive and complementary than imperative in realising firms' system building. System integrators exhibiting a high level of technological variation in the greener regime would adopt different BMs.



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Figure 9-1 System building and diversified complement among innovation activities[103]

[103] Author's elaboration

9.3 Research method

9.3.1 Case study and analytical strategy

In this chapter I proceed to analyse in depth the innovation processes at the level of firm. I use the analytical elements of "system building" as the focus device to organise data and abstract stylised facts on firms' innovation activities. In-depth case study is conducted on two selected incumbent firms, one representative of "specialist" OEM – BAIC, and one representative of "generalist" OEM - Changan. These two firms are studied because each adopts dramatically different innovation strategies, while both corporate groups have managed to proceed to product platformification, launched new EV brands and established separate EV-focused companies. I present a comprehensive, rich, detailed case report for each of them so that their innovation processes and activities can be understood in a systematic way and embedded in their value chains and learning environment. Based on the case studies, I inductively put forth a more generalised, process-based model of "system building" by incumbent firms in early phase of green transformation, whereby firms' innovation activities interact with and translate into system-level dynamics.

9.3.2 Measurement of "system building" elements

(1) Design rules and knowledge integration

Regarding design rules, I empirically look at the product architecture adopted for an EV model as a product system, concerning whether systematic re-design of the product is conducted, whether new product platform is developed, or only efforts are made on modification of existing vehicle models into EVs to varied extent. This can be evaluated objectively based on product model information. In addition, whether the design of product system is integrated or modularised – as a continuum - is also considered. This is also extracted from product model information, and compared between firms. For example, within the PHEV category, some

firms opt for a simple architecture of the sub-system, e.g., P2, while others apply a more integrated design, e.g., the dual model (DM) power system developed by BYD that mechanical combination of electric motor and ICE in the powertrain to optimise overall vehicle performance. The integrated design infers greater innovative challenges and efforts.

Regarding the depth of knowledge integration, a firm decides whether to develop the technologies and hub the knowhow in-house at each level down the product hierarchy. For example, firms developing battery modules themselves have deeper knowledge integration than those only designing and developing powertrains. In terms of measurement, I look for information on whether the system integrator does the technological development and design itself or outsource, or in collaboration with other organisations (e.g., suppliers). I exclude the situation when an OEM announces joint development, but actually no substantial input is seen.

The data for this analytical element comes from two sources. One is open-source data on product information disclosure, business report and media coverage, and the other is patenting activity. Based on an understanding of the core competences in the regime and consultancy with technological professionals and experts, I identify six critical categories of technological fields (Figure 9-2). The number of patents by technological fields by Changan and BAIC is presented in the data analysis in this chapter; the data for other OEMs is given in the appendix (see Appendix C The number of patents by selective Chinese OEMs in critical EV technological fields). The data for patent information on EVs is gleaned from the Derwent Innovation database, which is frequently used to study technological trends and patent analytics in electric mobility.

Figure 9-2 Critical technological fields in EV technological regime

IPC Code	Definition	Technological fields in EV regime
B60K	Arrangement or mounting of propulsion units or of transmissions in vehicles; Arrangements or mounting of plural diverse prime movers in vehicles; Auxiliary drives for vehicles; Arrangements in connection with cooling, air intake, gas exhaust or fuel supply of propulsion units in vehicles, etc.	Design and architecture for EV powertrain *(subsystem)* and chassis (*product architecture*)
B60L	Propulsion of electrically propelled vehicles; Supplying electric power for auxiliary equipment of electrically propelled vehicles; Electrodynamic brake systems for vehicles in general; Monitoring operating variables of electrically propelled vehicles; Electric safety devices for electrically propelled vehicles, etc.	Electric control units; Power battery management systems and their interfaces with adjacent technical systems, such as charging ports, battery swapping facilities, *(core component and interfaces with complementary assets*)
B60W	Conjoint control of vehicle subunits of different type or different function; Control systems specially adapted to hybrid vehicles; Road vehicle drive control systems for purpose not related to the control of a particular subunit.	Electric control system for hybrid vehicles (*core component*)
H01M	Processes or means, e.g., batteries for the direct conversion of chemical energy into electrical energy.	Power batteries modules and their manufacturing (*core component*)
H02J	Circuit arrangements or systems for supplying or distributing electric power; Systems for distributing electric energy.	Energy storage and its interfaces with adjacent technical systems (*core component and interface with complementary assets*)
H02K	Dynamic electric machines	Electric motors (*core component*)

(2) Positioning along the industrial value stream

It is measured by concrete activities that firms engage in upstream and downstream segments along the industrial value chain, and their specific focus prioritised along the value stream. This is empirically captured by the concrete activities they take part in. Upstream vertical integration (backward) at different levels can be seen in firm's control over certain components. Integration downstream is about the doing on its own the activities after the production of EV models and distributing them to the market, including distribution, marketing, service and other activities related to the deployment and diffusion of EVs. This data is compiled from open-source reports, firm's official websites and media coverage, etc.

(3) Sources of knowledge and resources

It is measured by from where and how firms acquire knowledge and resources that are necessary for developing new EV technologies, products and deploy new products in the market. A simple distinction is whether a firm sources them internally or externally, or a combination of them through various practice of open innovation. Indigenous efforts are embodied in R&D activities, financial and personnel input, as well as the building and usage of laboratories and test centres, etc. and personnel input. The accurate figure of R&D input may not be readily available due to business secrecy and ambiguity about EV technologies, but a general statement in business report, interviews and speeches openly made by firms' top management, credible media coverage and information gleaned from stock market and consultancy analysis help provide a full picture and enables triangulation of data. Data on external sourcing and various open innovation practices are also compiled and triangulated from above-mentioned source.

9.4 Case study

9.4.1 System building by generalists: the case of Changan

Changan is an OEM headquartered in Chongqing City, a secondary subsidiary of China South Industries Group, Co. Ltd. In the early 2000s, it transformed from military equipment and heavy-duty vehicle manufacturing to minivan and passenger vehicle manufacturing, and formally started its indigenous passenger vehicle business in 2006. Together with this was the initial establishment of a corporate R&D system with an international profile[104] in order to perform technology and product development functions for indigenous brand vehicles, under the leadership of Mr. Liuping Xu, then the executive of Changan Auto. Since China's

104 Changan's international R&D layout consists of overseas research centres in the U.S., UK, Japan, Italy, and it has research institutes domestic in Shanghai city, Beijing city, Ha'erbin city, and Jiangxi province.

concession to WTO, Changan formed JVs with international brands such as Ford, Peugeot Citroen, Suzuki, Mazda and so on. These JVs were not only the major source of financial income, but also learning on technologies, product platform, brand and manufacturing. For quite a few years, like other indigenous OEMs in China, Changan-made sedans were to a large extent a result of reverse-engineering and imitation.

It envisaged electric mobility as the future direction of technological development, and very early on took part in state-funded R&D projects for technological exploration. In 1998, Changan became part of the "Clean Car Action" and then 863 EV Major Project since 2001. It set up a new project team in 2002 to specialise in hybrid vehicle development based on Antelope vehicle platform produced by JV Changan Suzuki[105], which accomplished one of the 863 projects "ISG medium hybrid electric vehicle Changan sedan development". In the subsequent ISG whole vehicle development project (2003-2005), Changan accumulated experience in development and manufacturing of performance prototype and reliability prototypes of ISG HEV. In 2005, the first cycle of 863 major project concluded, and Changan decided to move on with the commercialisation of HEVs based on Jiexun vehicle platform[106]. After 11 rounds of prototype manufacturing, Changan launched its first - also the first in China - HEV model. This was achieved through collaboration with component suppliers and universities in the country, with Changan engaging battery modules, BMS, vehicle control and product system integration. These projects received funding support from MIIT and MOST at the central government level.

When Changan performed well in the 2008 Beijing Olympics EV demonstration and was ready to commercially launch its first HEV model, Chongqing city government expressed its support to strengthen local industrial capacity. In 2009, Changan and Chongqing Technology Venture

[105] Later Changan switched to Lufeng fengshang platform.
[106] This vehicle platform has its source in Italian and German design and technology.

Capital Co., Ltd. jointly invested in Changan New Energy Automobile Co., Ltd. (Changan NEA), a new subsidiary company, ready to formally commercialise its Jiexun model[107]. The R&D centre of its group, Changan Automobile Engineering Research Institute, was the source of core capabilities in vehicle and powertrain technologies, and Changan NEA company was responsible for application-oriented vehicle development. Production capacity was hosted in the Liangjiang New Area Industrial Park [108].

Along with a temporal commercialisation focus on HEV, Changan's top management maintained a strategy of technology multiplicity (explained in Chapter 7). The capability development in other technological solutions benefited a lot from collaboration with various partners in various forms. In BEV trajectory, Changan took the chance of acquiring the poorly performing Hafei[109], another SOE, integrated its Leopard model and turned it into BEV model E30. Earlier Hafei developed the Leopard model within an international R&D team but found it hard to attract consumers due to the infancy of EVs and high costs. Changan's E30 was then put into demonstration as taxi in Fangshan District, Beijing City[110]. In the meantime, Changan also developed its A00 BEV Benben Mini based on its popular ICEV model Benben. At the group level, FCV technology was also explored with minor interests by the research team at Changan Automobile Engineering Research Institute.

[107] According to informants, this subsidiary did not last long and was soon re-integrated back to Changan Auto group.
[108] It is a state-level economic develop zone, authorized by NDRC in the central government in 2010, with national and municipal policy support to cultivate high-tech industries.
[109] Hafei Motor was a state-owned automaker in Ha'erbin, the capitol city of Heilongjiang Province in Northeast China. It was affiliated to Aviation Industry Corporation of China. Once it had some success in MPV segment but backfired in passenger vehicle business. It had been sluggish until the central government intended Changan to acquire and merge it. In 2015, it was formally acquired by Changan Ford, the JV between Changan and Ford. However, because at that stage Changan's exploration in electric mobility was mainly at the group level, hence the capacity and early product exploration by R&D team in Hafei was naturally transferred to and utilized by Changan.
[110] Because the maximum electric drive range was only up to 160 km, E30 did not require specialized charging facilities.

Before the end of 2014, Changan's move in electric mobility was very cautious. Existing EV models were at an experimental stage, mostly put into demonstration programs in the public sphere at a small scale, rarely diffused to the private market. The market acceptance of this Jiexun HEV model was not enthusiastic at all due to technological deficits and high price, and it stopped production shortly after 2009. Other models such as E30 and Benben Mini, were also deployed in a very small volume. By 2014, Changan deployed over 5,700 EV models in 13 pilot cities through government purchase, taxi fleet and other public transport.

Changan had to shift to "pure electric drive" strategy during 2014-2015 when state policy reaffirmed its support for this strategy with intensified and more comprehensive policy measures. HEV development was aborted given the high costs and lack of competitiveness compared to international brands (e.g., Prius). In 2015, the company announced to develop a dedicated vehicle platform for each technological trajectory, and *"…up to 2020, marketize 34 brand-new products in three stages, among which there will be 27 BEVs and 7 PHEVs*"[111]. At the conference, Changan launched its first EADO BEV in the A class segment, followed by CS15 EV in later years, a compressed BEV model in SUV segment.

Though commercialisation of HEV stopped, the entire competence built up in the period was still useful. In terms of ICE competence, there was huge room for technological catch-up relative to global brands, and Changan's HEV effort largely overlapped with the overall capability building endeavours to develop high-performance ICEs. With the burgeoning of China's market demand for large-size, cost-efficient cars, the SUV segment was enthusiastically pursued by both automakers and consumers. The company made significant efforts to upgrade powertrain and vehicle technologies to compete with JV brands and other domestic counterparts for higher-price market segments. The key lay in the improvement of

[111] http://auto.sina.com.cn/news/2015-03-06/07001408058.shtml

the ICE power system, which was decisive of the size and integrated performance of the vehicle. An important source of technological learning came from its close collaboration with its overseas R&D centre in Birmingham, UK. Changan hence benefited a lot from the latter's strong competence in ICEV powertrain and power system technologies. These efforts supported the launch of CS series that targeted the SUV segment and proved quite popular in domestic market. The seminal NE powertrain platform as a result had the merit of fuel and energy saving, strong propulsion and high-level of system integration. Its first generation, NE 1.5 T, directly empowered CS series SUVs. Especially, C75 remained one of the top ICEV models in its market segment for several consecutive years.

With the improvement of powertrain technologies and the initial experiment with BEV models, Changan managed to integrate the two lines of technologies, with the help from global system supplier Schaeffler on electric power system, and rolled out its first PHEV model that was based on the EADO vehicle platform. In 2017, Changan continued to roll out CS75 PHEV adapted from the best-seller in the fast-growing ICEV business. Further, CS series models were also modified into BEV models, starting with CS 15 and followed by others.

Benben, EADO and CS series were all popular ICEV models and major revenue sources of sales revenue for Changan's indigenous brands. In 2015, Changan achieved a one-million sales volume in indigenous-brand passenger vehicles, nearly half of which was contributed by three ICEV models: EADO, CS35 and CS75. Correspondingly, it can be seen that Changan's EV models, including PHEV and BEV, were all adapted from these vehicle platforms.

Not only existing ICEV models experienced upgrading and renewal, but also the derived EV models. In the process, the company upgraded electric power system, BMS and vehicle control, to continuously improve product performance, quality and reliability. EV models were updated simultaneously with the renewal of corresponding ICEV models, while incorporating extended electric drive range - enabled by battery suppliers and improved battery management

technologies – and other EV technologies. For example, the first EADO BEV model only had an electric drive range of no more than 300km, but later models upgraded to 300 km and 460 km gradually and incorporated better battery safety and energy management measures [112]. This had a lot to do with battery suppliers, such as CATL, that provided power batteries with increasing power density and lower cost. At the same time, by developing vehicle models and subsystems and operating them in the market, Changan was able to learn and improve sub-system and lower-order technologies such as BMS, and raise the degree of system integration. The power train initially integrated three core components and then gradually expanded to five and even seven. This helped reduce weight and size, and as a result energy consumption, and finally improved overall vehicle performance with lower costs. These improvements in the sub-system were incorporated into EV models.

Another important line of efforts was seen in the integration of ICTs technologies into the provision of functions and services of vehicles regardless of ICEVs or EVs. According to one of the R&D team leaders and senior-ranking managers, this was a natural result of the company seeing the technological opportunities arising from the fast development of ICTs and related technologies.

> "*Originally intelligent technologies were explored by a small R&D team in a subsidiary company. Around 2013, 2014, we began to do autonomous driving when the concept was emerging. Now we are testing some L4 technologies all using BEVs, because BEVs are a battery platform for ICEVs. It turns out that this part grows bigger and bigger, and becomes a strategic direction for us. This year, the core theme of our campus recruitment is electric and intelligent vehicles…We now have an intelligent vehicle research institute hosting several hundred people, many experts.*" (Interview B1-03).

[112] The BEV model was named by its product series and drive range, e.g., EADO 460.

The integration of ICTs and other emerging technologies are very important to automakers embarking on electric mobility transitions:

> "*From my perspective, new energy vehicles are not realistic for our (corporate) leaders, but realist for our country. Neither enterprises nor consumers are interested because it only solves the power source problem – what change have you brought about when you turn an ICEV into an EV? Almost none. But if you say that you turn a human-piloting car into a self-piloting car, it is definitely attractive. People in their lives just need more and more convenience. This is why we say that intelligent vehicle is more lively than electric vehicles*." (Interview B1-03).

All those EV models adapted from existing ICEV platforms could not be said to be ambitious considering their moderate drive range and "incremental" product innovation efforts. Changan was eventually determined to engage in electric mobility transformation radically and fundamentally in 2017 with the announcement of its Shangri-La plan (see Chapter 7). Changan decided to invest heavy R&D resources to develop three comprehensively new EV platforms - two of BEV and one of PHEV - instead of continuing with modification of ICEV platforms.

> "*If you do BEVs and want good functions, literally you have to do completely new platforms. Because you need to put batteries on the chases; and once you put batteries on the chases, the vehicle platform overall has to change, and the entire driving system, suspension system and so on, all need to change…the platform experiences dramatic alternations, and it has to be developed anew. For example, VW's EQ platform is newly developed. Technically it is not complicated, but for an enterprise, you have to invest a lot of money to develop a new platform, because you must do a lot of tests, verifications, and so on, and all these cost money*". (Interview B1-01)

To support this strategic transformation, an organisational restructuring was carried out by establishing a separate new energy vehicle business unit. It had full functions covering strategic planning, product development, power system research institute and marketing and services. The new business unit could directly report to Mr. Huarong Zhu, the new chairman after Mr. Xu left Changan, and enjoyed greater autonomy. This business unit further grew into an independent company, Chongqing Changan New Energy Vehicles Technology Co., Ltd. Financial assets, personnel and IPs relevant to electric mobility in Changan Auto group were all transferred to this new company. Strategic investors were sought in order to pool a huger amount of money for R&D, commercialisation and market diffusion of coming EV models.

Changan gradually achieved a deeper degree of vertical integration by designing and producing the all-in-one electric power systems, but the development of battery cells and modules were still in the hand of suppliers. To secure fair-quality supply, Changan formed joint ventures with CATL and BYD, the two leading power battery suppliers in domestic market, after 2017. "*The objective of establishing a joint venture is that it is close to us, and to ensure the supply of batteries to us. Besides, the cost is lower.*" (Interview B1-02). More specifically, "*Changan does not do power batteries. In order to ensure supply and good quality, it invests in suppliers, for example, it is one of the shareholders of CATL, right? For shareholders, we have well negotiated that by principle they offer the lowest price and prioritise supply to us. Through this means, the problems with supply and cost are all solved*". (Interview B1-02)

Another consideration is the uncertainty of this complementary technology upstream: "*There is much uncertainty in battery technologies… for example, now it is NCM, and its composition is popularly 811. Next step people envisage solid-state batteries, and of course, many other new types of batteries. So, the technology itself is under development. If an automaker does it itself, you have to invest tremendous money, and this is not economic.*" (Interview B1-02) The power batteries by CATL were mostly NCM that supported long drive range, while those by

BYD are often Lithium iron phosphate with slightly lower drive range but also lower cost and higher safety. The two battery technologies provided solutions for Changan's various EV models targeting different market segments. For other component systems that concerned vehicle function and quality, Changan also achieved vertical integration, "…*like BMS, stronger enterprises tend to do it themselves…battery firms can help, but generally it is better for OEMs to do it, because BMS is closely related to your car, in terms of safety and many things else*" (Interview B1-02). By contrast, *"…electric motors are not technically sophisticated as power batteries, nor is its technological uncertainty. And its production is relatively easy. It can be integrated together with electric control systems, right? So, automakers do electric motors themselves.*" (Interview B1-02)

Accompanying the Shangri-La plan was the Intelligent Strategy, which stressed ICTs, digitalisation, intelligence and connectivity as another strategic pillar for Changan's corporate transformation. Taking the two strategies together, Changan aimed to transform from a conventional automobile manufacturer to a "smart mobility technology company". It cooperated with a wide array of technological companies, mainly in the field of ICTs, telecommunications, and AI. One concrete and typical effort was its collaboration with Tencent that successfully loaded WeChat, a dominant social media platform in China, onto CS75 PLUS model. These were also loaded in corresponding EV models.

Like other EV manufacturers, Changan also experimented with business models and service portfolios to assist EV market adoption, for example, by establishing its own mobility platform Changan mobility. However, the small scale of EV models made this self-owned platform very costly. Later, Changan gradually shifted the venue to another mobility platform, T3 Mobility, that were jointly established with FAW and Dongfeng. This could better pool resources and improve cost efficiency. Not surprisingly, Changan contributed to the majority of EV fleet in the T3 platform as the other two firms were sluggish in electric mobility transition.

Besides, Changan also cooperated with complementors within and beyond the sector to provide a wide range of services to EV users. It first formed a joint venture with TGOOD, a domestically leading charging ports construction and operating company, in 2017, and established the so-called NEV experience centre.

> "*It adopted in-person experience plus online purchase model. One the one hand, the experience centre has charging infrastructure inside and provide vehicle diagnosis and repairing services. On the other hand, it helps disseminate the knowledge about EVs and business models – comprehensively demonstrating how vehicle charging works and its characteristics, so that our customers can directly know about the interior architecture of EVs, try it out, and also enjoy car rental services*" (Interview B1-04)[113].

Following that, Changan went on to cooperate with State Grid to explore optimised charging solutions based on the latter's competence in utility service and energy sector. Special emphasis was put on battery-oriented service, which Changan as an OEM tapped into and capitalise on. It launched the "Battery Manager" function, an integrated user-oriented energy management solution where EV users could check the real-time status of power batteries and receive regular battery health reports. The company on the other side analysed and evaluates the usage of batteries based on big data accumulated, hence able to send reminders and customised usage recommendations and solutions to specific users. Later, life-long quality insurance was put forward that was attached to an EV model instead of its owner.

Before the Shangri-La Plan bore fruits, Changan continued to roll out an expanding matrix of EV models and upgraded them generationally. The E-Family series BEV models rolled out during 2019 and 2020 gained more coherence after several years of experimentation based on Benben, EADO and CS series respectively. It consisted of E-Pro, E-Rock, E-Star and E-Life,

[113] This is a historical interview, Sohu Auto with general manager, Ms. Lu Qianyuan, of the JV, in 2016. https://www.sohu.com/a/63155617_372880?_trans_=000019_wzwza

as generated from the upgraded ICEV models, i.e., CS 15, Benben EV, CS 55 Plus, and EADO Plus, respectively. What aligned them together was the usage of highly integrated electric power system, the adoption of high-power-density-battery, new vehicle exterior design and integrated service portfolio. However, these were still based on existing ICEV platform, but they were the units that Changan explored new business models and product-user interface while the new BEV platform schemed in the Shangri-La Plan was under development.

At the same time, Changan did not stop at CS series in technological, product and brand upgrading in the ICEV regime. A more radical move soon took place in 2020, when Changan launched a new ICEV product series, the UN series, that targeted a higher-end market segment to compete with JV brands. Models such as UNI-T, UNI-K and UNI-V were warmly welcomed in the domestic consumer market. The steady monthly sales of over 10,000 volumes were impressive given the higher price than domestic competitors[114] , the nascence of the product series, and the fact that many indigenous brands' product upgrading attempts backfired. The UNI series models loaded the second generation of NE power platform, NE 2.0, the result of continuous joint efforts between Changan R&D centre and UK partner to develop high-performance, highly integrated power system. Revolving this brand-lifting product series, Changan experimented with independent sales channel operation and newest services and forms of firm-user interaction, e.g., "playing together with users", "co-creating the dream car", livestream interactions between UNI-K engineers and users, etc. Alongside the E-Family series, these explorations and experiences in ICEV were also beneficial for marketing and service innovation in EV products.

The temporary success of the UNI product series should be attributed to the Arc Architecture as a result of years of technological accumulation, upgrading and integration. The ICE-based

[114] The baseline price was 130,000 RMB per car, while many other SUVs produced by domestic automakers were sold at a price slightly above 100,000 RMB.

competence supported the formation of the Arc architecture. It enabled platforms that covered market segments from A0 to C class, was compatible with eight engine modes, and flexibly accommodated hybrid electric drive solutions including LV-HEV, HV-HEV, PHEV, 48V HEV, etc. While this architecture was only preliminary in the UNI-series, it was open to updates and evolution. More importantly, different from conventional vehicle platformification, the Arc technological architecture encompasses multiple technological fields, not exclusive of electrification, but also ICT-based functions and technologies, such as advanced autonomous driving, scenario-based vehicle usage service, AI intelligent assistant, etc. Revolving around this Arc architecture, Changan aligned its collaborators within and outside of the sector and explored division-of-labour by development and deployment of new vehicle models.

Part of these afore-mentioned explorations were naturally incorporated into newly developed BEV platforms under new brand names and even new companies, the result of Shangri-La Plan. Two lines of effort were undertaken. The first was the launch of AVATR, a high-end electric, intelligent vehicle platform that was jointly developed by Changan, CATL and Huawei. The latter two companies, each highly competent in their fields of specialisation, provided power batteries and highly integrated electric drive units respectively. Boasting the integration of most advanced technologies on its BEV platform (CHN[115]) in the SUV segment, Changan was very ambitious of AVATR becoming a turning point for itself to transform into a high-tech company. While one could hardly find fault with the performativity of the vehicle itself, its high price (over 340,000 RMB) and nascence made consumers temporarily reluctant to spend money on it. By contrast, another line of effort was seen in the establishment of the digital, all-electric SL brand[116] and the launch of SL03 model. SL was exactly what the previously known Changan

[115] The abbreviation consists of the first character of each company name, i.e., C for Changan, H for Huawei, and N for Ning De Shi Dai (the Chinese spelling of CATL).
[116] SL is the abbreviation for Chinese spelling of Shen Lan （深蓝）, which means deep blue – the colour blue denotes purity, cleanliness environmental friendliness.

NEV company turned to become after it introduced strategic investors and conducted mixed ownership reform in order to better implement the Shangri-La Plan. The financial separation of the company from Changan Auto group and name change was intended to "make users focus more on SL". This newly designed EV platform also flexibly accommodated various technological configurations that worked on power batteries, including BEV, REEV and most recently FCEV. To differentiate from earlier BEVs, both AVATR and SL established their independent marketing and service channels, and the marketing and service practices were heavily informed by earlier explorations in both ICEV and EV models diffusion.

While Changan was catching up quickly after its strategy reorientation in 2017, and its competitiveness could be partly and temporarily seen in SL models and its Arc Architecture, challenges and uncertainty were still there. One important problem was whether Changan could perform and be recognised as a competent system integrator, given that its high-end platforms were co-developed with specialised complementors, and new companies were heavily influenced by strategic investors. Undoubtedly, Changan needed to carve out its core competence as the leader and orchestrator of the platform and differentiate itself from a growing number of other premium intelligent EV brands in China, by both incumbents (e.g., Aion by GAC, R by SAIC, GEEK by Geely) and new entrants (e.g., NIO).

9.4.2 System building by specialists: the case of BAIC

BAIC is a SOE reporting to the SASAC of Beijing City government. It has four brands, one of which is indigenous vehicle brand Beijing, including a passenger vehicle brand Senova. Quite a latecomer even in domestic market, Senova was established in 2012 through the acquisition of a Sweden vehicle platform, SaaB, in 2009 and modifying it to accommodate China's market characteristics. The technology acquisition concerned whole set of SaaB 9-3 and 9-5 vehicle platform and IPs in powertrain system. The first Senova model, D20, went to market in 2012.

It is commonly perceived that BAIC lagged in building indigenous capabilities in technological and product development in cars and sub-systems. At the group level, BAIC's passenger vehicle revenues are far more contributed by models from JVs with Mercedes Benz and Hyundai. By contrast, its non-light-duty vehicles, including Futian bus, Beijing Jeep and others, performed relatively well. Hence its early exploration of EV technology was mainly based on electric buses, with a minor focus on passenger vehicles. In 2007, the group established a dedicated R&D department, New Technology Department of Beijing Automotive Research Institute, to undertake deep-hybrid electric vehicle technology development under the supervision of the second-stage 863 major project and supported by Beijing Municipal City government as well. Like other OEMs at an early stage of technological exploration, BAIC tried ISG solutions in HEV technological trajectory because of its relative maturity.

In the presence of strong incentives as explained in chapter 7, BAIC became one of the early movers in commercialising and deploying EVs in China. In 2009, BAIC established BAIC New Energy Company (BAIC-NEC) that was financially separated from its parent group in order not to affect ICEV business performance on the balance sheet. Although it had a certain degree of technological exploration in ISG solution, this proved to be too challenging for BAIC as it lacked the necessary core competence in powertrain and vehicle development, hence it turned to BEV. The first BEV model, EV150, based on the Saab platform, was used for taxi fleet to accumulate vehicle usage data and service. Apart from this, Beijing government and other public authorities purchased BAIC's BEVs according to public procurement mandates. This first batches of EV models marked BAIC's commercialised exploration in the EV regime, as embodied in its "Blue Guardian Plan 1.0". BAIC, together with domestic suppliers of power battery cells and materials, invested in a joint venture Pride Power that provided power batteries for BAIC's EV models. Electric motors were sourced from a joint venture with a domestic specialised supplier Zhongshan Broad-Ocean Motor Co Ltd. These firms and their production

were hosted in the newly established Beijing New Energy Car Technology Industrial Park with support from local government.

Following EV150, some other BEV models also went into market deployment in Beijing. In the process, BAIC was able to test and upgrade vehicle product functions and quality. To assist market adoption and solve charging problems, it also explored various business models, at a small scale and sporadically, such as battery swapping, ride-hailing and car rental with specialised service providers. This proved to be very important as infrastructure and other complementary assets were insufficient. "*Through various aspects of innovation, especially in charging models in recent years, we integrate societal resources to address users' anxiety concerning drive range and charging, so as to 'pull' the sales of BEV models…We have made very useful attempts and collaborate with competent suppliers nationwide to ensure the selling and charging of our products.*" (Interview B6-01)[117], commented by Mr. Wenzhang Zhan in an open speech, then the chief EV engineer and minister of BAIC group strategy and planning department in 2015.

BAIC intensified its efforts in electric mobility after 2014, when stage policy was clear in supporting the transition with a "pure electric drive" orientation and generous subsidy. This marks the "Blue Guardian Plan 2.0". During this period, BAIC began to actively reach out to individual consumers and rolled out more BEV models. To support this strategy, it carried out an ownership reform and made BAIC - NEC a mixed ownership subsidiary company, BAIC-BJEV. Registered fund grew from 100 million to 2 billion RMB. This provided strong financial support and a business platform for the group to form further joint ventures with top component suppliers, including SK, a South Korean battery supplier, and SIMOTICS, electric motor supplier under Siemens, etc. Admittedly, BAIC's strategy to form joint ventures and

[117] This is a historical interview, with the speaker's remarks made in 2016 at an open speech. https://m.gasgoo.com/news/60358478.html

partnerships was to a large extent driven by the imperatives to roll out EV models while its own technological capability was limited, especially incapable of improving the function and quality of subsystems and component systems. "*By cooperating with Siemens, the function of our products' electric power system is improved…on such basis, we should transplant and transfer technologies and improve the function of whole product series*." (Interview B6-01)[118] Mr. Zhan explained.

By 2017, BAIC commercialised around ten BEV models, e.g., EH, EX, EU, EC and EV series covering a how range of market segments from A00 to B class, including both sedans and SUVs. These were all adapted from the existing Senova vehicle platform (originally Saab) in the ICEV regime. With the deployment and diffusion of these models, BAIC R&D team were able to improve product function and quality based on customer feedback, problems reporting and data accumulated from EV models. This resulted in the formation of integrated electric powertrain technology, called e-Motion Drive, that combined electric drive system (EDS), power distribution unit (PDU), super motor, high-speed motor reducer, etc. While BAIC was able to assemble these technologies into its BEV products, core competence of each part of the product system sub-units largely came from suppliers and partners.

In 2018, BAIC achieved backdoor listing in China's stock market. In this way, it was swiftly able to raise more financial resources for expansion of EV business and building up of complementary assets. The whole value chain collaboration further consolidated into the "Open & Sharing Strategy", announced by BJEV at its NEV ecosystem conference. "*During the period from 2018 to 2025, BJEV will implement comprehensive open and sharing strategy in all aspects including technology, R&D, manufacturing, capital, supply chain, after-sales, etc.*"[119] In the coming years, BAIC group and BJEV established the Beijing New Energy

[118] The same source as above.
[119] The strategy was announced in early 2018 by Mr. Zheng Gang, the manager of BJEV. https://www.sohu.com/a/215836313_275361

Automotive Technology Innovation Centre together with value chain collaborators to harbour these partnerships, relocated to the newly built BAIC Blue Park with 400 million RMB investment. This did not only involve technological and product development, but also downstream activities. Particularly, an accompanying Optimus Prime strategy was put in place to focus on building up battery charging and swapping ecosystems with utility company State Grid and local operators and suppliers. It aimed to invest 10 billion RMB into building 3000 solar PV- power storage integrated battery swapping stations nationwide, deploying 500,000 BEVs and utilising over 5Gwh battery energy from storage system. This business model sought to decouple the cost and business value of power batteries from EVs so as to facilitate EV diffusion. It was a daring business model, which Better Place once failed in the US and was tried by NIO in China. BAIC had been experimenting with this model even since 2011 partly due to the under-development of power batteries in the sector and lack of strong battery competence within the firm. By the end of 2020, BAIC had successfully installed 225 power battery swapping stations in 19 cities nationwide accomplishing 6.8 million times' swapping serving 22,000 EVs[120]. This was realised through close cooperation with value chain partners, State Grid on the utility side, and Aulton[121] on the supplier side.

BAIC's BEV models diffused quickly in local market and expanded to cover a wide range of market segments of different levels of size, functionality and cost-performance, including EC series in A00 segment, EX series in compact SUV, and EU series in sedan, etc. Among these diverse models, the EC series represented the majority of BAIC's overall BEV sales. This A00 segment BEV model only cost 60,000 RMB after all subsidies were calculated in. In 2018, EC topped China's domestic passenger EV sales rank, and took up over 50% of BAIC's annual

[120] http://www.energytech-expo.com/cnt_282.html
[121] Aulton is a specialized battery swapping solutions provider in China. It has been exploring battery swapping technologies since 2000, previously as Shanghai Dianba (a wholly owned subsidiary of Aulton New Energy Group). For more information on the company, visit its official website: https://www.aulton.com/index.php/en/list-26.html

sales volume that year. However, this by no means equalised technological competence. When national subsidy reduced dramatically in 2018 and 2019, the short-drive-range model EC series soon lost competitiveness. In December 2018, BAIC recalled around 70,000 BEVs from the market due to various quality problems. BAIC tried to shift focus to larger size segments, for example, EU and EX series. EU became BAIC's second best-selling BEV series with intensive demand creation measures in place. It enjoyed eye-catching sales records, with 90,404 models sold during Jan.- Nov. 2019. However, the majority of this was deployed in the market as mobility service, either by mobility business owned by BAIC, or jointly formed with other specialised ride-sharing platforms. For example, Jingju New Energy Automobile Technology Co., Ltd., a mobility-service firm cooperated between BAIC and DiDi, was the major operator of EU series.

While BAIC's BEVs enjoyed great sales in local markets and other cities where BAIC NEC built manufacturing sites, its ICEV business continued to shrink and lost competitiveness. The sales volume of Senova in 2017 and 2018 was only 860,000 and 650,000 respectively, and hardly had any chance to recover ever since. BAIC was not unaware of these circumstances, which were a reflection of long-standing problems of lacking strong technological capacity in the automobile industry. In fact, the group intended to increase its capacity and competitiveness by implementing the "dual upgrading strategy", the upgrading of both the brand and product. Part of this strategy was seen in the brand restructuring conducted after 2017, when the integration of BAIC NEC and Beijing Auto (the Senova-based ICEV business) resulted in a new brand BEIJING that produced a whole range of vehicles targeting lower-, middle- and medium-higher market segments, including existing models such as EV, EU, ET, EC series, and new BEV models to come (e.g., EX). The ICEV brand Senova was incorporated into this new brand and its assets were utilized for EV production, deployment and diffusion. This meant that the business and strategic focus fundamentally shifted from ICEVs to EVs.

Product upgrading was seen in both higher-end products based on existing platforms and a new BEV platform that supported completely new designs, product series and even brands. The EX-series rolled out in 2018 was an example of product upgrading. EX5, launched in 2019, loaded the third generation of BAIC's integrated electric power system technology, and the up-to-date ICTs sourced from partners (Baidu). EX5 was seminal for BAIC in that it is the first vehicle model that adopted the Darwin technology architecture, that harboured whole value chain technologies and services, including high performance power batteries, voice interface, assistant driving, vehicle-to-grid energy transmission, etc. The Darwin architecture was the result of BAIC's concerted efforts in executing the "Open & Sharing Strategy". The one loaded on EX5 was only preliminary, and its later versions incorporated the updates and expansion of technology and service units.

Realising that adaptation of the existing ICEV platform was no longer sustainable, BAIC also worked hard to develop a new, dedicated BEV platform. By collaborating with Huawei, a leading ICT company, BAIC launched a newly designed BEV platform under the new brand name of ARCFOX. ARCFOX models signalled BAIC's strategy emphasis on electric and intelligent vehicles that incorporated high-tech elements and fashionable designs as many as possible. This was backed by its cooperation with CATL, one of the most component domestic suppliers of power batteries, Huawei, a leading ICT company, and Magner that together with BAIC built the largest factory in the country to manufacture EV models. However, in the short term, the "dual upgrading" strategy in EV product and brand did not make BAIC perform better than other OEMs. The ARCFOX models, including ARCFOX-a, ARCFOX-t, etc., were priced very high (over 400,000 RMB) and did not attract many customers, given the fact that with the similar and sometimes lower price, people could get a Tesla model that performed better. It turned out that the total monthly sales of ARCFOX models did not exceed 1,000, while the BEV models made by domestic startups such as NIO could surpass 10,000 in certain months.

In face of intensive competition in the sector and a requirement of accumulation of strong technological competence, the prospect of ARCFOX, along with the entire BAIC electric mobility performance, is still unclear and could be very challenging.

9.5 System building by incumbent firms: A process-based model

From the single case study conducted on Changan (as a generalist) and BAIC (as a specialist), it can be seen that the process of system building is neither linear, nor mechanical, but evolutionary, boundary-spanning and inherently a process of reconfiguration of innovation systems. From a firm centric view, the three conceptual elements of system in combination exhibit qualitatively different characteristics overtime, which can be appropriately divided into four distinctive stages: (1) Project-based technological exploration; (2) Derivative experimentation; (3) Product platformification; and (4) Re-alignment towards system reconfiguration. This is the inductively generated process-based model of system building that explains how innovation activities and processes change overtime as green transformation unfolds at the firm level which catalyses changes at the system level.

9.5.1 Stage one: Project-based technological exploration

The first stage features pre-commercialisation technological exploration of e-mobility conducted in the format of R&D projects. Electric mobility is a peripheral part of a firm's technology strategy and does not enter business strategy. The technological development of EVs is limited in scope and is additive – or attached – to the firm's existing R&D portfolio without dramatically modifying internal or external organisational set-ups and value networks.

From the perspective of incumbent OEMs, there has not been established design rule for EVs. At this stage OEMs first need to build up the initial absorptive capacity, which is realised in a stepwise manner. They start from making sense of the overall product architecture to

understand how an EV model comes into being and how the model works. This step does not require a model to function well, but to assemble the subsystem and components together only to make it become a complete product system, resulting in a "theoretical prototype". After this architectural knowledge is mastered, the technological exploration then proceeds to developing an "engineering prototype", which is functional and usable while far from being commercially mature.

In the process, OEMs deepen their knowledge integration to at least the sub-system and component system level. This is because OEMs must understand the working of, e.g., electric power train and battery power system, to enable the prototypes to perform properly and firms are able to make adjustments and improvements when functional problems arise. The objective is to follow the developments in upstream complementary assets so as to make informed decisions on at multiple levels of vehicle product system. The learning of JAC before 2009 was illustrative.

"*We want to transform, then the choice of our path is critical. We use the method of exclusion. We invite experts from Hyundai to our company and listen to them…Toyota rolled out HEVs in 1998 in a large scale, but back then our R&D was very weak, and we hand not mastered AT, DCT, this kind of transmission technologies. So, it is very difficult to do the power diversion or P3 model on such basis*" (Interview B3-01).

"*It was apparent that HEV was impossible for us. FCEV was not feasible either, because GM had not overcome the technologies after many years past (we visited GM in the U.S. in 1995). Then what remained was lithium battery vehicles. At that time BYD was already doing it. So, we decided on pure electric drive strategy*." (Interview B3-02).

Because these learning activities are only explorative, OEMs often use small R&D projects as the avenue. They do not rely on internal technological competence; open innovation is

conducted mainly within the emerging sectoral system. Because the necessary knowledge and technologies are nascent, scattered and distributed, these OEMs use such exploratory projects as the means to pool resources, match competences, lower costs and reduce risks. This includes, in the first place, core component suppliers, that are involved in developing various stages of prototypes. Besides, the involvement of global OEMs is important as they are closer to technological frontier. At this stage, partnership with university and public research institutes matters a lot because that are the major locus of scientific and engineering knowledge of EVs, batteries and electric-chemical experiments. Due to the exploratory nature of these R&D projects with hardly expectations of economic return, these projects are often funded by public finance for a large part.

At this stage, system building is mainly technological oriented, not commercialisation oriented. Without substantial production and commercialisation activities, OEMs' positioning along the industrial value stream remains almost unchanged. Their major activities are system integration in the conventional sense and mostly conceptual and prototypical.

9.5.2 Stage two: Derivative experimentation

The second stage is called "derivative experimentation", when firms move from mere technological and prototypical exploration to small-scale, experimental commercialisation of green products. This does not mean that technological exploration has ended; instead, the experimentation with market deployment of EVs is itself a critical process of learning. From the perspective of the entire automaker's corporate group, ICEV business is the backbone and still in the process of technological catch-up. Business activities in the EV regime are only minor compared to incumbent ICEV businesses, but gradually get momentum and increase in the scale, frequency and diversity of green products. However, electric mobility does not develop as a standalone business, but is derived from the incumbent industrial regime in many

aspects while experimenting with new business models in a fragmented, piecemeal way along the industrial value chain.

There is still no established, original design rule for EVs, but derived from co-existing ICEV models in the firm's product portfolio and adapted to incorporate EV's functionality. The derivative experimentation in the EV regime is built on both technological upgrading in the incumbent industrial regime and the continuous integration of emerging technologies, e.g., ICTs, that bring added value to existing products.

For OEMs, technological and product upgrading in the ICEV regime is most important. Continuous R&D efforts are required in more sophisticated, better designed ICE powertrains that have stronger power performance and improves in parameters including fuel economy, energy efficiency and emission, compared to earlier years of cost innovation. Indigenous brands benefit a lot from cooperation with global OEMs. For example, Changan's NE1.0 and 2.0 power platform were co-developed with Birmingham R&D centre, and SAIC's CUBE-TECH was supported by GE. The other change is driven by converging, emerging technologies that add value to existing products, mainly ICTs, which are themselves constantly evolving. A variety of ICT-based technologies, for example, assistant driving, connectivity and in-car info entertainments broaden product functions and improve the condition of value-for-money given a certain vehicle. Chinese OEMs are keen to integrate these technologies into their vehicle models in order to make their products more attractive to customers. These enhanced capabilities allow for a broader array of product series to be developed and produced, especially SUVs that are very popular because of consumer preferences for large-sized, cost-efficient models. For example, Haval (of GMW), CS series (of Changan), RX5 (of SAIC), etc., are the backbone of vehicles sales of these OEMs. These SUV models are necessarily supported by enhanced ICE powertrains and integration of ICTs (e.g., SAIC's use of Ali YunOS).

The above-mentioned changes in the broader economic context form the basis on which car makers further derive EV models. The term "derivative" refers to the fact that design of EV product system is overall based on and modified from the evolving ICEV regime and incorporated technologies and services. In the experimental deployment and diffusion, EV models see generational renewal[122]. As time passes, the number, diversity and generations of EV models commercially deployed gradually increase, "mirroring" the product matrix and series in the ICEV regime, usually under the same brand name.

In the process, continuous learning from deployment and diffusion of EVs enable OEMs to achieve deeper knowledge integration downward along the product system hierarchy. With each generation of EV models and each product category rolled out in the market, the process of problem diagnosis and solving is the process of learning at the sub-system, component system and even core component level, such as the battery management system (BMS). However, OEMs temporarily often do not fully perform vertical integration but in collaboration with key suppliers as a common choice, often through joint ventures or other forms of partnership. Battery firms as emerging suppliers do not have the full competence, either, but need to learn from producing the type of power batteries that OEMs need for the end products. Therefore, the buy-supplier relation features intensive co-learning, co-development and co-production, and secured with capital relation or shareholding. For example, Chery collaborated with Yaskawa Electric Corporation in order to figure out high performance electric power system, and SAIC deepened and expanded technological partnership with existing integrated supplier HASCO Group to develop integrated electric powertrain. For OEMs aiming to optimise the safety and performance of power batteries, they have more in-house efforts, such

[122] This takes place in a shorter cycle time because of lower technological complexity of EV and the imperative to meet subsidy criterion that changes every year.

as to engage in structural design of battery modules, and the in-house design and development of electric motor and control units.

At this stage, OEMs' interaction with users and downstream activities in general becomes more intensive. Close interaction with users is also a must when they are unfamiliar with the products and functions. Because conventional 4S stores often do not have the necessary knowledge and capacity to solve problems associated with EVs, problem-shooting and user-education becomes the task of OEMs. For example, JAC sent an expert group to its 4S store to train service staff and answer questions about its iEV series models. From this perspective, learning by doing, using and interacting is an important part of knowledge acquisition and capability building for system integrators (Parrilli & Heras, 2016). Some OEMs choose to open or authorise specialised EV-focused 4S stores to perform this task.

Downstream activities also involve diverse BMIs. To kick-start and facilitate the initial deployment of EVs, this is extremely important so that EV models can still be taken up by certain groups of individuals and organisations despite their immaturity and deficiency. Because public transport is less demanding of product quality and functions and less sensitive to prices compared to individual, private consumers, it is often a good starting point for OEMs to experiment with their EV models. This first includes public procurement and public transport as a conventional form of 2B business. Another practice, the use of car-sharing and mobility-as-a-service, inspires OEMs to adopt BMI that is prevalent in the so-called sharing economy. Depending on their own resource portfolio and business strategy, OEMs either run their own mobility service by establishing a subsidiary firm or cooperate with specialised mobility service platforms, e.g., Uber[123] and DiDi. Either way, OEMs can get a variety of EV models running and tested in the market. This alters the cost structure of EVs, charging the usage rather

[123] Uber exited Chinese market in 2016, and Uber China merged with Didi.

than the purchase of EV models, and substantially reduces the cost faced by mass consumers. In this way, users are decoupled from ownership of EVs and hence are far less concerned about the costs and risks associated with owning an electric car, nor do they need to bear the anxiety of electric drive mileage or searching for charging infrastructure themselves.

9.5.3 Stage three: Product platformification

The growingly frequent technological, product and business model innovations in the second stage largely take place in a more or less fragmented, piecemeal, improvisational way and lack systemness. In the third stage, these previous cumulative, progressive and expansive innovation activities temporarily consolidate into product platformification. Technological and product innovation start to assume systemness oriented towards the formation of a coherent EV product platform. This is the most prominent feature of this stage. The EV product system begins to have its own design, no longer as a derivative of the ICEV platform. For OEMs, electric mobility is no longer a mere technological niche or a unit/branch attached or additive to existing ICEV business but grows to become a counterpart business to the ICEV regime despite still far smaller in size and scale.

The emergence of product platform specifically for electric mobility marks a radical change in design rules compared to previous product modification and adaptation. According to management literature, product platform refers to a type of internal (company) platform as opposed to industry-wide platform (Gawer & Cusumano, 2014). It means a set of assets organised in a common structure from which a company can effectively develop and produce a stream of derivative products. Product platforms are often created to meet the needs of different customers by modifying, adding, or subtracting different features. The automobile industry is a typical case, where a set of subsystems and interfaces form a structure that OEMs can develop and produce a family of products.

While the value of platform and modularity is well recognised in design architecture literature (Campagnolo & Camuffo, 2009; MacDuffie, 2013), this does not come easily and naturally for latecomer firms in developing countries. This marks a qualitative change in technological capabilities and product design and development capabilities. For indigenous, incumbent OEMs in China, two lines of efforts prove to be essential to accomplish this (at least preliminarily). First, the continuous technological upgrading in the ICEV regime. This time consuming yet important, necessary cumulative process ultimately enables some OEMs to design highly integrated power systems, e.g., the upgraded version of Changan's NE platform, Changan's CUBE-TECH power platform. Global source of technological learning plays an important role. Apart from aforementioned cases, the upgrading of Geely's ICE benefits a lot from M&A of Volvo, and GAC learns from Toyota which is known for its mature platforms. Of course, there are also indigenous efforts among OEMs that are less involved in institutional partnership with MNEs, such as Chery and GMW. Second, the iterative learning and capability building in the derivative experimentation stage leads to the development of highly integrated electric power system. Both lines of efforts are conducive of stronger system integration capabilities, hence OEMs grow more and more capable of integrating different technological elements based on a coherent design principle.

In addition, emerging technologies in adjacent sector, e.g., ICTs, are continuously integrated into the products, services and other offerings residing in the passenger vehicle to increase its value-for-money, and raise product and brand profile. This goes beyond conventional automobile electronics but involves more connectivity and intelligence technologies. Overtime, ICTs also become more sophisticated and advanced with technological development, for example, vehicle-person interaction could understand and execute more challenging commands, such as simply asking the car to pull it off in the closed parking space in a shopping mall.

Given different directionality of innovation at firm level, two kinds of platformification of product system emerges. For generalist OEMs, product platformification takes place in two venues: in ICE-based solutions and power battery-based solutions. The ICE-based solutions utilise highly efficient and integrated ICE powertrain, which is flexibly integrated with electric power system that utilised power batteries to varied degree, from PHEV to MHEV and even 48V HEV. When no batteries are used, this are simply high performance ICEVs that have better environmental performance than earlier models. Battery-based solutions are specific to BEV platform that does not involve any degree of ICE in its powertrain. The design of power batteries and its integration with the overall vehicle product architecture optimises the function of the BEV, instead of adapting existing ICEV platform. In this case, OEMs as generalist achieve what is called "*dual platformification*", which mobilises and integrates the core competence in both the old and new technological regime. By contrast, OEMs as specialists have largely failed to cultivate the necessary system integration capabilities in the ICEV regime, hence find it difficult to roll out indigenous ICE-based hybrid platform. It only focuses on BEV product platforms. This is called "*singular platformification*". The difference can be illustrated by the figure below (Figure 9-3).

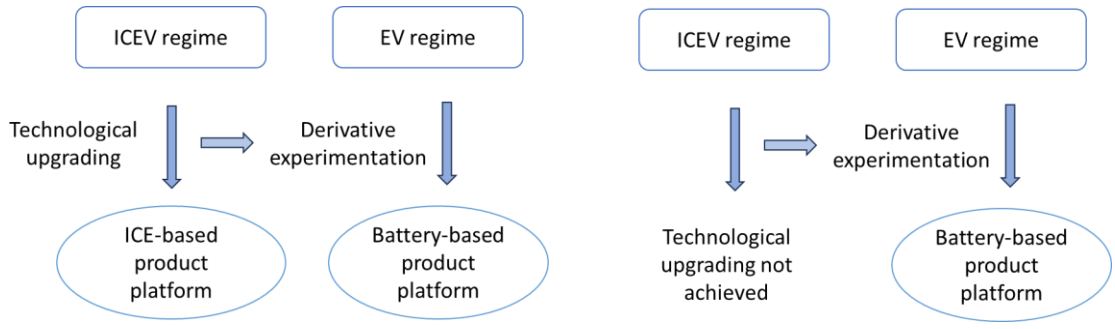


Figure 9-3 Product platformification by generalists (left) and specialists (right)[124]

[124] Author's elaboration

For OEMs, product platformification brings the benefit of cost reduction and economy-of-scale from product development stage and final manufacturing. It means standardisation of subsystem and component system designs, which further enables the shared use of components and parts. For ICE-based solutions, the shared use and nimble adjustment of powertrain sub-system platform and vehicle product system platforms can lead to a 70% of commonality in components across different product models. For power battery-based solutions, there is also shared use of more standardised battery packs, modules and even cells, and highly integrated electric powertrain that can accommodate three to seven different components and sub-components (e.g., Changan's 3-in-1 electric power train) depending on firm's specific product strategy.

What follows with product platformification is a clearer and more coherent boundary of the firm from a sectoral and industrial value chain perspective. In terms of upstream, OEMs tend to know more than they produce. This is partly driven by the necessity to understand and command the product architecture and design rules. With product platformification, the interfaces between different levels of product system hierarchy becomes more standardised. This reduces the degree of ambiguity and design multiplicity faced buy component suppliers, and increase economy of scale of their components. OEMs often choose to outsource production or engage in co-production with suppliers through joint ventures.

In terms of downstream, involvement of and interaction with users grows more intensive and self-aware. At this stage, as the number of individual consumers grow, OEMs put greater emphasis on marketing campaigns, user education and direct user interaction. What's more, because OEMs design EV product platform anew, they also involve users at an early stage, e.g., through means of crowdsourcing, to add certain features and functions into the product platform according to user preferences. The provision of services is not only drive by the necessity to solve product-related problems, but also to increase the price-premium of EV

models and let users have as good experience as possible. Under such circumstance, OEMs increasingly collaborate with core component supplier (batteries) and infrastructure providers to provide an integrated pack of service to users. The formation of joint ventures and new subsidiary companies among these business entities is a common. Some explore establishing their own EV-oriented 4S stores to host these integrated services and operations, and some go even more radical, skip the franchised 4S store model and open user experience centre in CBDs do directly engage the broader public and users. This is informed by the practice by Tesla and the service provision business models by major IT technological companies. Despite the growing body of individual users of EVs, the expansion of 2B business, through either subsidiary firm or third-party mobility service providers, continues.

9.5.4 Stage four: Re-alignment towards whole system reconfiguration

What critically differentiates the ongoing fourth stage from the third one is that qualitative change moves beyond the product system and leads to a higher-order reconfiguration of the corporate innovation system. I make the argument that this change in the fourth stage has the propensity to move towards the emergence of an industrial platform.

According to Gawer and Cusumano (2014), product platform is still an internal platform, or company-level platform, at most incorporating supply chain platforms with standardised interfaces between vertical linkages. Industrial platform, by contrast, is an external platform at the industry level. It is defined as "products, services, or technologies developed by one or more firms, and which serve as foundations upon which a larger number of firms can build further complementary innovations and potentially generate network effects" (Gawer & Cusumano, 2014, p. 420). What resembles to internal platform is a foundation for reusable common components or technologies, but this foundation in industrial platform is open to outsider firms.

Existing research on industrial platform is limited and mostly on industrial platforms in ICTs and telecommunications sector (Cusumano, 2022; Gawer, 2009; Gawer & Cusumano, 2014), and little is known about external industrial platform that focuses the manufacturing sector. The longitudinal case study in this chapter indicates that the notion of "product platform" is no longer sufficient to characterise the level and nature of "system building" by incumbent OEMs. It is further argued that the transformation of the automobile industry towards sustainability should be rightfully characterised as an emerging industrial platform. From the perspective of OEMs, their innovation activities and processes qualify two important criterions for becoming an industrial platform (Cusumano, 2008). First, it performs a function that is essential to a broader technological system. Second, it solves a business problem for many firms and users in the industry. In the case of electric mobility, the electric car is still the focal product, but more importantly, it is the basis and physical carrier where multiple technologies, services and business models are inter-connected and integrated to deliver electric mobility as an industrial regime with its own value proposition. The eventual function is no longer the selling of EV models from the producer side, or the purchase and ownership of a commodity from the user side, but the utility of a means of mobility that is sustainable and intelligent.

Therefore, the design rules in this stage are not about the product platform itself, but the architecture of the industrial platform. The basic contents in this architecture, in the first place, are technologies and their interrelations. For OEMs as generalist, at least three types of technologies, each having their own regime characteristics, are integrated: core competences in the incumbent regime, especially powertrain and product system integration; electric power system and related technologies and interfaces; converging, emerging technologies from adjacent sectors, such as ICTs. What differs in the fourth stage is that they are not additive to the product platform, but organically form an integral part of the overall architecture and value proposition for the electric mobility. Each represents a technological regime itself and has its

own design rules that govern lower-order units. But taking the industrial platform as the reference point, they are modular units.

As such, the industrial platform provides the foundation to involve services and business models as integral part as well. In previous stages, business models are often adopted to assist the deployment and diffusion of EVs, and are supplementary to technological and product innovation. In the fourth stage, the adoption of business models to provide product-life-cycle services and utility consolidates into the type of product-service system (Tukker, 2004; Williams, 2007) that is result oriented. Services and business models hence become inherent to it, not an additive.

Moreover, the architecture of the industrial platform enables the continuous incorporation of new developments in each technology, services and business models, and hence is over-arching and ever evolving. Changan's manager commented on the Arc Architecture and BEV technology platforms: "*We facilitated its development…the intelligent aspect of electric mobility is no longer the conventional electronics, but an upgrading to an architectural design that is closely related to users' feeling and perception*." (Interview B1-03)

Similar observations can be found in SAIC's Nebula architecture (Figure 9-4):

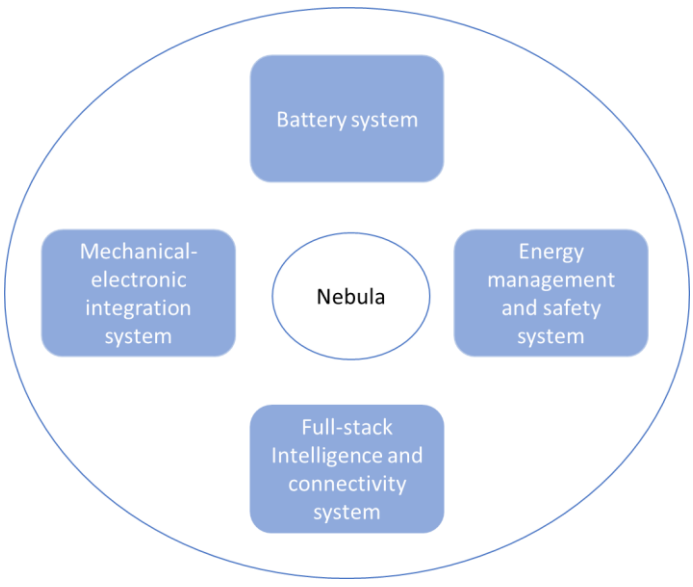


Figure 9-4 An illustration of SAIC's Nebula architecture[125]

Such technological architecture as over-arching design rules are also put forth by Geely (SEA-M architecture), BYD (e-platform), BAIC (Darwin architecture), Chery (Mars architecture), etc. Admittedly, not all indigenous OEMs have successfully proceeded to this stage. For example, JAC seemed to lose the momentum after 2017, and Zotye had to exit the market in face of technological and financial difficulties.

With over-arching, ever-evolving technological architecture as the governing design rule, OEMs become the orchestrator of the industrial platform, rather than be just a vehicle manufacturer and producer. While they are in upstream and downstream activities in an unprecedented scope, it is not possible for them to conduct all of these activities own their own. The openness of industrial platform to "outsider" firms enable the formation of an ecosystem revolving around electric mobility. This includes component suppliers, complementors within and outside of the sector, infrastructure providers and various services providers – all "plugged in" to the organisational boundary of the OEMs. Capitalising on highly elaborated downstream segments allow these firms to make money from the deployment and diffusion of EVs. This might be problematic when the scale is small; once scaling up, networks effects and increasing return becomes more apparent.

OEMs tend to vertically integrate core component technologies into their own knowledge boundary. This is not only driven by the needs to optimise overall design and system integration, but also bargaining power over the supply chain. If they have not chosen to do so in previous stages because of formidable R&D input and lack of in-depth electrochemical expertise, at this stage they begin to invest in their own in-house R&D of power batteries and related materials technologies in order to fully integrate this competence. For example, GAC launches its

[125] Author's elaboration based on open-source data.

technological strategy in 2020 to develop most up-to-date power battery technologies in house in the coming years in order to compete with top players in the emerging sector. Similar move can be seen in Changan, Geely, GWM and many others. Some partly choose to not work alone but in collaboration with component suppliers. Whatever the means, the objective is the same: to bring the core competence in house.

With the nature and scope of system building moving from product platform towards industrial platform for electric mobility, and OEMs' transformation towards industrial platform orchestrator, these firms experience organisational restructuring and corporate identity re-formation. At this stage, OEMs establish a specialised electric-mobility company that is financially independent from ICEV business, has autonomy of decision-making on business, technology and product strategies about EV, and an entire set of organisational functions as does the incumbent automobile company. Moreover, this new firm puts heavier emphasis on R&D, service provision, marketing campaign and user engagement. Accompanying this organisational restructuring is the change of corporate identity. These new firms no longer present themselves to investors and the public as automobile or EV manufacturers selling mass-produced, cost-efficient ICEV models, but high-tech and service-oriented firms that specialise in integrated electric mobility provisions to optimise user experience and environmental sustainability. While there is a long way to accomplish this ambition, these firms are validly on their way.

9.5.5 Synthesis

The "system building" by incumbent firms in the focal sector undergoing early green transformation features multi-dimensionality – the simultaneous evolution of design rules and knowledge integration and positioning along the industrial value stream, supported by coordination of various sources of technology and resources. Throughout the four stages

analysed above, it is found that the dynamics of three other analytical elements exhibits several qualitative changes overtime, which is presented in the table below (Table 9-1).

Table 9-1 The dynamics of "system building" in different dimensions

	Design rules and knowledge integration	Dynamic positioning along industrial value stream	Sources of knowledge and resources	Accompanying changes
Stage 1 Project-based technological exploration	Modification of ICEV product models, learning at the product system and sub-system level.	Product system integration.	NIS: ST&I policies, R&D platform to combine knowledge and talents from GIS; SSIP: very limited suppliers.	Change in the R&D organization
Stage 2 Derivate experimentation	Modification of ICEV product models, deeper learning at sub-system and component system level, product variety increases, gradually mirroring ICEV product matrix.	Product system integration, moderate vertical integration, involvement in downstream activities (marketing, services, etc.) supported by BMIs.	NIS: ST&I policies, demand creation, industrial policy; RIS: demand creation, deployment of EVs, infrastructure; GIS: technological upgrading; SSIP: scattered suppliers within sector, and limited infrastructure providers, ICTs firms outside of the sector.	Emergence of subsidiary to execute EV deployment.
Stage 3 Product platformification	The design of new EV platform. (Generalists: battery-based and ICE-based platforms; specialists: only battery-based platform). Deep integration in sub-systems and component systems.	Product system integration, moderate vertical integration and more intensive downstream activities supported by coherent BMIs.	NIS: ST&I policies, industrial policy, demand creation, RIS: demand creation, deployment of EVs, business model experiment, infrastructure; GIS: technological upgrading, architectural knowledge and co-development; SSIP: more competent suppliers, complementors within and outside of the sector.	Dedicated business unit to run EV business in parallel to ICEV business
Stage 4 Realignment towards whole system reconfiguration	The design of architecture of electric mobility industrial platform that integrates various tech-regimes (ICEs, battery systems, ICTs, etc.) Knowledge integration towards the core component level.	Product system integration and architectural design, intensive R&D and product-life-cycle services. Deeper vertical integration to the core component level.	NIS: ST&I policies; demand sustaining; RIS: demand sustaining, business model experiment and industrial clusters building; GIS: architectural knowledge, and co-development; SSIP: a forming ecosystem of suppliers, operators, service providers, ICTs, etc.	Change of corporate identity, and organizational restructuring

The design rules and scope of knowledge innovation reflects the nature and degree of technological and product innovation by incumbent OEMs in their transition towards electric mobility. Design rules see a path of change from modification of existing ICEV product system, firstly to the design of the EV product system. This is achieved by continuously incorporating technological improvements in derivative experimentation stage, and the upgrading of core competences in the ICEV regime (in the case of generalists). Another qualitative change is that design rules tap into the higher-order architecture of the industrial platform of electric mobility.

In the process, OEMs deepen their scope of knowledge integration downward the product system hierarchy (see Figure 9-5 and Figure 9-6), as well as outward to converging technologies and interfaces with related sectors.

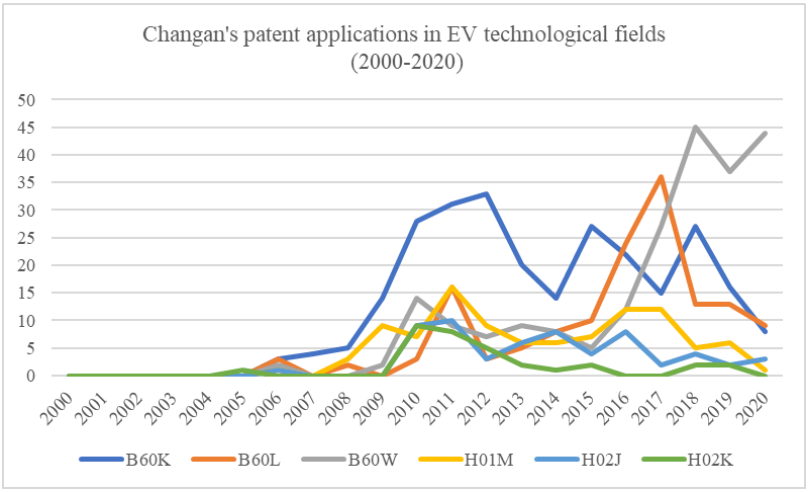


Figure 9-5 Changan's patent applications in EV technological fields (2000-2020)

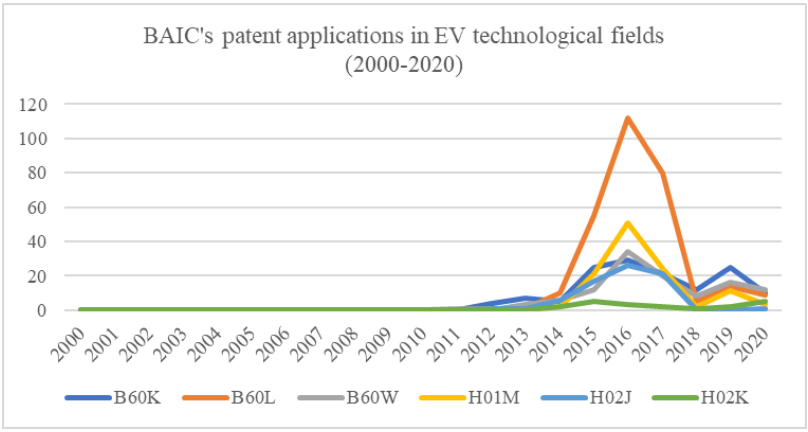


Figure 9-6 BAIC's patent applications in EV technological fields (2000-2020)

electric mobility's' dynamic positioning along the industrial value stream, there is a clear forward movement to segments after production of EVs, manifested by growingly intensive services and BMIs that propagate into product-service systems oriented towards the utility of electric-mobility. While the backward movement is not finished, there is strong tendency by component system integrators to control the upper segments of the value chain, e.g., battery

cells, even critical materials. In defining and redefining product and technological architecture, system builders are in effect redefining the industrial architecture and their division of labour wherein. The organisation itself is also transformed internally. This involves the initial modification of the organisation of R&D activities, to business activities, and eventually to the creation of a new firm oriented to electric mobility. This new firms also carriers the transformed corporate identity from automobile manufacturers to mobility technology and service providers. Therefore, the process-based, stepwise model of "system building" by firms revolving around certain directionality of innovation could be further generalised as the follows (Figure 9-7):

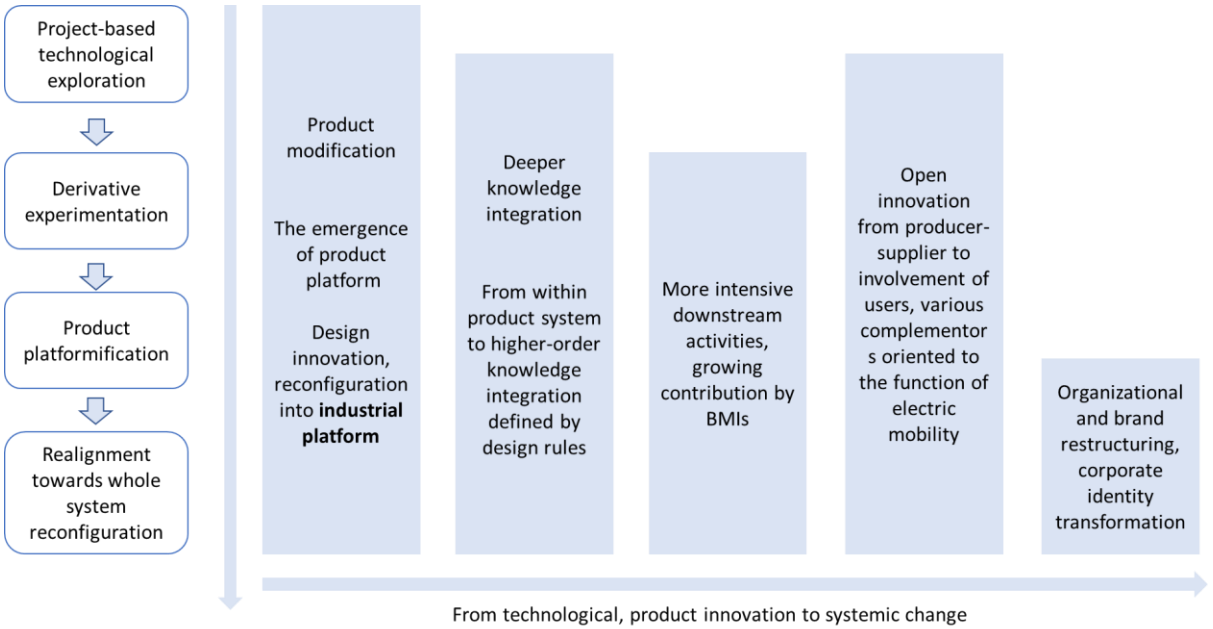


Figure 9-7 The process-based model of system building by firms[126]

9.6 Conclusion and discussions

Green transformation of multi-tech, multi-component industrial sectors is not solely technological change, but the transformation of the sectoral innovation system as a whole. As system integrators, incumbent firms' innovation strategies, activities and processes inevitably

[126] Author's elaboration based on the inductively developed theoretical model.

alter artifacts and the linkages, the industrial value chain and inter-organisational networks and interaction. Hence, firm innovation in essence is inherently a process of changing the sectoral system they are embedded in. This chapter approaches this comprehensive, systemic and boundary-transcending role of firm as "system building".

The multiple, longitudinal case study has shown that system building by incumbent firms are multi-dimensional. It is not only that directionality of innovation diverges, according to the findings in the previous empirical chapters, but also that to materialise and concretise the directionality firms exhibit distinctive characteristics in design rules and depth of knowledge integration, their dynamic positioning along industrial value stream, and the sources of technology and resources. Only by investigating these dimensions at the same time and their interrelations can firms' innovation activities and processes, and the building of the emerging sectoral system, could be sufficiently understood.

Moreover, changes in these elements do not take effect in a mechanical or linear way. I further find that from a dynamic perspective, system building exhibits qualitatively different characteristics overtime. I inductively generalise them into a process-based model. It consists of four stages: project-based technological exploration, derivate experimentation, product platformification, and re-alignment towards whole system reconfiguration. Underlying these system building elements is the complementarity between technological and product innovation on the supply side of green technologies, and the bridging role of business model innovation to the demand side and downstream of industrial value chain. By exploiting these elements and their linkages, and the change overtime, this chapter uncovers how firm-centric innovation activities propagate into system level dynamics and outcomes.

This chapter contributes to innovation management and innovation system research from several aspects. First, by formally defining and delineating "system building" integrating the

narrow and broad version of "system integration" concept, it makes one of the few first attempts to systemically understand the nature and processes of firm innovation in early phase of green transformation, unpacking its complexity, multi-dimensionality and temporality. The analytical elements are derived from the building blocks of the open systemness perspective of SSIP, hence is not specific to the automobile industry but can be applied to other manufacturing sectors that undergo transformative change.

Second, through an inductive, longitudinal study, this chapter puts forward a process-based model of firm-centric system building, hence explaining how incumbent firms in the focal sector engage green transformation dynamically. This uncovers the nature and qualitative change in firms' innovation activities and processes. Moreover, it contributes to the knowledge of how firm-level activities translate into sectoral-level dynamics and configurations in a stepwise and non-linear way. This necessitates a connection between innovation management and innovation system literature, while each of them alone could not sufficiently address this topic.

Third, while several studies have started to explore various types of business models in sustainability, I demonstrate the bridging role of business models in the process of system building by incumbent firms and its changing property. An important argument advanced through the multiple case study is that BMIs are indispensable to complement technological and product innovation in the early phase of sectoral transformation towards sustainability. This is because they are essential in connecting the supply side of green technologies to the demand side so that a temporal value proposition could be exploited to sustain the commercial deployment of green products. This inevitably leads to system integrators' extensive and various involvement in downstream activities, hence changes the content of value stream segments and the way they are connected. From a dynamic perspective, it is argued that if in the early stages BMIs are supplementary, then when system building proceeds to the

emergence of industrial platform then BMIs consolidate into an inherent part of the broader PSS oriented to electric mobility. Therefore, this study adds to the understanding of the role of BMIs in the both firms' innovation processes, as well as in the interaction of firm innovation and system-level dynamics. It also contributes to the multiplicity of BMI (Del Sarto et al., 2022).

A related aspect of contribution is the study of industrial platform. The industrial platform literature itself is very nascent and mostly in ICTs sector, empirically based on cases from Western economies. For the first time, this chapter takes an explorative step in assessing and investigating the industrial platform in the manufacturing sector and context of green transformation, and in emerging economies. This is not to claim that the electric mobility is definitely taking the form of industrial platform, if we only adopt the original definition. However, the case study has shown that the way technologies, PSSs, assets and value stream segments is connected is no longer sufficiently captured and explained by existing literature. It exhibits the key characteristics of industrial platform that are arguably different from industrial platforms in ICTs. If it is the *adoption* of industrial platform by a broader scope of organisations that matters in the ICTs, then for manufacturer sectors in green transformation, industrial platform proposes a higher-order, sectoral boundary spanning, accommodating *design rule that governs* the interdependency analysed above and delivers the idea, utility and function of green innovation as an integrated offering, and participants – including system integrator as the orchestrator – find it commercially, environmentally and institutionally sustainable. Therefore, this chapter can be viewed as an experimental step towards this conceptual and theoretical advancement, and an invitation to more academic research along this direction.

This chapter has several limitations that warrant future study. This has something to do with the temporality and focus on incumbent firms in emerging market economy, which has already pointed out in previous empirical chapters and hence is not repeated here. One additional

limitation is that this study has not fully engaged in the role of digitalisation in the green transformation in the automobile industry. This constitutes an important part of the technological, product and business model innovations of system integrators, both in China and worldwide. Future study should specifically examine this topic and contribute to the study of business firms in “twin transitions” (Fouquet & Hippe, 2022).

Chapter 10 Conclusions and discussions

10.1 Main findings and discussions

Directionality of innovation is important in addressing "grand challenges" and bears significant developmental consequences but is under-researched especially in developing countries and emerging economies. Existing literature in diverse disciplines and theoretical perspective has not sufficiently explained the forces shaping and driving the directionality of innovation in the context of industrial sectoral transformation towards sustainability. This thesis fills the gap by providing a political economy and evolutionary understanding of the directionality of innovation in the early phase of green transformation. Specifically, it looks at the impact and effectuation of green industrial policy - a manifestation of state intervention - and firm innovation strategies in response in shaping the directionality of innovation, and the resulting capability building processes and outcomes.

Three interrelated conceptual and theoretical efforts are made to build an analytical framework on the topic: (1) an integrated understanding of directionality of innovation that considers both the normative and positive dimension of technical change; (2) a view on green industrial policy not as mere policy instruments but an evolving set of institutional arrangements that belong to the broader "endogenous institutions" (Geels, 2014); (3) an open systemness approach (Becker, 2007) to SSIP framework that gives analytical prominence to political and economic actors as heterogeneous change agencies that dynamically interact with each other revolving around directionality of innovation in the variegated sectoral system. An integrated analytical framework is built on such basis following an "appreciative theorising" strategy (Nelson, 2008).

Based on a longitudinal, embedded case study on China's early transition to electric mobility in the past two decades (early 1990s - 2020), I have addressed three interrelated sub-questions in the presiding empirical chapters. Firstly, I analyse the impact of green industrial policy, represented by the "pure electric drive" industrial strategy and its supporting policies and regulations, on directionality of innovation by embedding the link in the SSIP and looking at the interactions and feedback loops and their outcomes. While this elucidates the casual mechanisms at the sectoral level, the second sub-question proceeds to understand how incumbent firms perceive and configure their choice of directionality of innovation in response to state intervention[127], with a focus on firm heterogeneity. This explains the actual pathways of technical change at a disaggregated level, and attends to process of organisational homomorphism and isomorphism over time. Thirdly, given the innovation strategies adopted by different incumbent firms, the last sub-question zooms in to the firm level to understand the innovation processes and activities that translate into system-level dynamics. Because of the transcending nature of green transformation and boundary-spanning characteristics of innovation activities, I conceptualise firm innovation activities and processes as "system building". The chapter inductively develops a process-based model of system building based on a multiple case study on incumbent firms. While each empirical chapter has discussed their findings respectively, now it is possible to bring them together under the overall research topic and summarise the major findings.

In the presence of technological multiplicity in green transformation, different technological trajectories and configurations within the scope of green regime are biased towards certain competences and resources while obsoleting others. This creates the opportunity space for the state sector to tailor green industrial policy that selectively directs innovation towards the

[127] State intervention and green transformation is closely related, because green transformation is often policy driven and highly institutional in nature.

technological trajectories that fit better to the country's comparative advantage. This underlies the rationale of China's national technological strategy of “pure electric drive” formally published in 2012 and characterising the entire 2010s. This strategy gained dominance in domestic policy debate in the broader context of China's industrial catch-up, structural transformation in the manufacturing sector and national ST&I policy turn to “indigenous innovation” when the promises of globalisation and technology transfer have been found unfulfilling. With this intervention, China seeks to carve out its own way of green structural change that would help it build up power-battery related value chains and vertically and horizontally related sectors.

Finding 1: China's framing of green industrial policy in electric mobility transition is the outcome of interaction between technological and political dynamics. There are two forces at work: first, technological multiplicity inherent of green structural change of the industrial sector; second, national political and policy factor, especially ST&I policy paradigm shift and strategic catch-up intention of the political leadership.

Finding 2: The second, a related finding is that the above-mentioned political-technological dynamics results in the kind of green industrial policy that deliberately shapes directionality of innovation in favour of competitive advantage. This is realised by speeding up the process of technological substitution via intervening the process of technological variation, the latter being narrowed down by policy incentives that unevenly channel innovation activities into technological trajectories and configurations that imply competitive advantage.

That said, technological multiplicity in SSIP as an open system has capability building implications. Some technological trajectories and configurations depart less from the existing regime, and hence less “competence destroying” (Utterback, 1996). Some other technological trajectories and configurations count on more novel technologies and assets, hence more “competence destroying”. The former features strong path dependence, but fewer challenges

to develop new technologies (e.g., ICE-based solutions in electric mobility); the latter features weak path dependence, but more significant innovation challenges related to new technologies (e.g., battery-based solutions in electric mobility). When incumbent industrial regime is underdeveloped, then the more competence-destroying solutions receive more policy attention because of their higher technological opportunity, lower switching costs to green technologies and less path dependence.

Hence, this leads to **finding 2-a**: The imbalance and diversity in the technological regime characteristics provides the basic condition for selective policy intervention to take effect, and this selectivity strongly characterises the nature of green industrial policy.

With this pre-condition, the influence of green industrial policy could only be sufficiently understood not as a stand-alone variable, but a rethinking of the concept itself and its embeddedness from a political economy and evolutionary perspective (**finding 2-b**). The empirical analysis points to three aspects that are particularly important: first, a rethinking of the nature and characteristics of green industrial policy; second, the embeddedness of green industrial policy in the broader "endogenous institution" (Geels, 2014), and third, the embeddedness of green industrial policy in the SSIP as an open system.

Green industrial policy should not be reduced to the content and count of policy instruments. Instead, it should be understood as an evolving, integrated set of policy and regulatory arrangements. This necessitates the coherence of green industrial policy design that targets segments along the industrial value chain. From example, there is synergy between supply-side policies (e.g., financial subsidies for EV) and demand-side policies (e.g., procurement and vehicle license plate regulation), concerning not only the end product, but also value chain's upstream (e.g., power battery) and downstream (e.g., charging infrastructure). Green industrial policy hence inevitably intersects with other policies in macro economy or sector-specific regulations. Moreover, this involves policy, regulatory and institutional change with emergent

problems from green transformation and the progression of value chain stages. While the issue of policy design, policy mix and policy learning has already been mentioned elsewhere in various policy science and governance literature (Bennett & Howlett, 1992; Boon & Bakker, 2016; Rogge & Reichardt, 2016), the related conditions and characteristics that make green industrial policy work has not been explicitly and systematically theorised and supported by empirical evidence. This thesis addresses this gap and puts forth the notion of ***"dynamic institutional complementarity"***, which has been argued to underly the capacity for green industrial policy to facilitate technological substitution in a multi-tech, multi-component sector.

When the aforementioned "dynamic institutional complementarity" works in a selective way (finding 2-a plus finding 2-b), different locations in the technology-product matrix are disproportionately affected by intentional policy intervention. Reading from the empirical analysis, the *causal mechanisms* between green industrial policy and directionality of innovation can be generalised as a combination of four simultaneous effects (**finding 3**): cost reduction, demand creation, technological learning and capability building, and positive network effect.

The seemingly complex story of China's early transition to electric mobility, in its positive aspect, is hence clear: ST&I policy (mainly the 863 Major Project) played the role of initial funder for technological exploration and functions as a platform for combination and recombination of knowledge (domestic and from the global innovation system) to build up absorptive capacity, as well as for the initial formation of inter-firm networks. When it came to commercialisation of green technologies, financial subsidy was implemented to facilitate the deployment and diffusion of EV models. The amount of subsidy was contingent on battery-related technology performance. It reduced the cost faced by both end product manufacturers as well as power battery suppliers transmitted through supply relation. At the same time, demand creation policies such as public procurement and public transport adoption of EVs

secured certain scale of EV production and diffusion in the beginning, which gradually gave way to private consumption. ST&I policy continued to support technological development, with an output orientation on functional vehicle-use power batteries. This helped consolidate buyer-supplier relations and facilitated co-learning and co-specialisation between them. These combined to generate positive network effects and increase return to learning between OEMs and suppliers. The same effect also spread to the downstream when more demand-side polices were launched to promote the construction and usage of charging infrastructure. The critical batter-centred governmental R&D program and financial incentive did not exist naturally but were necessitated by the lack of these competences and complementary assets in the process of EV diffusion. Hence the configuration of green industrial policy was by no means a functional and rational engineering of technical change, but a process of consistent proactive envisioning, learning and adaptation.

However, the industrial policy played out differently and unevenly across the technology-product matrix. The above virtuous cycle got reinforced mainly in the small-sized, low-cost BEV passenger car segment, because this was most cost-efficient for both producers and consumers, and involved less innovation challenge when resources and time window were constrained. Hence firm innovation efforts became biased towards those favoured technological configurations by firms with best cost-performance. Without sufficient time to improve EV technologies while needing to bring EV models to market to qualify for subsidies, the function and quality of EV models could be undermined. Moreover, the variety of available EV models was inevitably limited given the narrow scope of technological variation, leaving the needs of other market segments underserved. These led to the performance gap in green technologies and products. Co-occurring with performance gap was capability gap in the under-developed technological configurations, for example, hybrid solutions that involved ICE-based competences. These two deficits are called “system gap” in the thesis, which spells out the

unintended consequences of the selection process in presence of green industrial policy intervention.

With the system gap, especially residing in a lack of technological capability accumulation in the hybrid technological configurations, many firms' innovation efforts were locked into the more simplified BEV architecture. The implication on capability building is paradoxical: As a latecomer, China wanted to shape its comparative advantage through green structural change on a path that relied more on alternative competences, but under the influence of technology performance-contingent subsidies, the resulting disproportionate deployment and diffusion of small-sized, low-cost, A00/A0 segment BEV models had left the medium-sized segment in a relative vacuum along the "ladder of growth" (Brandt & Thun, 2016). The latter is where the weakness lies in China's automobile industry in the ICEV regime, which turned out being exacerbated and risking being perpetuated by the green industrial policy.

Finding 4: Green industrial policy that is selective in technological multiplicity generates and reinforces network effects in certain technology-product-market segment, but undermines others. This creates a system gap – consisting of performance gap and capability gap - and leads to unintended and undesirable technological – market lock-in.

To this point, the aggregated pattern at the sectoral level indicates that green industrial policy can be a double-edged sword for capability building and competitiveness. Underlying the complex interaction between green industrial policy, technology-product matrix and market segmentation is the innovation strategies and activities by OEMs in the focal sector. A closer look at the industrial architecture in the EV regime reveals a certain degree of diversity, which is persistent, despite the influence of policy rents. This points to the importance of firm heterogeneity in shaping the directionality of innovation on the ground. Even among incumbents, not all of them "buy-in" green industrial policy preferences, and the degree and form of "buy-in" reflected in firms' innovation strategies and activities are contrasting.

Therefore, the thesis has argued that it is important to examine how the object of green industrial policy - automobile OEMs - actually perceive and "buy-in" state intervention as a response to green industrial policy. As a preparatory step, in Chapter 6 I operationalise "directionality of innovation" at the level of firms in terms of whether they are active or reluctant to engage electric mobility (technological substitution), and whether they engage it broadly or narrowly (scope of technological variation). This results in a 2 x 2 matrix. I select twelve incumbent OEMs and characterise firm heterogeneity according to the matrix using the year 2015 as a line of division. The twelve firms fell into all the four types in the matrix before 2015, and over time they converged in active technological substitution and diverged in scope of technological variation, and the latter seems to be consolidating.

To what extent these firm-level patterns could be attributed to green industrial policy, and what factors account for these patterns, is hence key to understanding state-business interaction. Neither green industrial policy itself nor firms' own characteristics could satisfactorily explain these diversified innovation strategies and how firm heterogeneity plays out in the dynamics of sectoral green transformation. Instead, an integrated, system-firm interaction is needed to provide a comprehensive and unbiased understanding. Therefore, I develop a novel framework to examining the interplay between system level and organisational level factors. At the system level, I focus on the variegated incentive structure firms are embedded in that are derived from core building blocks of the open SSIP. At the organisational level, I look at the role of technological capability in the incumbent regime, and firms' overall resource portfolios. It is found from multiple case study in Chapter 7 that **finding 5**: In the early phase of green transformation, firms' strategic choice of directionality of innovation in response to state intervention and its change overtime is the result of interplay and mutual activation between the variegated incentive structure a firm is faced with, and its resources and incumbent-regime technological capability.

The incentive structure is in essence an integrated decision-making environment, where no single incentive has definitive and unambiguous implication for firm behaviour; rather, it is their combination, interaction and mutual activation that defines the nature and content of firms' incentive structure and hence behavioural patterns. Incentive from green industrial policy is only part of the firm-centric incentive structure, and its impact could not be understood alone, but its interaction with other incentives. What stands to matter is *the degree of incentive compatibility* in the firm-centric structure, which measures to what extent these incentives in their aggregation go in line with green industrial policy preference.

It is found from that (**finding 6**) given other factors constant, the higher the degree of incentive compatibility, the more active incumbent firms are to engage technological substitution, and that their specification in technological variation more accurately reflects state policy selectivity.

Switching to organisational factors, a direct finding is that **(finding 7-a)** firms' technological capability in the incumbent regime and their overall resource portfolio positively affect their ability to develop and experiment with EV technologies and diversity technological configurations overtime.

Moreover, **(finding 7-b)** the two factors are not mutually substitutive, but complementary; the lack of either of them proves to disable incumbent firms from intensified innovation efforts in green technology and to broaden their scope of technological variation.

This corroborates the resource-based and capability view of the firm. It also advances the literature in the sense that when transformative change takes place in a multi-tech, multi-component sector, it is necessary to bring the resource-based view and capability view of firm together to understand behavioural change of business actors.

The empirical results further shed light on the moderating role of these organisational factors in the link between incentive compatibility and firms' innovation strategy. **Finding 8**: The moderating effect of firm-level characteristics is not definitive, but contingent. It strengthens the aggregate effect of incentive structure along the same direction of the latter.

Put it another way, whether technological capabilities and resource possessed by incumbent firms manifest themselves to be forces of path-dependence, i.e., constraint of technical change, or path-changing, i.e., enabler of technical change, depends on the degree of incentive compatibility.

This contingent interplay between the system level and firm level factors leads to the formation of four types of innovation strategies among firm groups:

Finding 8-a: When incentive compatibility is high, and both organisational factors are strong, a firm is inclined to be active in technological substitution and maintain a broad scope of technological variation. When it comes to specification of technological configurations, its capabilities and resources enable it to balance political pressure and market-oriented incentives. This type of strategy features Type I firms and is called *"leading with strategic balancing"*.

Finding 8-b: When incentive compatibility is high, but at least one organisational factor is weak, a firm is inclined to be active in technological substitution, whereas exhibits a narrow scope of technological variation, specialising in limited technological configuration(s) that is most cost-efficient for the firm. This type of innovation strategy features Type III firms and is called *"selective leading"*.

Finding 8-c: When incentive compatibility is low, and both organisational factors are strong, a firm is inclined to be reluctant in technological substitution (especially in terms of commercialisation stages and afterwards in the innovation chain), whereas exhibits a broad

scope of technological variation to follow as many technological solutions as possible. This type of innovation strategy features Type II firms and is called *"versatile following"*.

Finding 8-d: When incentive compatibility is low, and at least one organisational factor is weak, a firm is inclined to be reluctant in technological substitution, and exhibit a narrow scope of technological variation by focusing on the technological configuration(s) that is/are most cost-efficient and practical for itself. This type of innovation strategy features Type IV firms and is called *"selective following"*.

The interplay also applies to the evolutionary dynamics overtime after 2015:

Finding 8-e: With the degree of incentive compatibility increasing for incumbent firms, they become all very active in technological substitution. Previous followers turn to pursue more radical transformation strategies.

Finding 8-f: Filling the technological capability and/or resource gaps is a necessary condition for firms to broaden the scope of technological variation over time. Those who are not able to fill the gap(s) are locked-in to the narrow technological specialisation that only relies on alternative core competence (in the thesis, this refers to power batteries).

Nevertheless, the increase in incentive compatibility overtime is not a natural outcome and should not be taken for granted. It is brought about by three factors: first, continuous cost reduction in the EV industrial value chain; second, the accumulation of innovation efforts and technological developments along the industrial value chain; third, intensified technological and product market competition in the EV regime. While the first two points relate to the improved technological opportunity and appropriate condition in EV technological regime, the third factor seems to be more decisive in changing the nature of incentive structure faced by incumbent firms. It is the competitive pressure from early movers, both domestic and global, that motivated many reluctant, half-hearted OEMs to take electric mobility seriously since 2015.

It is noticeable that the intensified competition is partly attributed to regulatory change that lowered the entry battery to EV start-ups as well as FDI in the automobile industry (a typical example is the localisation of Tesla in Shanghai without the mandate to form JV with SOEs). This again demonstrates the characteristics of green industrial policy to be an evolving set of institutional arrangement that features "dynamic institutional complementarity". I proceed to conclude that:

Finding 9-a: In early phase of green transformation, between-firm competition is a strong force to reduce system inertia and change firm-centric incentive structure, hence motivates collective action in technological substitution.

Finding 9-b: To facilitate sectoral change towards sustainability, competition policy is a necessary and important part of the entire green industrial policy.

Integrating the findings about green industrial policy, variegated incentive structure and firm heterogeneity, now it is possible to bring them together and reach a more comprehensive understanding on the role of green industrial policy in shaping directionality of innovation and sectoral change in early phase of green transformation.

When technological opportunity presented by transition to electric mobility is initially ambiguous, ST&I policy produces the benefit of absorptive capacity building and preliminary network formation. It is incumbent OEMs and regions that are eager to catch-up and push forward industrial structural change based on their perceived competitiveness that show the strongest incentive to engage technological substitution on the ground (manifested by some Type I and Type III firms, and among them quite a few lack strong technological capability in the ICEV regime). This not only has a demonstration effect on green industrial policy framing at the national level, but also resonates with by political leadership and a ST&I policy paradigm shift in the broader political context. Dynamic institutional complementarity of green industrial

policy hence works to support the “pure electric drive” strategy. Its contribution to positive network effect between cost reduction, learning and demand creation facilitates collective action among those eager early movers to undertake technological, product and business model innovations. However, this also indirectly leads to system gap and technological and market lock-in to small-sized, low-cost BEV models that are less sophisticated, leaving many other locations in the technology-market matrix less attended.

By contrast, in the beginning, many other incumbent OEMs see greater short-term technological and business opportunities in the continuous capability building and upgrading in high performance ICEs to compete in the medium and big size car market segments with higher price premium. While policy rents do not induce intensive innovation efforts among these firms to the “pure electric drive” strategy, the combination of R&D program, financial subsidy and demand creation still maintains a certain degree of exploration and experimentation of various EV models. In the process, OEMs are able to experiment with different combinations between the core competences in both the ICEV and EV regime.

With collective action in innovation in electric mobility among early movers, regulatory change to add to market competition, and policy learning to focus more on complementary assets along the industrial value chain, all incumbent OEMs are increasingly motivated to engage electric mobility. Those OEMs with a focus on high-performance ICEs, more sophisticated system integration and product and brand upgrading competing for domestic market dominance play an important role of filling system gap that is indirectly brought about by green industrial policy. Seeing the deficits, there is in turn an adjustment of green industrial policy to re-embrace technological multiplicity.

Finding 10: The impact of green industrial policy on directionality of innovation and consequential sectoral change is partial, mixed, and exhibits temporality.

Chapter 9 further elucidates the performance outcome of firms' different innovation strategic from the perspective of "system building" as a portfolio of innovation activities and processes revolving around given directionality of innovation. It puts emphasis on how firm-level activities translate into system level dynamics as system building unfolds. I differentiate firms as specialists versus generalists in terms of scope of technological variation, and trace their changes overtime in design rules and depth of knowledge integration, dynamic positioning along industrial value stream, and the sources of knowledge and resources. I use these three elements to guide data analysis and construct the entire change process in incumbent firms' innovation processes and activities. Two in-depth, longitudinal case study on Changan (representative of generalists) and BAIC (representative of specialists) uncover that (**finding 11**) "system building" experiences four qualitatively distinctive stages, which is inductively generalised into a process-based model: stage one - project based technological exploration, stage two - derivative experimentation, stage three - product platformification, and stage four - realignment towards whole-system reconfiguration. In the process, each of the three elements is found to exhibit the following change dynamics:

Finding 11-a: in design rules, there is a change from product modification and adaptation of incumbent regime product to the emergence of product platform in the EV regime, and eventually the overarching industrial platform architecture as a higher-order design rule governing the electric mobility regime. OEMs' knowledge integration deepens down the product system hierarchy, as well as transcends the boundary of the product system.

Finding 11-b: there is a parallel movement both upstream and downstream the industrial value chain, and the latter is particularly pronounced. However, OEMs' down streaming is not a mechanical or linear movement, but is accompanied by business model innovations, which together reconfigure the value network of electric mobility and division of labour within. This leads to the reshaping of industrial architecture.

Finding 11-c: open innovation plays an important role in supporting firms' system building. It involves not only within-sector and related-sector actors, but also resources and actors from regional, national and global innovation system - complementary to each other at different locations of innovation value chain and at different stage of system building. The nature of open innovation is initially driven by functional necessity, but with system building unfolding, open innovation becomes an inherent coordination mechanism of learning and co-specialisation in the industrial platform in-the-making.

Throughout the four stages, firms' system building activities gradually transcend organisational and sectoral boundary, and towards the broader socio-technical system. It is further found that this is accompanied by organisational change itself: **finding 11-d** - Towards the later stage of system building, firms experience organisational restructuring and transformation of corporate identity that are coherent and aligned with the green industrial regime.

10.2 Uncertainty and challenges in the global context

10.2.1 Industrial architecture in the making

Though I have focused on incumbent firms in terms of their innovation strategies, processes and activities under green industrial policy intervention, the sectoral change is still in "era of ferment". The types and numbers of major players in the focal sector and the configuration of industrial architecture is far from being settled.

Start-ups in the electric mobility regime are also important players. Towards the year 2020, the majority of EV start-ups in China have disappeared, but some have survived and several start-ups are prominent players and thought of as prospectus competitors to incumbent OEMs. They are NIO, XPeng and Li auto, among others, all established since 2014 when the entry

requirement was amended by the central government to allow firms without ICEV manufacturing experience to work on BEVs. Their approach to electric mobility differs from incumbent OEMs in several ways. First, they focus on a single BEV model in the beginning and have largely stuck to the same product series, without a large product matrix or family as in the ICEV regime. This is partly because of their limited financial resources and scale on the one hand, and the significant risks associated with EV on the other. In addition, highlighting a flagship EV model helps distinguish them from other EV models in the market. Second, their financial investment mainly comes from the capital market, at least in the first several years of development, which makes then particularly responsive to the interests of investors. Partly for this reason, they put great emphasis on high-tech elements and added-value services in order to attract investments and secure a high valuation in the stock market. Third, for similar reasons, as well as because of lack of accumulated manufacturing capabilities, they engage intensively in downstream activities, where battery and energy related services become an added value and raise price premium of BEV models. For example, NIO launches a life-long battery swapping plan to charge users for changing batteries through monthly subscription. This turns out to be a selling point almost unique to NIO because of several years' continuous input and accumulation in downstream activities. Fourth, a related characteristic of these start-ups is that they are more daring to try new business models that help bring their product-service systems to market.

It would be misleading, and too late, to claim incumbent advantage or trap; the same applies to new entrants. The latter may be a strong disruptive force because of their emphasis on radical innovation and no path-dependency in the ICEV regime. However, they are more vulnerable in a complex product sector that requires large scale investments and cash flow, accumulation of technological capabilities and mature corporate management system. Moreover, because of start-ups' focus on design and downstream activities, there is emerging division of labour

between them and incumbent firms. One typical example is the collaboration between JAC and NIO, where NIO provides product design and development, brand image and services, while JAC specialises in manufacturing and mass production. Hence NIO's BEV models actually went out from their joint manufacturing centre.

It is not only the incumbent-new entrant relation is in "era of ferment", but also vertical relation between OEMs and core component suppliers in the EV value chain, as well as between OEMs and emerging players from the IT and ICT sector. In terms of vertical relation, transaction costs theory and industrial organisation literature predicts that OEMs have the constant motivation of vertical integration (Adner & Kapoor, 2010). This is manifested in the initial establishment of power battery R&D and even production centres by OEMs such as GAC - at least the announcement of corporate strategy to do so. However, power batteries represent an important complementary asset of high added value and innovation challenges, which makes vertical integration a challenging task. So far, powerful battery suppliers such as CATL, Fudi (the part of BYD that specialises in batteries), FinDreams[128], Gotion and Farasis still enjoy large market share in China, and CATL even secures its supply relation to selected EV models from global brands (e.g., CATL-BMW). For the moment, leading battery supply firms specialise in battery cells and R&D in the technological frontier of electro-chemical and material sciences. They are also tapping further upstream to the energy sector so that OEMs would not easily erode their comparative advantage. It remains to be seen where the boundary of firms would end up. The same happens to the division of labour between OEMs and important "suppliers" from ICTs, for example, those involved in connectivity and sophisticated assistant and autonomous driving technologies. While these suppliers want to cultivate their edge through software,

[128] FinDreams is the power battery firm spin-off from BYD and was established in 2019. Before that, BYD had very thorough vertical integration by producing both EVs and batteries itself. In 2019, FinDream was one of the five core component supply firms that were separated from BYD and opened up their intermediary products supply to all OEMs.

OEMs are equally interested in some of the technologies in order to better control product design and R&D process, and improve the integrated performance of their vehicles. Therefore, in the emerging electric mobility industrial platform, despite OEMs as platform orchestrators is unequivocal, how the architecture and inter-firm relation would eventually take shape is still uncertain.

10.2.2 Competitiveness versus sustainability: a trade-off or balance?

China's transition to electric mobility is heavily influenced by green industrial policy, but not exclusively attributed to it. The chosen pathway, i.e., to speed up the pace of technological substitution of ICEVs by EVs is achieved by intervening into the process of technological variation so that certain technological trajectories and configurations - those based on power batteries as core competence - receive more policy support than those more reliant on conventional power systems. The intended and unintended consequences both point to the result that China has chosen a pathway of radical decoupling with existing industrial regime from the end product perspective, and the ambition to build up competitiveness based on power batteries and automobile technological and industrial convergence with ICTs.

Then one question to ask is whether the objective of industrial competitiveness has been achieved. According to the findings of this thesis, and other most recent literature on electric mobility (Altenburg et al., 2022; Xiong et al., 2022), the answer should be a cautious, partial and temporary “yes”. It is not to say that Chinese EV sector as a whole has surpassed the West, but rather its progress compared to the ICEV regime in the past several decades, as well as to what EV sector in developed countries has proceeded, is distinctively well-performing despite many deficits. Most recently, Altenburg et al. (2022) have found that China is indeed leapfrogging technologically in electric mobility’s certain technological fields (e.g., batteries, electric buses) based on the quantity and quality of patents.

This argument can be further supported by several recent facts. First, China has topped in the volume of EV production and sales in most of the time over the past years. The quality and function of EV models have been consistently improved and a number of OEMs are able to tap into the medium-sized segments and luxury BEVs. Second, among these EV sales, indigenous brands occupy a major domestic market share, which is different from the situation in the ICEV regime when most sales went to JV brands. Third, at the global level, most recently some indigenous brand EV manufacturers have started to export EV models, launched their EV brand and product series and customer experience centre in other countries, especially in Europe such as Norway, Netherlands, Germany, etc. Despite the fact that this is only a start and many difficulties are to be seen, the single fact that EV brands and products from an emerging market economy is being accepted and recognised by developed country customers is a meaningful step. Fourth, in terms of open innovation, China has shifted from relying on almost single directional inward FDI in the ICEV regime to co-development and co-specialisation in the electric mobility ecosystem. For example, NIO is involved in building battery swapping infrastructure in European countries in cooperation with local partners to provide net-zero solutions. Fifth, the competitiveness of supply chain is stronger compared to the ICEV regime era, too, which has already been mentioned in subsection 10.2.2.

In the short term, it seems that the degree that competitiveness goal is achieved is higher than sustainability. Because the automobile is only the end product, zero-emission or low-emission from the end product does not mean that the entire sector has transformed towards sustainability; other segments in the industrial value chain matter, especially when the network linkages are extensive and complex. This is where much controversy about BEV lies. There is no lack of criticism that the “clean” car transition is by no means carbon free if one looks at the energy input. In China, electricity as a secondary energy source is predominantly generated by burning coals. Besides, the production process of EVs in total also has more emissions than

the production of ICEVs (De Souza et al., 2018; Van Mierlo et al., 2017). Scholars have used life-cycle assessment of the energy consumption and carbon emission from electrification of automobiles to have a more comprehensive picture. Despite that the conclusions are mixed, a most recent Nature Sustainability study argues that in aggregate "Even if future end-use electrification is not matched by rapid power-sector decarbonisation, it will probably reduce emissions in almost all world regions" (Knobloch et al., 2020, p. 437). At present the well-to-wheel environmental performance of EV in Europe is two to three times better than in China. However, efforts have also been made to green the upstream sectors and production processes in the country. In particular, the proportion of coal in electricity generation has reduced from an 80.96% high in 2007 to 62.93 % in 2021[129]. Given sufficient time and structural change in upstream sectors, it is highly probable that emission would eventually be significantly reduced in the transport sector in the transition toward electric mobility.

Moreover, for developing countries and emerging markets where resources and capabilities are far more constrained than those in developed countries, an early focus on industrial competitiveness is helpful to provide sufficient incentives for the private sector, especially business firms in the incumbent industrial regime, to embrace technical change. This is part of the reason why Rodrik (2015) views green industrial policy as a second-best option for developing countries in transformation to green growth.

10.2.3 The challenges arising from domestic and global context

China's transition to electric mobility and the sustainability and competitiveness prospect faces challenges from both domestic and global environments. In the country, the cost of developing, producing and deploying EV is still high after subsidy-scheme phased out. With macro

[129] https://ourworldindata.org/grapher/share-electricity-coal?tab=chart&country=~CHN Our World In Data, which is further based on BP Statistical Review of World Energy (2022), Ember's European Electricity Review (2022), and Ember's Yearly Electricity Data (2023).

economy worsening during covid-19 pandemic and the shrinking size of population and workforce, market demand for automobiles (including EVs) may decline, which poses further constraint on diffusion of EVs in domestic market. In addition, the sustainability aspect about electric mobility transition deserves more attention and greater efforts, so that the EV sector genuinely becomes an engine of green growth.

Policy, regulatory and industrial change at the global level also raises challenges to China's electric mobility transition. There is an existing agenda of green transformation in Western countries in the automobile industry, which is partly reflected in the similarly eminent timeline to phase out ICEV sales in the 2030s and 2040s[130], and up to now the most stringent carbon emission standards published in April 2019 at the EU level. Seeing China's fast expansion of the EV sector and battery value chain, some developed countries have started to use more green industrial policy in response. For example, German authority in its legislation raised subsidy per EV from 4,000 euros to 6,000 euros on EV models priced below 40,000 euros. At the same time, global OEMs are intensifying their commercialisation efforts in electric mobility. VW group raised EV sales target towards 2030 from 15 million to 22 million. Telsa, the top EV start-up, has reaped gigantic EV market share both in China and the globe and is leaving many competitors behind via its popular Model 3, Model S and Model Y.

Furthermore, the green restructuring of the automobile industry has encountered severing geopolitical challenges. This is partly because of the intensified competition in the sector for technological development and market share, but also that a reconfiguration of global value chain and competition for lithium and other material resources from continents such as Latin America and Africa. This is exacerbated by the disruptive influence of covid-19 pandemic, as well as the trade-war between the U.S. and China and the subsequent geopolitical changes.

[130] Norway is most radical in terms of the deadline to phase out ICEV sales, with the target years set to 2025.

Despite that there is strong rationale and call for international cooperation to tackle "grand challenges" such as climate change (Keenan et al., 2012; Kuhlmann & Rip, 2014), countries must think seriously and tactically about geopolitical context and its implications to better coordinate for the future of human society.

10.3 Policy and management implications

The findings of the thesis bear important policy implications for developing countries and emerging economies in structural change towards sustainability. It is important to have an integrated and holistic view of green industrial policy, instead of focusing on a single policy instrument. This can be supported by relating industrial policy design to innovation and value chain segments of the sector under green transformation. ST&I policy is especially important to complement green industrial policy, not only for building up the absorptive capacity of business firms, but also as a platform for knowledge recombination and network formation. Moreover, with sectoral change proceeds, enough attention should be paid to the interface between green industrial policy with the broader macroeconomic policies, and the intersection between the focal sector and its vertically and horizontally related sectors. This necessitates institutional change with regards to how coordination within the public sector and different programmes could be better achieved dynamically.

Another key lesson is about the selectivity of green industrial policy, which is highly debatable in both theory and practice. While it makes sense to focus on competitive advantage in the beginning to provide sufficient incentives for incumbent actors, intentional and early termination of certain technological solutions within the possibility scope of technological multiplicity by policy incentives should be avoided. Instead, it is important to encourage technological and product diversity to preserve the necessary absorptive capacity and capability stock in the private sector. This makes a difference for constructing "a ladder for growth" and

avoiding undesirable lock-in. And it is the decision of private actors themselves to focus on certain technological configurations that best suit their incentive structure and resource and capability profiles. One related implication for policy makers is hence to take into consideration the responses from business actors. In the earliest design stage, questions should be asked about what incentives are implied by a certain policy and a mixture of them, and how they could possibly play out. This means that a top-down approach of governance dominated by technological rationality should give way to coordination between public and private sector to illicit sufficient information, enable mutual learning and open-ended debate on pathways of change. The last but not least implication is that policy makers need also consider the international political economic dynamics, and think about how the proposed policies and their implementation would bear for trade, international cooperation and competition.

There are also important management implications on innovation strategies and processes for incumbent firms facing transformative change. First, firms need to take a holistic view of their innovation strategies and processes because of their system level implications in combination. This draws our attention to design thinking that brings those elements together under an overarching system change proposal. Innovation processes and activities would hence work with each other in a more coherent and productive way. Second, despite policy intervention, firms need to maintain a certain degree of technological multiplicity and diversity for them to navigate the prolonged and uncertain selection process. Third, seizing and exploiting windows of opportunities opened up by green transformation does not mean to abandon the existing trajectory of capability building as a whole. It is important to focus on capability building that has added value for system integration, for any technologies and products, including green ones, depend on strong system integration capabilities to have good functionality and performance. Fourth, in systemic change, incumbent firms need to think about the potential change of industrial architecture and their shift of position and division of labour within. Last but not

least, firms need to treat open innovation, not as an option, but as an inherent part of the broader ecosystem revolving around the development, deployment and diffusion of green technologies and products, guided by design rules mentioned in the first point in this paragraph.

10.4 Limitations and future directions of research

There are several limitations about the thesis which point to future fruitful directions of research. For in-depth, longitudinal case study from a sectoral perspective, this thesis has focused on a single sector in a single country. Because the characteristics of sectors and institutional context in a certain country matter, future research should look at other sectors and country cases, and move to comparative study. This will help validate, challenge and refine the findings in the thesis, hence deepen and broaden the research on green industrial policies, innovation processes and industrial dynamics in the context of early-stage green transformation.

The open systemness approach adopted in the thesis marks a preliminary experimental step to bridge political economy and innovation system literature to better make sense of the driving forces and processes of system transformation. It is of course not a definitive framework, and a lot of conceptual and theoretical work remains to be done, for example, the more explicit implications of open systemness for rethinking building blocks of SSIP, and the operationalisation of directionality of innovation could still be improved. Besides, this experimental framework is based on industrial sectors, which may limit the generalised implication and wider applicability of the idea of open systemness. Future research could look at other types of innovation systems, for example, technological innovation system (TIS) and socio-technical systems (STS), as well as considering the geographical scales. Further, it would be exciting to see how innovation system concept in general could be re-interpreted and refined to better account for transformation of innovation systems to address “grand challenges”.

There is also limitation in methodological aspect. A case study design is adopted to uncover the interactions, process and evolutionary dynamics. Future research could think about quantitative methods or mixed methods design to examine larger scale of data and provide a more statistically robust examination of the topic. This would help increase the internal and external validity of the research. The current thesis does not do so because of the questions asked and the quality and availability of data. In terms of interactive dynamics in an innovation system, one may consider system dynamics modelling and agent-based modelling (De Cian et al., 2020; Samara et al., 2012), which, however, would further require alternative conceptualisation and operationalisation of variables. For the analysis of firm innovation strategies and processes and their outcomes, one may also consider configurational approach to comparative case study (e.g., fuzzy set QCA) (Kraus et al., 2018).

Last but not least, the temporality of the current case and the early stage of green transformation leaves space for further research as well. The electric mobility transition is still in "era of ferment" and a lot of technical, institutional, regulatory and market changes both within the country and at the global level may add to the development of the topic. These challenges and contingent factors are already mentioned in sub section 10.2.2 and 10.2.3. Future research should look at a longer time frame and situate the research topic in international political economy dynamics, which means that more inter-disciplinary work, both theoretical and empirical, is needed.

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Appendix

Appendix A. Interview questionnaires

Business managers at OEMs

1) General questions

- Could you please briefly talk about yourself, especially your work experience in the automobile industry, and in the current organization in particular?
- What motivates you to engage in electric mobility?
- Please talk about the history of your corporation in the industry and electric mobility. What are the major strategic steps taken that matter for the current performance?

2) Government policy

- Can you talk about your corporate's perception of EV policies when they were issued? What are the policies that proved to be most influential on your organization?
- What do you think are the expectations of policy makers in EV sector? Can you describe the reactions from the industry?
- When making relevant decisions on EV development, what factors did your corporation take into consideration? How do you weigh the pros and cons, and what are the major tradeoffs?
- Did your company participate in any state-led or local-government-led R&D programs? What proved to be most influential and helpful? What did your company do in the program and what were the results?
- Apart from R&D programs and investment, what other support did local government provide that proved to be helpful to your organization? Were there any requirements on the company in turn?

3) Technology and innovation strategies

- What technological trajectories did your organization choose in electric mobility in the beginning? Why?
- How have technological trajectories changed up to now? Why are the changes?
- Would you describe your corporation's engagement in electric mobility as radical or non-radical? Or to put it another way, is it active and eager to develop EV technologies and commercialise them shortly? Why?
- Regarding the strategic measures to support electric mobility strategy, please talk about the topic revolving the following point in more details:
  - ⇒ What are the main strategies concerning electric mobility? Why are they formulated like that?
  - ⇒ How are these strategies implemented? In particular, what technologies, products and business model are seen?
  - ⇒ How much and how R&D efforts are organised to develop and commercialise EV models?
  - ⇒ Regarding the capability development of the vehicle model, power system, and core component (battery, electric motor, electric control system), how much did your corporation do it itself? How much is outsourced to or cooperated with suppliers? Why?

4) Performance

- Objectively, how do you evaluate the competitiveness of your company in the automobile industry in China, in the ICEV regime and EV regime respectively? What are the strengths and weaknesses?
- What are the most successful and popular EV models that have ever been deployed by your corporation? What made them successful?

5) Outlook

- What should be the kind of EV manufacturers that can survive and be competitive in the coming 10 years? If your company wants to achieve that, what do you think are the most important tasks and challenges ahead?

Business managers at component supply firms and other complementors

1) General questions

- Could you please briefly talk about yourself, especially your work experience in the automobile industry, and in the current company in particular?
- What motivates you to engage in electric mobility?
- Please talk about the history of your company in the industry and electric mobility. What motivates it to enter the sector of electric mobility? What and when was the specific entry point chosen?

2) Technology and product in the EV sector

- What technological fields and products are your company specialized in?
- What products does your company supply to EV manufacturers?
- What are the major downstream customers so far? Which sources the most from your company?
- How has the technological and product portfolio changed over time since your company entered the sector? What contributes to the change?

3) Technology and innovation strategies

- What capabilities did your company have and not have when it first entered the sector? How did it build up the capability it needed?

- Did your company participate in any state-led or local-government-led R&D programs? What proved to be most influential and helpful? What did your company do in the program and what were the results?
- In terms of product development, in what way does your company work with downstream customers? Using a typical product supplied by your company for example, what are the technological requirements raised by OEMs to your company? How did you fulfill those requirements?
- Did your company cooperate with downstream customers in product development? In what way(s)? What did your company get through the cooperation?

4) Performance

- Objectively speaking, in your technological and product field, how competitive is your company in China? What are the strengths and weaknesses?

5) Outlook

- In your perspective, how will industrial architecture in your specific sector change in the coming 10-20 years?
- To maintain survival and stay competitive in the future, what tasks your company must do, and what are the major challenges?
- What is your company's expectation held on policy makers and downstream customers?

Policy makers, policy consultants and other "insiders"

1) General questions

- Could you please briefly talk about yourself, especially your experience in policy making or consultancy at the national level?
- What motivates you to engage in electric mobility?

2) Activities and roles

- What are the major activities you have undertaken in policymaking or consultancy? What are the major policy initiatives/agendas/programs you are involved in?
- What are your roles in them? What contribution did you make to the framing and/or implementation of policies?

3) The framing of green industrial policy?

- How would you describe the development path of electric mobility in China? What are the major milestones?
- What were the rationales underlying national EV-related policies before the subsidy scheme?
- How did the debate over technological trajectory look like before 2012? What were the major voices and by whom?
- Why was the "pure electric drive" strategy eventually established? What do you think is the most important factor?
- After 2015, do you think there is an important policy change that you want to mention or highlight? If so, how and why it is important? What are the implications?

4) The implementation of industrial policy

- At the level of central government, what is the division of power to carry out the "pure electric drive" strategy? What are the most important actors?
- What is the division of power between central and local government (pilot cities)?
- How would you describe the role of local government in implementing industrial policy? What localities are more proactive and what localities are less active? Why?
- What are the typical industrial policy practices at the local level that you evaluate as important for the diffusion of EVs? Could you give an example based on your experience?

- What are the major challenges facing the implementation of industrial policy? How are they addressed?

5) The influence and outcome of industrial policy

- Overall, would you think the green industrial policy is successful? If so, in what terms?
- How do you think industrial policy under the "pure electric drive" strategy has influenced the development trajectory of China's EV sector?
- What are the major problems and lessons with the industrial policy practice in China?
- From your perspective, how is the green industrial policy in China different from developing countries (e.g., U.S., Germany, Japan, etc.)

Technological professionals, experts

1) General question

- Could you please briefly describe yourself and your experience in the field of EV. What motivated you to embark on research in this area? What are your expertise and duties?

2) Technology dimension

- Back to early 2000s, what are the strengths and weaknesses in China's EV technology development? What was the distance from the global technology frontier?
- Could you please compare major technological trajectories in the EV regime. From your perspective, which specific one or more than one that China has comparative advantage?
- Could you please compare different solutions of power batteries. From your perspective, which specific one or more than one that China has comparative advantage?
- In the EV technology value chain, which segment do you think is most challenging and important for industrial upgrading?

- Would you think EV is the best way to achieve sustainability goals in the automobile industry? Why or why not?

3) Policy dimension

- From your perspective, in 2012, what was the rationale for the "pure electric drive" strategy? Does it make sense to you?
- Could you talk about how the "pure electric drive" strategy affect China's EV technology development?
- Have you ever engaged in policy consultancy in EV-related fields at the national or local level? If so, could you describe your experience in more detail?
- Overall, do you think China's industrial policy to facilitate EV development is successful? Why or why not?
- To-date, what aspect of the current industrial policy approach needs adjustment? Why and how is it?

4) Final remarks

- Up to now, that is the distance between China's EV technology and sector, and the global frontier? Why aspect has China been most successful and unsuccessful?
- How different is China's approach to electric mobility transition compared to developed countries, for example, the U.S., Germany and Japan?
- From your perspective, what does the future of electric mobility look like?

Appendix B. Firm-level variable measurement (2010-2020) supplementary data[131]

Year 2010

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,000	63	52,963,401	183,317	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	525	11	228,842,359	5536	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	2,429	2	30,456,426	/	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	3,386	/			Acquisition of Volvo.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	253	/	23,698,275	/	/	Not SOE, no institutional back up, and Baoding city is small.
BAIC	10	/	/	/	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.

[131] Several points need to make here. First, Chery is not listed on the stock market; all other OEMs are. Second, the statistics is not an accurate reflection of the variables, but a reference. As pointed out in the empirical analysis, existing literature and industrial experts' opinions are also part of the measurement but are not specifically listed here due to limited space. However, the idea of multiple data source and triangulation is for the purpose of increasing validity. Third, some statistics seem to be abnormal, for example, the number of patents granted to some SOE groups (e.g., FAW, Dongfeng, BAIC, etc.). The problem is that in some years the statistics includes the entire group, including heavy duty vehicles and parts. OEMs perform better in heavy duty vehicles; therefore the number of patents should not be used to exaggerate technological capability in the light-duty vehicle area. The number of total assets does not include that of JVs (this is why Changnan's total assets do not seem to be many), therefore, some firms' real resources are not accurately captured. However, the author is aware of all these nuances in the data analysis. This note is also used for readers to get an idea of how this data is used contingently. Geely's data is missing due to inaccessibility to its annual reports.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,000	63	52,963,401	183,317	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	525	11	228,842,359	5536	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	2,429	2	30,456,426	/	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	3,386	/			Acquisition of Volvo.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	253	/	23,698,275	/	/	Not SOE, no institutional back up, and Baoding city is small.
BAIC	10	/	/	/	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.

Year 2011

2011	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,000	63	52,963,401	183,317	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	525	11	228,842,359	5536	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	2,429	2	30,456,426	/	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	3,386	/			Acquisition of Volvo.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	253	/	23,698,275	/	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	93	/	21,801,000	/	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	608	/	14,736,040	17,693	-	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	2,852	/	/	/	JV with Israel (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	142	/	/	/	-	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	248	/	16,289,294	8,103	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	3,102	/	19,408,762	9,429	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	152	/	44,611,887	29,537	JV with Toyota, Honda and Fiat.	SOE, institutional and financial back up, and local government support.

Year 2012

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	2,904	65	68,710,488	166,411	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	1,998	3	317,202,999	/	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	1,506	/	46,117,605	15,176	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	6,794	/			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	1,431	/	42,569,397	/	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	883	/	31,782,000	/	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	949	/	19,569,178	20,254	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	2,988	/	63,932,961	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	51	/	/	/	/	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	180	/	16,330,563	7,460	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	622		18,602,495	10,113	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	266	/	49,433,949	34,726	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2013

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,112	75	76,392,911	159,440	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	2,492	2	373,640,741	144,955	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	806	/	53,364,694	30,877	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	5,622	3			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	2,347	1	52,604,809	64,719	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,721	/	85,396,000	22,371	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	3,254	/	23,672,235	21,848	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	2,217	/	66,180,859	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	95	/	/	/	/	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	172	/	21,086,280	6,893	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	1,660	/	20,191,845	10,290	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	274	/	/	/	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2014

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,164	85	94,008,855	187,028	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	3,026	8	414,870,673	151,820	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	916	10	69,687,353	34,260	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	2,464	11			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	1,875	/	61,345,252	71,575	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	898	/	109,859,000	22,015	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Simens.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	4,848	/	26,864,179	20,763	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	2,107	/	64,362,510	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	37	/	/	/	/	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	120	/	20,935,598	7,067	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	740	/	19,439,253	10,560	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	288	/	62,371,783	45,819	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2015

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	3,144	82	115,485,755	196,026	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	3,504	3	511,630,691	163,817	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	971	/	89,413,989	37,457	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	988	29			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	965	/	71,910,627	68,999	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,073	/	168,900,000	25,461	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Siemens.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	5,486	/	38,903,800	27,411	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,821	/	66,783,648	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	19	/	/	/	/	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	96	/	18,038,458	7,484	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	379	/	20,217,939	10,542	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	322	/	67,219,688	67,205	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2016

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	5,314	142	145,070,778	193,842	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	4,018	1	590,628,138	171,395	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	1,628	/	106,510,474	36,029	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	2,838	32			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	1,769	/	92,309,161	71,617	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,593	/	167,403,000	25,159	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity)	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	5,254	/	49,214,598	28,732	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,724	/	76,739,456	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	41	/	/	/	/	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	149	/	19,048,874	7,840	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	359	/	21,504,535	6,803	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	485	/	82,146,241	75,672	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2017

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	6,290	49	178,099,430	200,949	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	4,584	5	723,533,131	180,749	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	1,452	/	106,125,115	39,138	JVs with Ford, Suzuki, Mazda, PSA, etc. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	2,840	42			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	1,666	/	110,547,074	68,505	/	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,650	/	172,034,000	22,844	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Siemens.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	6,156	/	44,510,293	30,469	/	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,873	/	83,690,038	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	64	/	33,171,808	16,210	JV with Ford (project had no progress).	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	349	/	18,537,953	7,027	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	508	/	17,787,912	6,624	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	590	/	119,656,441	84,290	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2018

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	6,734	68	194,571,077	220,152	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	5,694	5	782,769,850	217,511	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	2,235	15	93,488,854	36,029	JVs with Ford, Mazda, etc. JVs with Suzuki and PSA exited. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	4,636	70			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	2,207	/	111,800,411	63,455	JV with BMW on EV.	Not SOE, no institutional back up, and Baoding city is small.

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,629	/	193,212,000	20,431	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Siemens.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	5,102	/	47,491,505	26,580	JV with NIO. JV with VW.	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,456	/	80,540,960	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	184	/	32,479,109	15,165	JV with Ford (project had no progress).	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	1,830	/	18,628,194	6,871	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	406	/	19,629,713	6,865	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	1,627	5	132,173,759	94,856	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Year 2019

	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	6,658	89	195,641,593	229,154	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	4,540	14	849,333,280	216,360	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	1,043	9	97,617,054	36,764	JVs with Ford, Mazda, etc. JVs with Suzuki and PSA exited. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	5,766	84			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	2,040	/	113,096,409	59,756	JV with BMW on EV.	Not SOE, no institutional back up, and Baoding city is small.

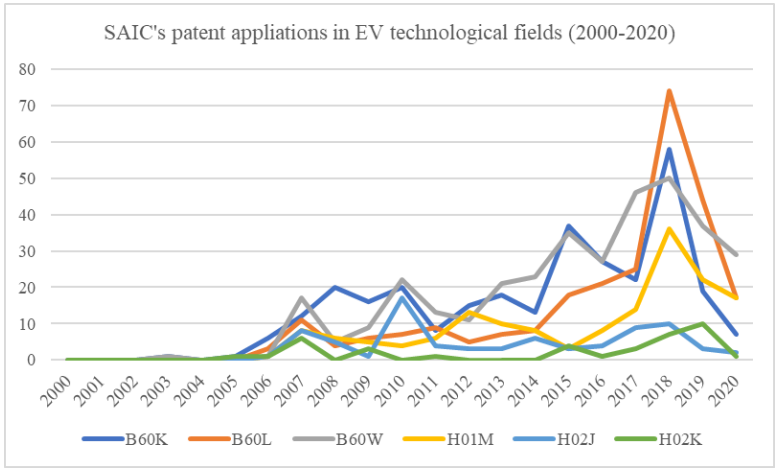
	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	1,884	/	196,393	21,712	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Siemens and Magna.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	735	/	43,854,516	24,487	JV with NIO. JV with VW.	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,279	3	/	/	JV with Israel and Jaguar Land Rover (not performing well)	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye	95	/	20,436,580	8,098	JV with Ford (project had no progress).	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	226	/	19,655,194	/	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
Dongfeng	1,182	/	18,818,908	6,982	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	2,782	1	137,409,528	93,854	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

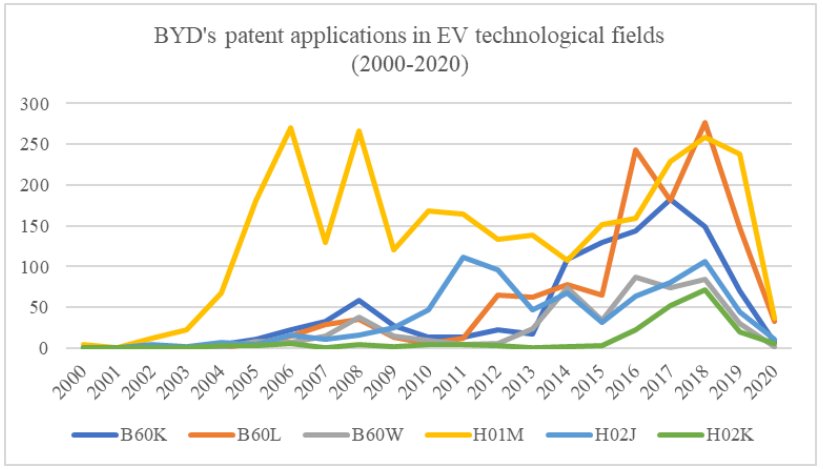
Year 2020

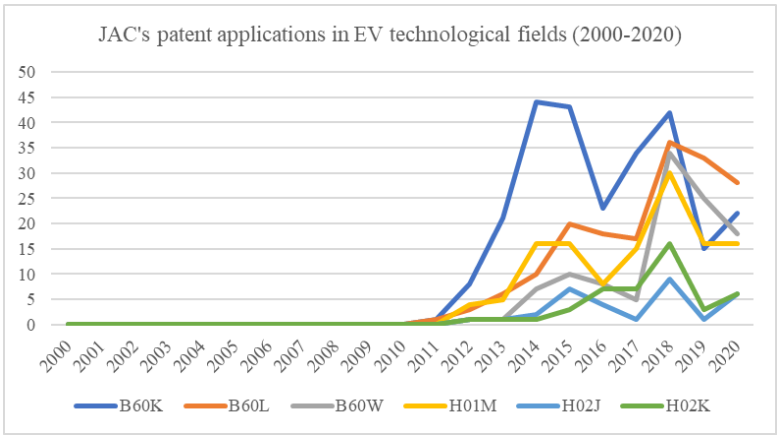
	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BYD	5,628	108	201,017,321	224,280	/	Not SOE, no institutional backup, but Shenzhen city government has generous policy support
SAIC	4,886	7	919,414,756	204,815	JVs with GM, VW, and supply network of international profiles.	SOE, Shanghai Municipal government back up and policy support
Changan	2,221	16	120,915,805	40,298	JVs with Ford, Mazda, etc. JVs with Suzuki and PSA exited. Globalised R&D platform.	SOE, financial and institutional back up from parent group CSGC, and policy support from Chongqing Municipal city.
Geely	5,546	57			After-acquisition of Volvo. Tech JV in Sweden.	Not SOE, no institutional backup, but has policy support from many local governments.
GWM	2,782	/	154,011,491	63,174	JV with BMW on EV.	Not SOE, no institutional back up, and Baoding city is small.

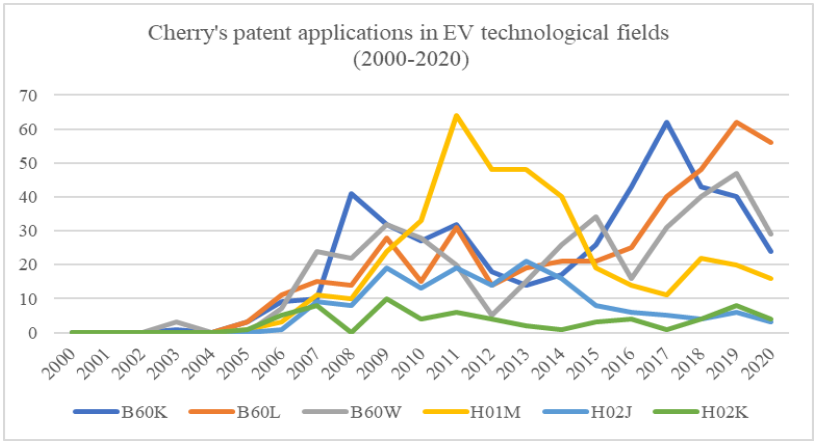
	Technological capability		Overall resource portfolio			
	Patents (CN)	Patents (US)	Internal: size as a proxy		External (selective)	
			Total assets (1,000 RMB)	Total employees	Institutionalised partnerships	Governmental backup
BAIC	717	/	193,703,000	21,038	JVs with Mercedes Benz and Hyundai (but limited absorptive capacity). Cooperation with Siemens and Magna.	SOE, financial and institutional backup from Beijing Municipal government, and policy support.
JAC	1,790	/	42,117,491	24,661	JV with NIO. JV with VW.	SOE, back up from Hefei city government. But Hefei is only moderately developed.
Chery	1,658	/	/	/	JV with Israel and Jaguar Land Rover -	SOE, but Wuhu is a small city and governmental resources are limited.
Zotye (ST*Zotye)	/	/	9,584,532	2,143	JV with Ford, but Zotye went bankrupted.	Not SOE, no institutional back up, and Jinhua is a small city, government support limited.
FAW	4,138	/	/	/	JV with Audi, Toyota, Honda, etc. (but limited absorptive capacity).	SOE, institutional and financial back up, and local government support.
Dongfeng	257	/	20,163,001	4,957	JV with Honda, Nissan, Citron, etc. (but limited absorptive capacity)	SOE, institutional and financial back up, and local government support.
GAC	3,012	2	/	/	JV with Toyota, Honda, Fiat and Mitsubishi.	SOE, institutional and financial back up, and local government support.

Appendix C The number of patents by selective Chinese OEMs in critical EV technological fields[132]

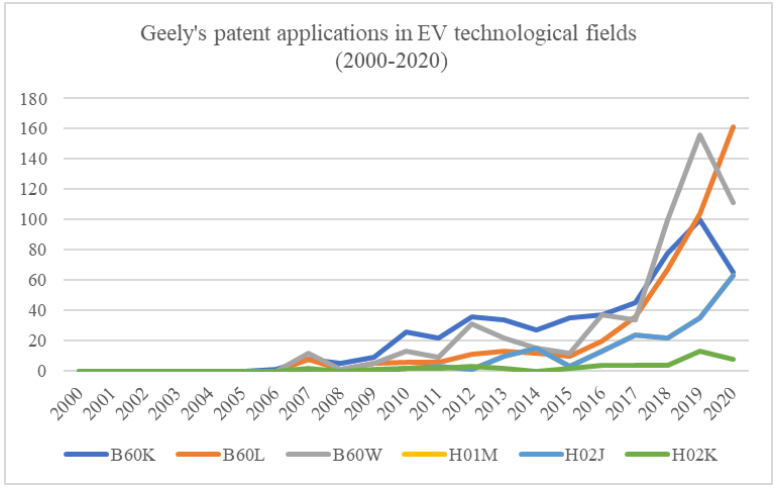


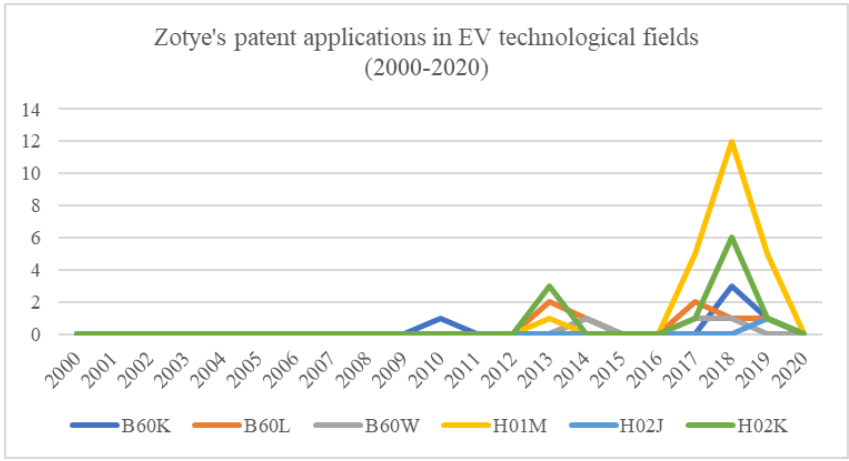






[132] The patents of Changan and BAIC is already listed in Chapter 9; the patent data of FAW and Dongfeng was unavailable due to change in data access.


Geely's patent applications in EV technological fields
(2000-2020)
180
160
140
120
100
80
60
40
20
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B60W
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H02J
H02K


Zotye's patent applications in EV technological fields
(2000-2020)
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2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
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