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ÉCOLE DOCTORALE SCIENCES ÉCONOMIQUES,
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Université Clermont Auvergne



Ecole Doctorale des Sciences Economiques, Juridiques, Politiques et de Gestion

Laboratoire Clermont Recherche Management (EA3849)

**LE RATTRAPAGE TECHNOLOGIQUE ET LA DYNAMIQUE DES
FENETRES D'OPPORTUNITE :
PERSPECTIVES DES INDUSTRIES CHINOISES**

**TECHNOLOGICAL CATCHING UP AND THE DYNAMICS OF
WINDOWS OF OPPORTUNITY:
INSIGHTS FROM CHINESE INDUSTRIES**

Thèse présentée et soutenue publiquement le 23/10/2024
pour l'obtention du titre de Docteur en sciences de gestion

par

Lu XU

Sous la direction de **Anne ALBERT-CROMARIAS**

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Abstract

This thesis explores the complex and trendy phenomenon of technological catching up with a focus on technological uncertainty and windows of opportunity (WOPs). This thesis provides a comprehensive framework for understanding how latecomer firms can bridge the gap with leading counterparts across various industries. The study integrates insights from process theory, technological uncertainty, and sector-specific dynamics, highlighting the critical importance of adaptive strategies and proactive policymaking.

The main body of this thesis compasses three empirical studies (Chapters 2-4), which addresses three key areas: the impact of technological uncertainty on catching up processes, the evolution of government policies in creating and sustaining WOPs, and the unique WOPs emerging from exogenous shocks such as the COVID-19 pandemic. Specifically, Chapter 2 investigates how technological uncertainty and WOPs influence catching up patterns in four different Chinese manufacturing industries. The empirical second study, Chapter 3, focuses on the Chinese electric vehicle industry's catching up process, highlighting the evolution of government policies and the interplay of technological and market WOPs. The third empirical study, Chapter 4, analyses the accelerated digital transformation and its WOPs, driven by the COVID-19 pandemic containments in China. Through a combination of case studies and theoretical analysis, this thesis demonstrates the dynamic interactions between different types of WOPs and their role in facilitating technological advancement. The findings emphasise the necessity for tailored strategies and policies that consider sector-specific characteristics and the unpredictable nature of technological and market environments.

This thesis contributes to the established literature in three ways. First, we differentiate the patterns of catching up processes in the early and late stages. This provides a novel taxonomy of catching up patterns to conventional ones, enhancing the explanatory power of catching up strategies. Second, this thesis highlights how the evolution of policy, from

initiation to consolidation and repositioning, affects the emergence and utilisation of WOPs. We open up the black box of how different types of WOPs, which vary throughout the stages of the catching up process, facilitate catching up by providing unique opportunities for innovation and growth. Third, this thesis provides a timely investigation into how social crises, such as the COVID-19 pandemic, create unique and complex Relative WOPs. This understanding enriches WOPs studies by examining them in a turbulent context and provides insights into how crises can catalyse innovation and change, offering latecomers opportunities to leverage their dynamic capabilities.

This thesis helps managers understand the structural nature of the catching up process, allowing them to craft more effective strategies at different stages tailored to their specific technological contexts, whether it involves exploiting existing technologies or exploring new ones. This thesis offers policymakers a roadmap on how to support industrial development and create an environment conducive to innovation and growth in latecomer industries. Understanding the dynamics and complexity of WOPs during crises helps firms leverage these opportunities for transformation and other innovations, while policymakers can design more responsive and supportive measures during such times.

By addressing existing research gaps in technological catching up and WOPs, this thesis advances academic knowledge in the field of technological development and strategic management. By focusing on Chinese manufacturing sectors, this thesis offers practical examples and referential models that can be applied in other emerging economies for both latecomer and incumbent firms.

Keywords: Strategic Management, Technological Catching Up, Process, Technological Uncertainty, Windows of Opportunity, Policy, Market Demand, Manufacturing, Electric Vehicle, COVID-19, Digitalisation, China

Résumé

Cette thèse explore le phénomène complexe et d'actualité du rattrapage technologique en mettant l'accent sur l'incertitude technologique et les fenêtres d'opportunité (Windows of Opportunity - WOP). Cette recherche fournit un cadre complet pour comprendre comment les entreprises retardataires peuvent combler l'écart avec les leaders dans diverses industries. L'étude intègre des perspectives issues de la théorie des processus, de l'incertitude technologique et des dynamiques sectorielles, soulignant l'importance critique des stratégies adaptatives et de l'élaboration proactive des politiques publiques.

Le corps principal de cette thèse comprend trois articles académiques, qui constituent les chapitres 2 à 4, abordant trois domaines clés : l'impact de l'incertitude technologique sur les processus de rattrapage, l'évolution des politiques gouvernementales dans la création et le maintien des WOP, et les WOP uniques émergeant des chocs exogènes. Plus précisément, le Chapitre 2 examine comment l'incertitude technologique et les WOP influencent les modèles de rattrapage dans quatre industries manufacturières chinoises. Le Chapitre 3 se concentre sur le processus de rattrapage de l'industrie des véhicules électriques en Chine, mettant en lumière l'évolution des politiques gouvernementales et l'interaction des WOP. Le Chapitre 4 analyse la transformation numérique accélérée et ses WOP, poussée par les mesures de confinement durant la COVID-19 en Chine. À travers une combinaison d'études de cas et d'analyses théoriques, cette thèse démontre les interactions dynamiques entre différents types de WOP et leurs rôles dans la facilitation des avancées technologiques.

Cette thèse contribue à enrichir la littérature de trois manières. Premièrement, elle différencie les schémas des processus de rattrapage aux stades précoce et avancé, fournissant une nouvelle taxonomie qui améliore le pouvoir explicatif des stratégies de rattrapage.

Deuxièmement, cette thèse met en évidence comment l'évolution des politiques affecte l'émergence et l'utilisation des WOP. Nous éclaircissons la manière dont différents types de WOP facilitent le rattrapage en fournissant des opportunités uniques pour l'innovation et la croissance. Troisièmement, cette thèse étudie la façon dont les crises sociales créent des WOP uniques et complexes. Ces apports enrichissent notre connaissance des WOP en les examinant dans un contexte mouvementé et fournissent des clarifications sur la manière dont les crises peuvent catalyser l'innovation et le changement, offrant aux retardataires des opportunités afin de tirer parti de leurs capacités dynamiques.

Cette thèse aide les gestionnaires à comprendre la nature structurelle du processus de rattrapage, leur permettant d'élaborer des stratégies plus efficaces à différents stades, adaptées à leurs contextes technologiques spécifiques, qu'il s'agisse d'exploiter des technologies existantes ou d'en explorer de nouvelles. Elle offre aux décideurs politiques une feuille de route sur la manière de soutenir le développement industriel et de créer un environnement propice à l'innovation et à la croissance dans les industries retardataires. Comprendre les dynamiques et la complexité des WOP pendant les crises aide les entreprises à tirer parti de ces opportunités pour la transformation et d'autres innovations, tandis que les décideurs peuvent concevoir des mesures plus réactives et de soutien en de telles périodes.

Cette thèse fait progresser les connaissances académiques sur les WOP dans le domaine du développement technologique et de la gestion stratégique. Elle offre des exemples pratiques et des modèles de référence applicables au secteur manufacturier chinois et à d'autres économies émergentes pour les entreprises retardataires et établies.

Mots-clés : Stratégie, Rattrapage technologique, Processus, Incertitude technologique, Fenêtres d'opportunité, Politique, Demande du marché, Fabrication, Véhicule électrique, COVID-19, Numérisation, Chine

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To all who walked beside me on this journey long and grand,

You mark this thesis with a gentle hand.

These pages hold not just my voice, but echoes of your grace,

A collective symphony in this embrace.

As ink meets paper's silence, and thoughts take final flight,

I pen this heartfelt gratitude beneath the stars tonight.

For in this quest for knowledge and in this humble art,

I carry each of you forever in my heart.

General Introduction

a. Research background

With the evolution of the global economy, the developed countries have established their positions as leaders in industrial upgrading, so that they are dominating the international trade and competition (Hurry, 1993). Newly industrialized countries strive to align their achievements and capabilities with those of more developed nations to enhance their competitiveness (Xu et al., 2018). This process of technological catching up is important for fostering a sustainable economic growth and maintaining global strategic position (Lee, 2013; Mazzoleni & Nelson, 2007).

After the World War II, Japan had emerged as a pioneer of the catching up strategy, which successfully revitalized its economy (Jung & Lee, 2010). In the semiconductor industry, Japan managed to bridge the technological gap with the US, which result in it becoming a global leader in this manufacturing sector (Cho et al., 1998). Similarly, the Japanese camera industry has caught up and forged ahead of Germany's previous dominance (Kang & Song, 2017). These demonstrated Japan's catching up strategy which emphasized innovation and strategic investment in technology.

The success of Japan's catching up strategy inspired other now developed Asian economies, especially South Korea, Singapore, Taiwan, and Hong Kong, which are also known as Asian Tigers due to their rapid development technological and economic growth since the 1960s (Choi et al., 2020; Kozlova & Noguera-Santaella, 2019; Lim et al., 2009; Park & Lee, 2006). They have achieved excellence in different manufacturing sectors. For instance, South Korea in semiconductors and memory chips (Cho et al., 1998; Shin, 2017), Singapore in electronics (Hobday, 1995), Taiwan in cameras (Kang & Song, 2017), and Hong Kong in steel and nuclear power (Lee & Ki, 2017; Sung & Hong, 1999). These sectors witnessed significant

developments thanks to strong institutional support, technological advancements, market preference changes.

Since the 1990s, the emerging economies have been playing more and more important roles on the global arena (Akbari et al., 2020; Buckley & Hashai, 2014; Fu et al., 2011; Lamin & Livanis, 2013). For example, the BRICS, which is an acronym for five newly advanced economies: Brazil, Russia, India, China and South Africa. These countries, with considerable economic potential, are largest entity on the global landscape in terms of the land coverage, population and the combined DGP (Jütten, 2024). Among the BRICS, China has achieved significant movements in catching up with world-leading industries as a fast-moving emerging economy. This is demonstrated in many sectors, such as automotive, mobile phones, high-speed trains, etc. (Jin & von Zedtwitz, 2008; Gao et al., 2014; Nam, 2015; Rui & Bruyaka, 2021; Mei & Zhang, 2022). To be more specific, the Chinese automotive industry has evolved from a latecomer to a forerunner with the considerably developed production and innovation capabilities (Gao, 2014). The Chinese mobile phone industry has seen its rapid technological advancements and global market penetration with the foreign leaders' falling behind (Jin & von Zedtwitz, 2008). The Chinese high-speed railway system has become one of the most advanced with the largest network in the world as a result of its successful technological catching up (Mei & Zhang, 2022). Figures 0.1, 0.2, and 0.3 show examples of some Chinese industries development progresses.

Figure 0.1 illustrates the percentage of the population in China covered by different mobile network capabilities over time, including 2G, 3G, 4G, and 5G networks. It shows a significant expansion in mobile network coverage, particularly with the introduction and rapid growth of 4G starting around 2013, which reached nearly complete coverage in subsequent years.

Figure 0.1 Mobile network coverage by population growth in China ¹

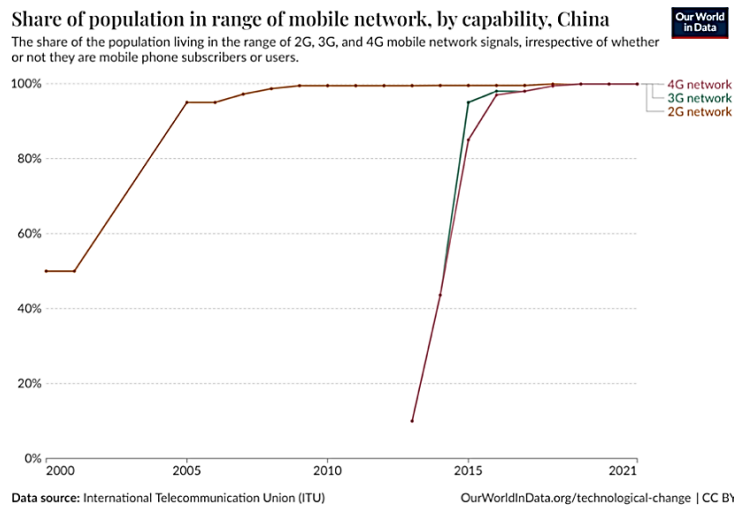


Figure 0.2 highlights the length of high-speed rail tracks in operation by country as of 2020. China leads by a substantial margin, boasting over 35,000 miles of high-speed rail track, significantly surpassing other countries. Spain, Japan, and France follow, each with approximately 2,000 to 3,000 miles of track. This comparison shows China’s massive investment in high-speed rail infrastructure, aiming to enhance connectivity across its vast territory, reduce travel times, and promote economic growth.

Figure 0.2 Length-Based Ranking of High-Speed Rail Networks ²

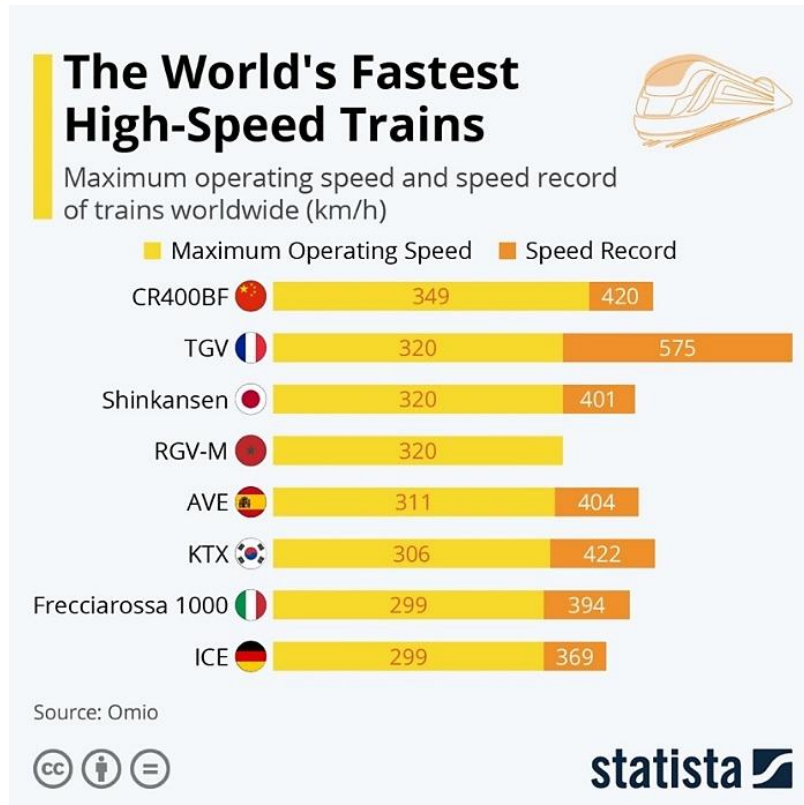


¹ <https://ourworldindata.org/grapher/population-covered-by-mobile-network-by-network-capability?tab=chart&country=~CHN>

² <https://www.statista.com/chart/17093/miles-of-high-speed-rail-track-in-operation-by-country/>

Figure 0.3 shows the world's fastest high-speed trains based on their maximum operating speeds. China's CR400BF tops the list with a record-breaking operating speed of 349 km/h, followed by France's TGV.

Figure 0.3 Speed-Based Ranking of High-Speed Rail Networks ³



b. From phenomenon to research

The catching up phenomenon involves the latecomer and forerunner countries or firms where there is a gap between these two parts, in terms of technology, production capabilities, and market presence (Cechura et al., 2017; Dai et al., 2021; Hain et al., 2020; Liu et al., 2023; Quitzow et al., 2017). The gap is then closed or narrowed down by the latecomer's fast development. This process is particularly common in the context of newly industrialized countries and emerging economies (Xu et al., 2018). To understand this phenomenon in a better manner, scholars in the management discipline have studied the catching up strategy at three levels, namely: macro national level, meso industrial level, and micro firm level.

³ <https://www.statista.com/chart/10792/the-worlds-fastest-high-speed-trains/>

At the macro national level, the focus is on how entire countries can catch up with more developed nations. Pioneering works by Abramovitz (1986) and Gerschenkron (1962) established the foundation for our understanding in how the economic and institutional factors facilitate national catching up. Gerschenkron (1962) highlights the role of governmental intervention and industrial policies in creating a climate to facilitate the catching up, while Abramovitz (1986) points out the importance of countries' social capabilities in absorbing advanced technologies. Following studies by the iconic catching up strategy scholars like Freeman (2002), Lee (2005), Malerba & Nelson (2011) expand on these ideas. They examine how innovation systems, knowledge diffusion, and learning mechanisms contribute to the catching up at macro national level. Freeman's (2002) pioneering work emphasized the role of national innovation systems in fostering economic growth and technological advancement. He argued that a country's ability to catch up economically depends significantly on its capacity to develop and sustain robust innovation systems. These systems encompass a wide range of factors, including government policies, institutional frameworks, and the interactions between various actors such as universities, research institutions, and industries. Building on Freeman's (2002) insights, Lee (2005) further explores the mechanisms of knowledge diffusion and their critical role in the catching-up process. He highlights how latecomer countries could leverage existing global knowledge and technologies to accelerate their development. He points out that effective knowledge diffusion requires not only the absorption of foreign technologies but also the adaptation and improvement of these technologies to suit local conditions. This process involves learning through various channels, such as foreign direct investment, licensing agreements, and international collaborations. Malerba & Nelson (2011) add another layer of complexity by examining the learning mechanisms that underpin the catching up process. They investigate how firms in latecomer countries can develop dynamic capabilities through continuous learning and innovation. According to their studies, the

catching up process is not linear but rather involves iterative cycles of learning, experimentation, and feedback. Additionally, Furman & Hayes (2005) and Fagerberg & Srholec (2005) further provide empirical evidence linking innovation capacity and economic growth which reinforce the critical role of national policies and institutions in fostering technological advancement and economic growth at macro level. Furman & Hayes (2005) find that factors like investment in R&D, robust intellectual property protections, and well-developed educational systems contribute to a more dynamic and innovative economy, capable of producing high-value products and services. Similarly, Fagerberg & Srholec (2005) expand on this idea and show that countries with effective governance structures, transparent regulatory environments, and strong institutional support are better positioned to foster innovation and, consequently, achieve economic growth.

At the meso industrial level, researchers have focused on how specific industries and local areas, such as clusters and regions, in various countries can achieve catching up. This includes examining the role of territorial development and the industrial districts, which emphasises the significance of localised economic activities and interactions in fostering innovation and growth, such as a specialised labour market, knowledges spillovers, suppliers and serviced providers, and social factors (Marshall, 1890/2013; Becattini, 2017). The established studies have been discussing this matter from multiple perspectives and provide various interpretation of the catching up mechanism. Some studies highlight the importance of industry clusters and networks on enhancing learning and innovation. Notably, Porter (1998) building on the foundations laid by Marshall (1890/2013), introduces the concept of business cluster and argues how these cluster provide a conducive environment for knowledge spillovers, access to specialized skills and suppliers, and intense local competition, all of which drive innovation. These cluster dynamics are crucial for latecomer aiming to close the gap with more advanced counterparts (Delgado et al., 2014; Henn & Bathelt, 2018; Jia, Li et al., 2017;

Lorenzen & Mudambi, 2013). Government policies is also a critical factor at meso level of catching up (Figueiredo & Cohen, 2019; Kwak & Yoon, 2020; Ortolano & Wang, 2013). In addition, latecomers' participations in the global value chain bring opportunities for the access to advanced technologies which facilitate emerging market firms to catch up (Giuliani et al., 2005; Zhang & Gallagher, 2016). For example, China's mobile phone industry and renewable energy industry benefit from the government support and global collaboration to catch up (e.g. Jin & von Zedtwitz, 2008; Binz et al., 2017). In the mobile phone sector, Chinese companies have integrated into global supply chains by partnering with leading multinational corporations for components, technology, and expertise. Support from the government has further bolstered this growth, providing subsidies, grants for research and development, and infrastructure investments. These together allowed Chinese firms to enhance their product quality and innovate more rapidly (Gao, 2014; Li et al., 2019). Similarly, in the renewable energy sector, Chinese firms have actively engaged with global value chains by collaborating with international companies and research institutions (Wu & Mathews, 2012). Government support has been pivotal here as well, with subsidies for renewable energy projects, feed-in tariffs to encourage production, and significant investments in green technology research (Quitow et al., 2017; Zhou et al., 2020). By participating in global value chains, Chinese companies have not only improved their technological capabilities but also positioned China as a fast-developing player in both the global market.

At the micro firm level, research focuses on how individual firms within countries and industries can catch up with leading firms. Scholars like Kim (1998) and Xie & Wu (2003) studied the role of firm-level innovation and learning processes in achieving technological advancement. Buckley & Hashai (2014) and Iacovone & Crespi (2010) examined how firms leverage global networks and strategic alliances to enhance their technological capabilities. Some other studies provide insights into the strategies that firms in emerging markets use to

compete with global leaders, such as investing in research and development (R&D) and acquiring foreign technologies (Gao, 2014; McDermott & Corredoira, 2010). There are also studies analyse the importance of managerial capabilities and organizational learning in firm-level catching up (Jonsson & Vahlne, 2023; Xiong & Monin, 2015). Strong and centralised managerial practices empowered the Samsung Electronics, as managers who possess strong leadership skills, market knowledge, and the ability to adapt to changing environments, to close the gap with leading counterpart, Sony which suffered from its fading management (Joo & Lee, 2010). In addition, a culture of continuous learning within the organization enables firms to respond more effectively to external challenges and opportunities, facilitating technological and market advancements (Kiamehr et al., 2015). The impact of government support and institutional environments on firm innovation and competitiveness is also explored and discussed (Zhu et al., 2011). Government aid for R&D activities significantly enhanced innovation performances of Turkish and Polish firms (Szczygielski et al., 2017). Government's intervention promotes the catching up with an indigenous innovation approach for complex technology by providing targeted support and creating a conducive environment (Gao, 2015).

By examining catching up strategies at these three levels, scholars have developed a comprehensive understanding of the mechanisms and factors that enable latecomer countries and firms to close the gap with more advanced counterparts. Among these studies, most of the attentions have been given to technological catching up, whose main focuses are often R&D investments (Miao et al., 2021), technology transfer and acquisition (Fu et al., 2011), absorptive capability (Howell, 2019), innovation systems (Jung & Lee, 2010), and government policies (Corrocher et al., 2021), etc. On the other hand, non-technological catching up strategies lies on the foundations of managerial and organisational improvements, such as process optimisation (Zhang et al., 2017), marketing (Chu, 2009), supply chain coordination (Xiong & Monin, 2015), and human resource developments (Yaya et al., 2019), etc. The

effectiveness of technological and non-technological catching up strategies can be context-specific (Dosi, 1982). In some industries, technological innovation may be the primary driver of catching up, such as semi-conductor manufacturing (Rasiah et al., 2012), while in others, process improvements or marketing strategies may be more critical, such as wine industry (Morrison & Rabellotti, 2017).

Technological catching up involves not only adopting existing technologies but also innovating and creating new ones to leapfrog traditional development stages. Latecomers can catch up by acquiring advanced technologies from forerunners through licensing agreements, joint ventures, or mergers and acquisitions (Jonsson & Vahlne, 2023; Khan & Nicholson, 2015; Kumaraswamy et al., 2012; Tsang, 2002). Latecomers' productivity and efficiency can benefit from learning by doing, which involves reverse engineering, adapting technologies to local conditions, and incremental improvements (Miao et al., 2021; Zhang & Zhou, 2016). Latecomers can also forge ahead by developing new technologies that bypass traditional industrial development stages (Yu et al., 2022). The Japanese and Korean camera industries have made significant catching up with and even surpassing their Western counterparts by focusing on the development of new technologies, Single-Lens Reflex and Mirrorless camera mechanisms respectively (Kang & Song, 2017).

Windows of opportunity (WOPs) play a crucial role in the catching up context. These windows are periods during which external conditions are favourable for significant advancements by latecomer firms (Perez & Soete, 1988). They can arise from technological shifts, policy changes, or shifts in market demand (Lee & Malerba, 2017). By effectively leveraging these windows, latecomer firms can overcome initial disadvantages and achieve rapid progress (Hansen & Hansen, 2021; Lee et al., 2005; Qiu et al., 2013; Vértessy, 2017). Understanding how WOPs function and how firms can strategically utilize them is critical for grasping the dynamics of industrial and technological catching up.

c. Empirical setting

China, as one of the world's leading manufacturing countries, has made significant strides in catching up with international standards in several industries, including automotive, electronics, and high-speed rail (e.g. Ho et al., 2017; Jin & von Zedtwitz, 2008; Liu et al., 2011; Mei & Zhang, 2022; Nam, 2015; Quitzow et al., 2017). Despite this progress, China's past economic growth has heavily relied on labour-intensive production methods, inefficient resource utilisation, and market expansion (Choi et al., 2020). These approaches, while effective in the short term, have raised concerns about sustainability and long-term economic stability.

To address these challenges, China is increasingly focusing on innovation and green development (Zhou et al., 2020). This shift reflects a strategic move towards more sustainable practices and the exploration of new opportunities that can drive future growth. For instance, the Chinese government has implemented various policies to promote the development of new energy vehicles and renewable energy sources, aiming to reduce environmental pollution and improve energy efficiency (Binz et al., 2017; Li et al., 2020; Quitzow et al., 2017).

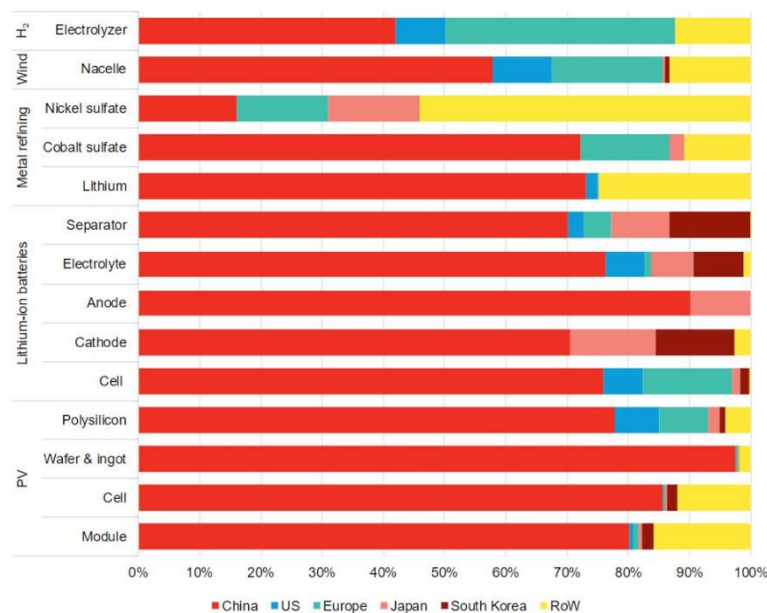
Industrial upgrading in China is now viewed as a continuous process driven by the accumulation of technology and knowledge (Guo & Zheng, 2019; Hu et al., 2022). This process requires concerted efforts across various industries to enhance efficiency and quality, thereby avoiding the "middle-income trap" where countries stagnate after reaching a certain income level (Liu et al., 2017). The middle-income trap occurs when countries fail to transition from resource-driven growth based on low-cost labour and capital to growth based on high productivity and innovation (Aiyar et al., 2013; Lee, 2013).

Efforts to foster innovation and green development are evident in several initiatives. For example, the Made in China 2025 strategy aims to upgrade China's manufacturing

capabilities, emphasising high-tech industries, innovation-driven development, and sustainable practices (Li, 2018; Liu et al., 2022; Zhang et al., 2020). This strategy includes substantial investments in R&D, the promotion of advanced manufacturing technologies, and the establishment of innovation centres to support industrial transformation.

Furthermore, China’s focus on green development is reflected in its commitment to international environmental agreements and the implementation of strict environmental regulations (Boisot & Meyer, 2008; Boussemart, 2015; Wang & Li, 2014). The government has set targets for reducing carbon emissions and increasing the share of renewable energy in the energy mix (Baeumler et al., 2012). Accordingly, a wide array of policies is initiated, such as curbing high-emission projects, boosting renewable energy production, and leading global manufacturing in renewable energy technologies⁴. These efforts are part of a broader strategy to transition to a more sustainable and resilient development model (Landini et al., 2020; Prud’homme, 2017).

Figure 0.4 Clean energy manufacturing capacity by location



Source: BloombergNEF. Note: By factory location. PV, hydrogen and battery components expressed in MW, MWh, m² or tons. Nickel is the class 1 variety, and lithium is in lithium carbonate equivalent. H₂ is hydrogen. Data as of October 2022, except electrolyzers which refer to a 2021 and nacelle data which are for 2020.

⁴https://english.www.gov.cn/news/202312/06/content_WS656fac3ac6d0868f4e8e1eb1.html

As Figure 0.4 indicates, China contributes for 40–80% of the global production of five key clean energy technologies: batteries, electrolyzers, heat pumps, solar photovoltaic, and wind turbines⁵. Contemporary Amperex Technology Co., Limited (CATL), the leading EV battery manufacturer worldwide, holds a dominant position in the global EV battery market with a 36.8% share as of 2023, followed by another Chinese company, BYD, which has a 15.8% share, making it the second-largest EV battery manufacturer⁶.

d. Research structure

Despite significant advancements in understanding how emerging economies like China achieve industrial and technological catching up, several gaps remain in the literature. The overarching research gap is the limited understanding of the dynamic interactions between various types of WOPs - technological, institutional, and market - and their role in facilitating catching up and sustainable development. This general research gap can be further developed into three specific research gaps, each addressed by one of the three articles under discussion.

The state of the art regarding WOPs involves a combination of strategic planning and adaptive management, with a growing reliance on technological and managerial approaches to enhance decision-making in time-sensitive contexts (Vértesy, 2017). The ongoing technological transformation across industries is a major source of WOPs (Dai et al., 2021; Lee et al., 2005). Companies that successfully navigate this transformation can enhance operational efficiency, customer engagement, and innovation capability (Zhou et al., 2020). Institutional frameworks and regulations play a significant role in opening or closing WOPs (Yap & Truffer, 2019). Changes in legislation, such as new environmental regulations or tax incentives, can create opportunities for businesses to innovate or enter new markets (Kwak & Yoon, 2020).

⁵ <https://about.bnef.com/blog/localizing-clean-energy-value-chainswill-come-at-a-cost/>

⁶ <https://cnevpost.com/2024/02/07/global-ev-battery-market-share-in-2023/>

Market conditions, such as changes in consumer demand, competitive actions, or economic cycles, create WOPs (Guo et al., 2019). Companies that can accurately gauge market sentiment and predict shifts in demand can exploit these windows to introduce new products, expand into new regions, or adjust pricing strategies (Lee & Malerba, 2017).

While existing research has explored the concept of WOPs individually, there is a lack of comprehensive frameworks that examine how technological, institutional, and market WOPs interact dynamically to support technological catching up. This gap is particularly critical for understanding how latecomer economies like China can leverage these opportunities to achieve sustainable and inclusive growth (e.g. Bell & Figueiredo, 2012; Lee & Malerba, 2017; Lema et al., 2020). Therefore, this thesis aims at answering the main research question of **“How do windows of opportunity influence the process of technological catching up?”**

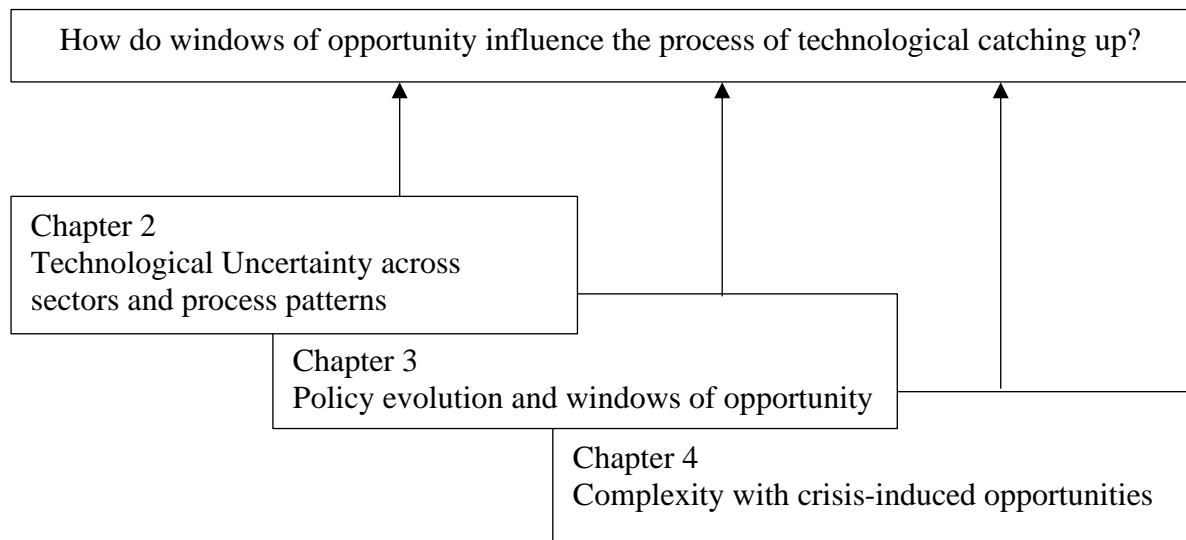
To answer this general question, we break down the research gap from three perspectives. In the first empirical study, Chapter 2, we identify the research gap of inadequate analysis of technological uncertainty in catching up processes. While previous studies have examined the role of technological advancements in catching up, there is limited research on how varying levels of technological uncertainty affect different sectors. The specific dynamics of technological uncertainty and its impact on the catching up processes across various industries remain underexplored. This study addresses this gap by comparing how different levels of technological uncertainty influenced catching up patterns across the general equipment, pharmaceuticals, home appliances, and electronic devices sectors. It applies process theory to explain the observed catching up cycles in these sectors, providing a clearer understanding of the challenges and opportunities presented by technological uncertainty. However, the study identifies the need for a detailed analysis of policy evolution and the interaction of multiple WOP types, which remains a significant limitation.

Existing research often overlooks the detailed mechanisms through which government policies evolve and create WOPs for industrial catching up. There is a significant gap in understanding how these policies can systematically generate opportunities that enable latecomer industries to catch up with global leaders. Chapter 3 fills this gap by analysing how government policies have evolved to create technological and market WOPs in the Chinese electric vehicle (EV) industry. It provides a detailed examination of how these policies interact with technological advancements and market demands to facilitate the catching up process. Despite this, the study notes the necessity of understanding how exogenous shocks and crises might create WOPs differently, highlighting a considerable area for further research.

The impact of exogenous shocks, such as the COVID-19 pandemic, on the creation and utilisation of WOPs has not been thoroughly explored. Current literature lacks a comprehensive analysis of how such shocks can suddenly open new windows for technological and industrial advancements. Chapter 4 addresses this gap by investigating how the COVID-19 pandemic created unique WOPs that accelerated digital transformation across various industries. It introduces the concept of relative WOPs, emphasising the uneven distribution of opportunities among firms and regions. Nonetheless, the study identifies remaining gaps and areas for further exploration regarding the impact of exogenous shocks on WOPs creation, suggesting a need for continued research in this domain.

By addressing these specific research gaps, the three chapter-articles collectively contribute to a deeper understanding of how different types of WOPs interact and support technological catching up in emerging economies like China. Figure 0.5 is a synthetic graph showing how the three articles address different specific research gaps which are Technological Uncertainty, Policy Evolution, and Exogenous Shocks, which aims at answering the general research question.

Figure 0.5 Narrative Progression of Three Papers (Chapters 2,3, and 4)



e. Theoretical contributions

This thesis makes significant theoretical contributions to the understanding of technological catching up in emerging economies by synthesizing insights from three key studies. The main contributions are centred on the dynamic interactions of WOPs and their role in facilitating the catching up process in China. Examining technological, institutional, and market WOPs collectively rather than in isolation, this thesis develops a comprehensive framework that captures the complex and dynamic interactions between these different types of opportunities. This approach addresses the overarching research gap and provides a more holistic understanding of how latecomer firms and economies can leverage multiple WOPs simultaneously to achieve catching up.

By applying process theory (Kouamé & Langley, 2018; Van de Ven, 1992), Chapter 2 provides a framework to understand the cyclical nature of catching up processes. It explains how firms navigate periods of high uncertainty by leveraging WOPs and adapting their strategies dynamically. This theoretical contribution helps to elucidate the iterative and non-linear pathways that firms often follow in their catching up journeys (Yaya et al., 2019). The synthesis of findings from this study also highlights how different levels of technological

uncertainty impact catching up processes differently across sectors. This contribution enriches the literature by showing that sector-specific factors must be considered when designing policies and strategies for catching up (McDermott & Corredoira, 2010; Tzeng et al., 2022; Xu et al., 2018). This perspective diverges from more generic views by emphasizing the unique challenges and opportunities each sector faces. It is critical for understanding the continuous adjustments and learning processes that firms undergo, complementing the evolutionary economic approaches suggested by (Hansen & Lema, 2019).

Chapter 3's analysis of policy evolution in the Chinese electric vehicle industry provides valuable insights into the mechanisms through which government policies can create and sustain WOPs. This theoretical contribution emphasizes the role of proactive and adaptive policymaking in facilitating technological advancements and market competitiveness in emerging economies (Ahn, 2017; Goedhuys & Srholec, 2015; Wei et al., 2020). This thesis adds a clearer understanding of policy evolution, complementing existing frameworks and highlighting areas where current policies may need adjustment. By studying how policies interact with technological advancements and market demands, this thesis presents the policy-driven dynamics of catching up. This challenges the static nature of some policy analyses, arguing for a more dynamic, responsive policy framework. This knowledge is important for policymakers aiming to foster sustainable industrial growth (Corrocher et al., 2021).

In Chapter 4, the exploration of how the COVID-19 pandemic created unique WOPs for digital transformation underscores the significant impact that exogenous shocks can have on accelerating catching up progress. This contribution expands the theoretical framework by incorporating the role of unexpected global events in shaping industrial trajectories (Dosi, 1982; Hobday, 1995; Mathews, 2002; Spanos & Voudouris, 2009). It also complements the works on crisis-induced innovation, providing a more structured analysis of these phenomena (Kim, 1998; Miao et al., 2021; Lim et al., 2009; Wan & Yiu, 2009). The discussion on the coined

concept of relative WOPs clarifies the characteristics of the COVID-19 pandemic-induced WOPs, which are chrono-relativeness, spatial relativeness, and inertia, as firms' abilities to recognize and seize these opportunities vary over time, across regions, and due to previous WOP influences. It significantly enriches the established conversation on WOPs (Dai et al., 2021; Hansen & Hansen, 2021; Lee & Malerba, 2017; Perez & Soete, 1988).

f. Implication values

The findings and theoretical contributions of this thesis have profound implications for both academic research and practical applications in policymaking and executive decision-making.

By providing a comprehensive framework that integrates technological, institutional, and market WOPs, this thesis advances the academic understanding of the multifaceted nature of industrial catching up (Hansen & Hansen, 2021; Kwak & Yoon, 2020; Lee & Malerba, 2017; Shin, 2017; Zhou et al., 2020). The sector-specific insights and analysis of policy mechanisms offer valuable directions for future research to explore the impacts of different types of WOPs across various industries and contexts. This research enriches the existing literature by challenging the one-size-fits-all strategy often implied in broader studies (Simpson et al., 2012). Our strategic focus should pivot from identifying benchmarks or best practices to developing dynamic capabilities and organizational agility (Teece et al., 2016).

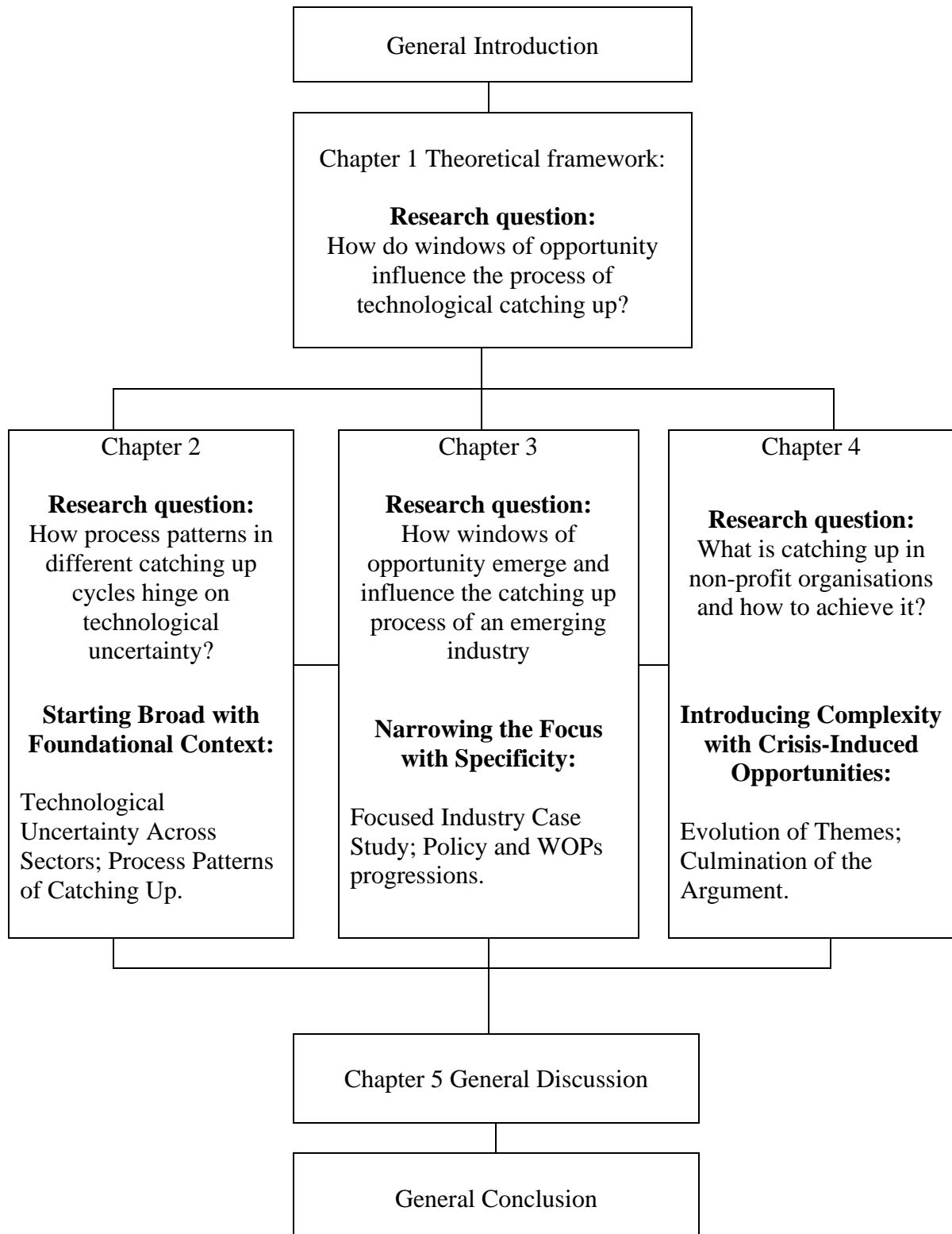
The insights into the mechanisms of policy impact and the role of exogenous shocks underscore the need for proactive and adaptive policymaking. Policymakers in emerging economies can use these findings to design more effective strategies that create and leverage WOPs to drive sustainable industrial growth.

The concept of relative WOPs highlights the importance of ensuring that the benefits and resources provided by these opportunities are accessible to a broad range of stakeholders.

Policymakers must consider inclusivity to ensure that the benefits of industrial catching up are broadly shared. Ensuring that all firms, regardless of size, location, or current level of technological capability, have fair access to the opportunities presented by WOPs. This prevents the concentration of benefits in already dominant firms or regions and promotes balanced industrial growth. Providing training, education, and capacity-building programs to enable all firms to take advantage of new technologies and market opportunities. This helps to level the playing field and ensures that all firms can compete effectively in the transformed industrial landscape.

This thesis also offers several key takeaways for executive decision-making. Managers should adopt a proactive approach to innovation by building dynamic capabilities within their organizations to quickly adapt to technological changes and leverage WOPs. Recognising the unique technological uncertainties and opportunities in different sectors, they should tailor strategies to address specific needs. Understanding and aligning with evolving government policies can help capitalize on policy-driven WOPs. Managers should focus on sustainable practices by incorporating green initiatives and investing in resource-efficient technologies. Enhancing organizational agility is crucial to respond effectively to exogenous shocks and maintain business continuity. Promoting equity and inclusivity ensures fair distribution of opportunities across regions and firms of various sizes, supported by capacity-building programs. Prioritizing digital transformation, especially post-crisis, can unlock unique WOPs for digital innovation. Staying cautious about market changes and adapting business models accordingly is essential to capture emerging opportunities and remain competitive. Figure 0.6 demonstrates the overall logical thread of the chapters in this thesis.

Figure 0.6 The global structure of the thesis



Chapter 1 Theoretical Framework

This chapter lays the theoretical foundation for understanding of catching up and windows of opportunity (WOPs). Despite significant advancements in the literature on catching up, several gaps remain, particularly regarding the technological uncertainty, the patterns of its process, dynamic interactions between different types of WOPs. This chapter aims to identify these gaps by presenting a comprehensive review of existing literature, establishing the epistemological foundation of the study, and outlining the methodological approach adopted for addressing the gaps.

The literature review, Section 1.1 provides a detailed review of the key concepts and established studies in the field of catching up, focusing on the antecedents, processes, and patterns at various analytical levels. It also reviews the concept of WOPs from three main categories, institutional, technological, and market-demand WOPs.

Section 1.2 outlines the epistemological foundation of the study, explaining the philosophical approach and theoretical perspective adopted. The study is grounded in an interpretivism epistemology, which emphasizes understanding the complex, dynamic, and context-specific nature of technological catching up.

Section 1.3 provides a brief overview of the methodological approach used in this thesis. It includes the overall research design, methods used to collect data, and the case study approach employed to analyze the data and derive findings.

1.1 Literature review

This section provides a detailed examination of the key concepts and theories centered on technological catching up. It is structured into several subsections, each focusing on a specific aspect of literature. Subsection 1.1.1. reviews the concept of catching up in general, describing how latecomers close the gap with forerunners in terms of industrial and

technological capabilities. It discusses historical examples and theoretical perspectives on the mechanisms and strategies that enable catching up. Subsections 1.1.2, 1.1.3, and 1.1.4 focus on the studies of technological catching up. And respectively, these subsections review the antecedents, processes and patterns of technological catching up, at different analytical levels: national macro level, industrial/cluster meso level, and firm micro level. Subsection 1.1.5 reviews the concept of WOPs from three categories.

1.1.1 Catching up

A catching up phenomenon involves three key elements: the forerunner, the latecomer, and the interval between them. The latecomer strives to reduce this interval in order to catch up with the forerunner. This interval is typically gauged by the disparities in income, productivity, and technology between the two entities (Lee, 2013). Among these factors, technological advancement is often considered the most crucial, as technological catching up usually precedes improvements in income, productivity, and market performance (Lee & Lim, 2001). Successful convergence and potential surpassing of the forerunner by the latecomer are the outcomes of effective catching up (Abramovitz, 1986).

1.1.1.1 Research levels

The literature on catching up sheds the spotlight on the importance of building technological capabilities, such as the ability of firms to generate and manage technological change, and the ability to understand, assimilate, and improve upon existing technologies, as well as to create new technologies (Hobday, 1995; Kim, 1997). In this thesis, the technological capability is an inclusive concept which considers all the skills, knowledge, learning processes, and abilities that enable a firm, industry, or country to generate, manage, and utilize technological change for innovation and production. Besides that, the institutional environment of an economy is also recognized as a decisive factor (Bernardes & Albuquerque, 2003;

Mazzoleni & Nelson, 2007). National innovation capability is shaped by a collection of interrelated factors, including fundamental infrastructure, industrial dynamics, and the relationship between them, which has a determinant of economic performance (Hu & Mathews, 2008). Furthermore, investments in R&D are crucial for sustaining technological advantages (Hu & Mathews, 2005). The institutional environment, coupled with the technological regime, elucidates how firms in latecomer countries catch up in certain industries, considering factors such as technological trajectory, knowledge accessibility, and discontinuity (Landini et al., 2017; Lee & Lim, 2001; Mu & Lee, 2005; Park & Lee, 2006).

At macro level, institutions have played a pivotal role in fostering the growth of East Asian economies (Han et al., 2004; Hobday, 1995; Kozlova & Noguera-Santaella, 2019; Miao et al., 2021). The rapid advancements seen in countries like South Korea can be attributed to strong governmental institutions, strategic policy interventions, and effective governance structures, which collectively created an environment conducive to economic growth and technological innovation. Various social dimensions, including knowledge, openness, finance, governance, and democracy, are deemed critical for economic catching up (Akbari et al., 2020; Fagerberg & Srholec, 2005; Malerba & Lee, 2021; Shenkoya & Kim, 2020; Yaya et al., 2019; Yu et al., 2023)

. These dimensions contribute to creating a fertile ground for innovation and competitive business practices, thereby facilitating the catching-up process. When considering catching up from a market share perspective, both external and internal factors play significant roles. External factors such as governmental policies, market conditions, and international trade agreements can create opportunities or pose challenges for firms trying to catch up (Duysters et al., 2009; Gao, 2014; Kim & Lee, 2008; Li & Valentini, 2023; Mu & Lee, 2005; Xiong & Monin, 2015; Xu et al., 2023). For example, favourable government policies that support R&D and innovation can provide firms with the resources and incentives needed to enhance their

technological capabilities. Similarly, favourable market conditions, such as a growing demand for high-tech products, can spur firms to invest in advanced technologies and innovative practices.

At meso level, technological sophistication varies across industries, leading to industry-specific productivity gains through knowledge enhancement (Goedhuys et al., 2013). Hence, research has concentrated on the Sectoral Innovation System to understand the dynamics of catching up (Fagerberg & Srholec, 2005; Godinho & Ferreira, 2012; Intarakumnerd et al., 2002; Jung & Lee, 2010; Lee et al., 2009; Malerba, 2002; Martin & Johnston, 1999; Mei & Zhang, 2022). Emphasizing indigenous innovation alongside foreign technology introduction is vital for latecomers at the outset of catching up, with indigenous innovation gradually becoming the primary driving force (Fu et al., 2011; Wu & Mathews, 2012).

At micro level, latecomer companies' capability-building and catching up strategies have garnered attention (Joo & Lee, 2010; Kiamehr, 2017; Kim & Lee, 2008; Malerba & Nelson, 2011; Spanos & Voudouris, 2009). Capability-building is imperative for latecomer companies to enhance competitiveness and narrow the gap with frontrunners, focusing on areas such as manufacturing capability, absorptive capacity, and technology strategy (Spanos & Voudouris, 2009). The path dependence of technology development prompts latecomer companies to build technological capabilities through learning from frontrunners, initially through imitation. However, successful catching up entails a shift in leadership, with latecomers transitioning from mere imitators to emulators capable of developing their own capabilities (Duysters et al., 2009; Giuliani et al., 2005; Li & Kozhikode, 2008). Catching up strategies employed by Japanese and Korean companies aim to mitigate latecomer disadvantages by leveraging economies of scale, compressing time through technological leapfrogging, technology transfer, benchmarking, and resource leveraging, ultimately creating latecomer advantages (Cho et al., 1998).

1.1.1.2 Research Perspectives

Studies on the catching up phenomenon and its strategies consist of two branches: Strategy-as-Practice (SAP) and Strategy Process. These are two distinct but complementary perspectives in strategic management that have significant implications for how organizations formulate and implement their strategies (Floyd et al., 2011; Whittington, 2007).

SAP focuses on the day-to-day activities, practices, and routines through which strategy is enacted within organizations. It emphasizes the role of various actors in shaping strategy through their interactions and use of tools and methodologies. This approach is distinct in its focus on the micro level actions that collectively influence the broader strategic direction of an organization. It looks at how these activities are performed in real-time, emphasizing the practical work involved in strategy-making (Jarzabkowski et al., 2007). This approach also examines how their interactions, negotiations, and use of various tools contribute to the strategic outcomes (Whittington, 2006). From this perspective, the catching up is a set of actions taken by the latecomer to narrow down the gap vis-a-vis the forerunner via learning and absorbing advanced knowledge, knowledge base consolidation, capability building (Cho et al., 1998; Sung and Hong, 1999; Odagiri et al., 2010; Lee & Malerba, 2017; Dai et al., 2021).

Strategy Process research focuses on the sequence of steps or stages that organizations go through to develop and implement strategies. This perspective is concerned with the temporal flow of strategic activities, including formulation, execution, and evaluation. This branch looks at how strategies are formulated, executed, and evaluated over time (Burgelman, 1983). It investigates the process with a focus on progression and adaptation of strategies in response to changing environments and organizational contexts. (Langley, 2007).

Both approaches offer valuable insights into the complexities of strategic management within organizations. The existing catching up literature has predominantly focused on the SAP

perspective. However, there is relatively less emphasis on the Strategy Process perspective. This imbalance in the literature highlights a significant gap. While SAP provides a rich understanding of how strategy is practiced, it often overlooks the broader, structured processes that guide strategic management over time.

1.1.1.3 Research Emphasis

In this thesis, we focus on the technological catching up. Technological catching up is more technology-oriented, induced, or empowered, focusing on the direct enhancement of productivity through technology (Wong & Goh, 2015; Zhang & Zhou, 2016; Zhang et al., 2021). This includes the adoption of new technologies, investment in R&D, and building the necessary technological infrastructure (Binz et al., 2017; Dai et al., 2021; Li et al., 2020; Yap & Truffer, 2019). Non-technological catching up, on the other hand, is driven by market demand changes and managerial strategy shifts (Morrison & Rabellotti, 2017; Xiong & Monin, 2015). It involves improving performance through effective management and optimizing existing resources rather than direct technological innovation (Choi et al., 2020; Li & Kozhikode, 2008; Mathews, 2002).

So that, we adopt its definition as “*substantial improvement of technological capabilities by firms from technologically lagging countries in their process of closing the gap with incumbents in advanced countries, thereby approaching the global technological frontier*” (Miao et al., 2018, p.642). This definition highlights the progressive nature of catching up, emphasizing significant advancements in technological capabilities and the continuous effort required to bridge the gap with leading global counterparts.

In the following sections of the literature review, the catching up studies will be discussed from two branches of study, the antecedents from the SAP perspective and the

processes from the Strategy Process perspective, with specific attention to both non-technological and technological catching up.

1.1.2 Catching up antecedents

The interval that the latecomer aims to narrow can manifest as disparities in GDP, technology, and market share between them and the forerunner. Evaluations of latecomer companies' catching-up efforts typically revolve around their technological capabilities and market shares (Lee & Lim, 2001). In the pursuit of achieving technological standard-setting capability and dominance in market share, various antecedents come into play, each carrying different levels of priority and significance. Consequently, this thesis approaches the review of catching up antecedents by distinguishing between technological and non-technological catching up.

1.1.2.1 Macro level

At the macro level, the ability to learn is a crucial determinant of technological catching up. Learning by imitation, which depends heavily on the level of human capital per capita, is a foundational concept introduced by Gerschenkron (1962). This idea is supported by Fagerberg & Godinho (2005), who emphasize that nations with higher levels of education and training are better positioned to adopt and adapt existing technologies. More recently, Pan & Maslyuk-Escobedo (2019) have reaffirmed that human capital remains a critical driver of technological advancement in developing countries. Catching up at the national level also relies on multiple factors, including technological progress, independent innovation, market mechanisms, and institutional policies. Fagerberg & Godinho (2005) argue that a holistic approach that integrates these elements is necessary for sustained development. Lee (2005) expands on this by suggesting that strategic government interventions and policies tailored to specific technological needs can accelerate catching up. Khan & Nicholson (2015) further illustrate

how adopting a comprehensive development strategy can help latecomer nations bridge the technological gap with advanced economies. Technological outputs (such as patents and innovations) and inputs (such as R&D investments) both influence the development trajectory and learning ability of a nation. Ahn (2017) and Majidpour (2017) highlight that countries investing heavily in R&D are more likely to develop the capacity to catch up technologically. Shin (2017) notes that South Korea's focus on technological education and innovation has been pivotal in its catching up process, while Corrocher et al. (2021) emphasize the role of consistent policy support in maintaining this trajectory. The market base, technological progress, policy regulation, and innovation systems collectively shape the environment for technological catching up. Odagiri et al. (2010) discuss how market structures and competitive pressures can drive innovation, while Furman & Hayes (2005) highlight the role of supportive policy frameworks in fostering a conducive environment for technological advancements. Gao (2015) points out that a robust innovation system, characterized by strong linkages between universities, industries, and government, is crucial for sustained technological progress. Furthermore, the development of localized value chains, knowledge spillovers, and agglomeration effects significantly contribute to technological innovation and catching up. Park & Lee (2006) illustrate that regional clusters can enhance innovation through localized knowledge exchanges and collaboration. Ghazinoory et al. (2017) emphasize that creating strong regional innovation systems can help countries leverage local strengths and capabilities for technological advancement.

1.1.2.2 Meso level

At meso level, both internal and external environments significantly influence technological catching up. Factors such as technology trajectories, innovation capabilities, market structures, policy regulations, and timing play critical roles. Lee & Lim (2001) suggest that industries must adapt their strategies based on technological trajectories and market

conditions. Mu & Lee (2005) argue that innovation capabilities, supported by appropriate policy measures, are essential for industries to catch up. Rasiah et al. (2012) also highlight how market structure and competitive dynamics impact the catching-up process. The capabilities for learning and absorption are vital for industries aiming to achieve technological catching up. Kim & Lee (2008) emphasize that industries with strong learning capabilities can better assimilate and utilize advanced technologies. Kiamehr et al. (2015) provide evidence that industries investing in absorptive capacity are more likely to succeed in technological catching up. Scale effects and innovation significantly impact technological catching up at the industry level. Wu & Zhang (2010) illustrate that larger firms with substantial resources can leverage scale effects to innovate and improve their technological capabilities. Goedhuys et al. (2013) argue that innovation, driven by scale economies, is a critical factor for industries to enhance their competitiveness and catch up technologically. The performance of catching up is influenced by both technological and market factors. Xie & Wu (2003) and Joo & Lee (2010) highlight that industries must navigate both technological advancements and market dynamics to achieve catching up. Moreover, a balanced approach, considering both technological innovations and market strategies, is essential for successful catching up (Cavallaro & Mulino, 2008). Policy and market factors favour domestic clusters in low-tech industries to catch up with foreign clusters in the host country. Local clusters can leverage policy support and market opportunities to improve their technological capabilities and compete with foreign counterparts (Jia et al., 2017; Lorenzen & Mudambi, 2013).

1.1.2.3 Micro level

At the micro level, defensive strategies are important when technological catching up is achieved through different stages. Kim & Park (2019) emphasize the importance of policies in providing a supportive environment for firms to innovate and grow. Beyond the external factors, the internal factors are also very important for firms. Kim (1998) suggests that firms

must adopt defensive strategies to protect their technological advancements and sustain their competitive edge. Firms must strategically manage both technological innovations and market conditions to achieve successful catching up (Chandy & Tellis, 2000; Guo & Zheng, 2023; Normann & Hanson, 2018; Tidd & Bessant, 2020; Wu et al., 2014). Studies highlight that firms with strong knowledge bases, effective organizational structures, and entrepreneurial capabilities are better positioned to catch up technologically (Baden-Fuller, 1995; Göksidan et al., 2018; Mu & Lee, 2005; Ray et al., 2004; Yu et al., 2020).

Research on catching-up antecedents spans various levels of analysis. At the macro level, emphasis is placed on external environmental factors and their impact on catching up. These factors include political dynamics, technological advancements, economic conditions, institutional frameworks, and market dynamics. Conversely, at the micro level, greater attention is given to internal factors that influence catching up. These internal determinants encompass aspects such as organizational structure, organizational learning processes, strategic decision-making and implementation, and leadership dynamics within firms.

1.1.3 Catching up processes

Unlike the theoretical definition of SAP, Strategy Process focuses on understanding the reasons and mechanisms behind strategic management changes, including the evolution of formulation and implementation over time (Van de Ven, 1992). As a result, Strategy Process studies aim to address questions related to “how” and “why” strategic decisions are made and executed.

The catching up process is intricate, often requiring the complementary development of capabilities, skills, and institutions (Sharp, 1998). Unlike a linear technological progression, in which the latecomer simply races to catch up with the frontrunner, real-world catching up involves strategies such as skipping stages or forging entirely new paths to leapfrog outdated

technologies and bypass capital-intensive system development (Hobday, 1995; Perez & Soete, 1988). Examining technological capabilities, Lee & Lim (2001) outline three patterns of technological catching up observed across six Korean industries' technological evolution: path-creating, path-skipping, and path-following, with the former two recognized as forms of leapfrogging. Path-creating catching up, driven by a paradigm shift in technology, represents both a window of opportunity for the latecomer and a challenge for the frontrunner (Lee et al., 2005; Wu & Zhang, 2010). Regardless of the approach adopted by the latecomer, catching up entails a process of accumulating knowledge and developing technology, with the adoption of advanced technology progressing incrementally and piecemeal (Spanos & Voudouris, 2009). For path-creating catching up, the deviation from established technological trajectories begins in the early stages of capability building, and its development along the newly created path exhibits high volatility (Figueiredo, 2010).

1.1.3.1 Macro level

The process of technological catching up at the macro level is primarily driven by the upgrading of technological capabilities, which hinges on a country's ability to learn and improve. The importance of this learning process in facilitating technological advancements (Choi et al., 2020; Lee, 2005). However, merely introducing and imitating technology does not suffice for achieving independent innovation. While imitation can initiate the catching up process, countries must develop their own innovative capabilities to sustain progress (Duysters et al., 2009; Giuliani et al., 2016; Li & Kozhikode, 2008). Catching up is typically achieved in stages, often progressing from Original Equipment Manufacturing (OEM) to Original Design Manufacturing (ODM) and eventually to Original Brand Manufacturing (OBM). Hobday (1995), Kim (1997), and Sharp (1998) detail this staged process, noting that the timeline of development plays a crucial role. Malerba & Nelson (2011) and Giuliani et al. (2016) further emphasize the importance of time and stages in the catching up process.

1.1.3.2 Meso level

At the meso level, the catching up process is influenced by a combination of technological innovation, market orientation, and government support (Athreye & Godley, 2009; Cho et al., 1998; Fan, 2006; Kim, 1980; Kim & Lee, 2008; Mu & Lee, 2005; Park & Ji, 2020). The staged nature of catching up is also evident at the industry level, where cumulative learning and exclusivity play key roles in defining technological trajectories. Sung & Hong (1999), Lee & Lim (2001), and Mathews (2002) discuss the importance of these stages, while there are also studies further explore how industries progress through these stages and the importance of cumulative learning and the exclusivity of technological capabilities along these stages (Amsden & Chu, 2003; Garud et al., 2010; Guennif & Ramani, 2012; Jin & von Zedtwitz, 2008; Kumaraswamy et al., 2012; Lee & Malerba, 2017).

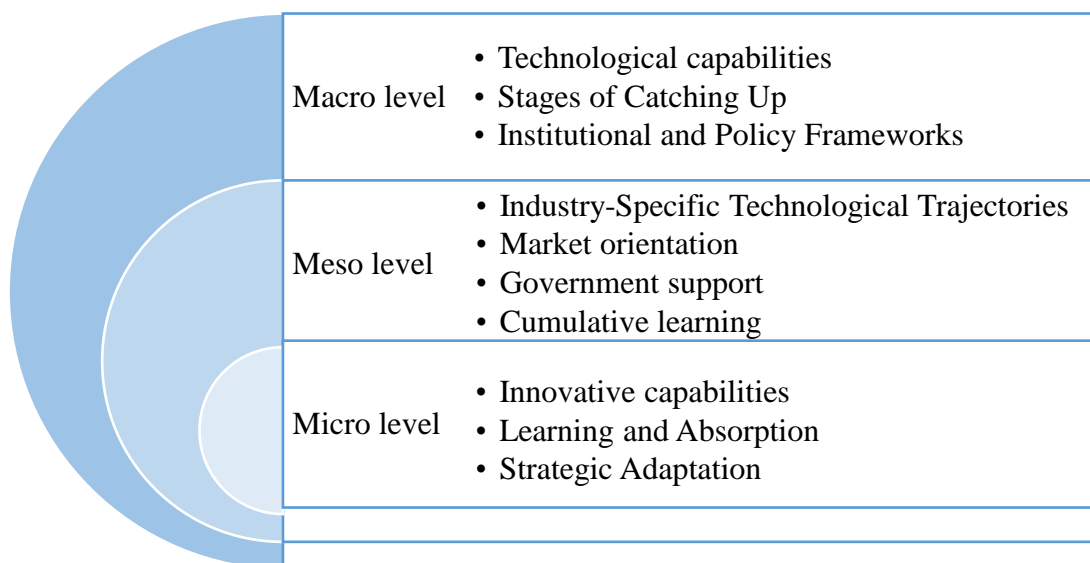
1.1.3.3 Micro level

Within firms, the process of technological catching up is shaped by the accumulation of innovative technological capabilities, learning, and absorption, as well as the development of innovation capabilities. The level and speed of these accumulations influence catching up (Bell & Figueiredo, 2012; Buckley & Hashai, 2014; Chandra & Dong, 2018; Figueiredo, 2010; Iacovone & Crespi, 2010; López-Pueyo & Mancebón, 2010). Market conditions and policies significantly impact the learning process and the establishment of technological standards (Kim, 1998; Malerba & Nelson, 2011; Nelson, 2007; Rasiah et al., 2012). Gao (2014) and Szczygielski et al. (2017) further elaborate on how market dynamics and policy frameworks shape the innovation process. Firms typically navigate different stages of catching up, requiring adaptive strategies at each stage. The established literature also mentions necessity of adopting defensive strategies once a firm has achieved a certain level of catching up to maintain its

competitive position (Choi, 2017; Choi et al., 2020; Kiamehr, 2017; Lee et al., 2017; Lee & Malerba, 2017; Xiao et al., 2013; Zhu et al., 2011).

Studies on the catching up process span across three levels of analysis: the nation, industry, and firm. At the national macro level, researchers often explore discontinuities, perceived as WOPs, which encompass changes in institutional frameworks, technological landscapes, and market demands. These investigations shed light on how nations leverage these shifts to propel their catching up efforts forward. At the firm micro level, scholars delve into the specific patterns and stages of catching up exhibited by individual companies. Here, the focus is on understanding the strategies employed by firms to narrow the gap with industry leaders and gain competitive advantage. Examining catching up at the industrial meso level provides an opportunity to synthesize findings from both macro and micro perspectives, offering a more comprehensive understanding of the catching up phenomenon. By analysing industry-wide dynamics, researchers can identify common trends, challenges, and success factors that shape the catching up process across a particular sector. Figure 1.1 shows different streams of literature mobilized in this thesis from different research levels.

Figure 1.1 Key Themes of Literature Streams on Catching Up Processes



1.1.4 Patterns in catching up process

Divergent typologies are integral to the segmentation of catching up process phases, highlighting the need to apply process theory to elucidate the general and specific characteristics of different phase paradigms. Moreover, it is imperative to consider the potential variables influencing the divergence of these paradigms.

Current research on catching up paths primarily follows the basic assumptions of the technology trajectory theory, which posits that technology development is a predictable, linear, and continuous process (e. g. Bojnec & Fertő, 2007; Mengis, 2021; Rasiah et al., 2012). For instance, Kim's (1980) study of the technology absorption process in the Korean electronics industry and Park & Lee's (2006) investigation of the relationship between the technology paradigm and technological catching up are based on this linear development trajectory assumption.

However, the assumptions of a linear and continuous catching up process should be reconsidered. First, the initial conditions of latecomer firms can vary significantly, and the external technological, market, and institutional environments for each latecomer might be different. Consequently, when latecomers implement catching up strategies to build capabilities and endogenize WOPs for leapfrogging, the outcomes may differ, resulting in success at various stages of catching up. Second, the strategy of latecomers in responding to WOPs does not always have to follow a technological trajectory. Depending on their initial conditions, latecomers can choose internal development, external sourcing, or a combination of both. Figueiredo's (2010) observations in Brazil support this view, arguing that firms' paths in accumulating innovative capabilities may deviate from the traditional technological trajectory.

From an industrial specificity perspective, non-technology-driven industries differ significantly from technology-driven ones. Their technological trajectory is less predictable, making them less suitable for the traditional assumptions of continuity and linearity (Cusmano et al., 2010; Galbreath, 2011; Galbreath et al., 2014; Galbreath et al., 2016; Giuliani et al., 2011; Xiong & Monin, 2015). Relaxing the assumption of continuity in technological catching up can make the theory more applicable to various contexts. However, this relaxation introduces new challenges, such as making the outcomes of technological catching up more difficult to predict. Therefore, further understanding of the catching up phenomenon can benefit from an interdisciplinary perspective, as suggested by Miao et al. (2018), which considers multiple levels of factors and explores the interaction mechanisms between them.

Research identifies several phases in the process of catching up, emphasizing the importance of transitioning through these phases. The existing studies highlight that the key to successful catching up lies in effectively crossing different phases (Figueiredo & Cohen, 2019; Giachetti & Marchi, 2017; Hobday, 1995; Iacovone & Crespi, 2010; Jin & von Zedtwitz, 2008; Kim, 1980; Lundvall & Rikap, 2022; Mathews, 2002; Park & Lee, 2006; Sung & Hong, 1999; Wu & Zhang, 2010; Xie & Wu, 2003; Zhang et al., 2023). Research also distinguishes between the early and late phases of catching up, noting the difficulties in transitioning into the late or mature phase (Binz et al., 2020). Plenty of scholars have explored the challenges associated with moving into these advanced phases in various contexts (Hobday, 1995; Landini et al., 2017, 2020; Seo et al., 2019; Wu et al., 2014). They argue that the strategies and dynamics of catching up differ between the early and late phases. Some further illustrate that catching up processes and outcomes vary significantly across these phases, reflecting the complex and non-linear nature of technological development (Figueiredo, 2010; Iacovone & Crespi, 2010; Miao et al., 2021).

1.1.5 Windows of opportunity

The concept of WOPs in technological catching up is grounded in the observation of technological discontinuities, as initially proposed by Perez & Soete (1988). These discontinuities, or the emergence of new technologies, can create significant WOPs at the macro level, enabling latecomer firms or countries to catch up with technological leaders. Established studies have explored how such technological shifts can form WOPs. For instance, Landini et al. (2017) analysed how the birth of emerging technologies can open WOPs, facilitating technological advancements and catching up. Mathews (2005) examined the crystal cycle and timing of entry into the TFT-LCD (flat panel display) industry, identifying four distinct business cycles between 1990 and 2003. His work highlights how entry timing within these cycles can represent critical WOPs for firms. Similarly, Lee & Malerba (2017) introduced the concept of the “demand window”, which refers to a new type of demand, a major shake-up in local demand, or a business cycle that creates WOPs for demand-driven innovation.

1.1.5.1 Institutional WOPs

Catching up is fundamentally a learning process, essential for firms’ capability development (Malerba & Nelson, 2011). Government interventions, through R&D programs and policies, play a key role in shaping this learning process and the accumulation of capabilities by domestic firms (Lee & Malerba, 2017). Governments can adopt a variety of policy instruments to achieve innovation goals, such as public procurement, R&D funding, and tax benefits for domestic firms (Xu et al., 2023). The role of government in providing R&D funding, developing laboratories, and fostering human capital is critical in the catching up process (Rasiah et al., 2010). Malerba & Nelson (2011) underlined the diverse policy tools governments use based on the sector and characteristics of the national innovation system. This includes developing human capital and leveraging state-owned enterprises. Gao (2015) provided a case study on the standardization of TD-SCDMA in China, illustrating how

government intervention can effectively guide technological development. Chu (2011) examined the Chinese automobile industry and found that industrial policies driven by a catching up consensus successfully promoted global competitiveness. These studies affirm the positive role played by governments in technological catching up.

1.1.5.2 Technological WOPs

Research on catching up originated by exploring technological catching up in technology-driven industries. Earlier studies focused on East Asian countries, emphasizing the importance of technological factors in catching up. Scholars have studied high-tech industries in South Korea and Taiwan, summarizing the catching up strategies of latecomers (Park & Lee, 2006). Other researchers examined the mechanisms of technological capability formation during the catching up process (Lee & Lim, 2001). Recent research has expanded to focus on how developing countries can catch up in traditionally developed technology-driven industries. Key antecedents include building learning and absorptive capabilities (Chuang, 2014; Fan, 2006), strengthening R&D efforts (Goedhuys & Srholec, 2015), implementing supportive policies (Chu, 2011), seizing WOPs (Lee & Malerba, 2017), and accumulating knowledge and capabilities (Kiamehr et al., 2014).

1.1.5.3 Market-demand WOPs

Relatively fewer studies have focused on market-related factors in the context of catching up. These can be divided into macro market environment studies and micro-market opportunity exploitation. The macro market environment influences catching up by providing a context within which latecomers operate. Market segmentation, for instance, can offer local firms with low initial capabilities a comparative advantage over multinational enterprises (Li et al., 2019). Lee (2005) highlighted the importance of a ‘trading market for technology’, which facilitates technological knowledge diffusion from foreign to local firms. Mu & Lee (2005)

found that the strategy of trading markets for technology, knowledge diffusion, and industrial promotion by the government are crucial for catching up. At the micro level, latecomers' efforts in exploiting existing opportunities embedded in the macro market environment are critical. Kumaraswamy et al. (2012) emphasized the importance of developing strong customer relationships and knowledge creation in integrating domestic industries with global value chains. In their study of Huawei, Guo et al. (2019) pointed out that Huawei's dual strategy of technology creation and market search continues to provide catching up opportunities. Wu & Zhang (2010) argued that matching demand WOPs with market exploratory innovation strategies facilitates catching up. Additionally, business model innovation plays a critical role in capturing market WOPs (Wu et al., 2010).

Besides the three categories of WOPs are studied, the established literature also investigates on the characteristics of WOPs, such as the size, the significance, exogeneity/endogeneity, the predictability, and the relativity. The size of technology-driven WOPs can vary greatly, reflecting the magnitude of the technological discontinuity and the corresponding variability in leadership changes (Landini et al., 2017). Some studies differentiate between "significant" and "marginal" WOPs, with significant WOPs leading to substantial industry changes. Giachetti & Marchi (2017) argue that firms implementing more significant changes during these windows are more likely to succeed. They also suggest that aggressive competitive actions increase the potential for a change in industrial leadership. WOPs can be either exogenous or endogenous, depending on the responses of various players. Even in exogenous technological windows, successful latecomers can 'endogenize' these innovations by building technological capabilities and developing new socio-technical systems (Lee & Malerba, 2017; Yap & Truffer, 2019). This process of endogenization is crucial for leveraging WOPs effectively. The ability to internalize and adapt external innovations can be a decisive factor in how well latecomers exploit these windows. The predictability of WOPs

formation is challenging. Case studies by Guennif & Ramani (2012) show that catching up can differ significantly between countries due to variations in the instruments, timing, and implementation of policies. India and Brazil, despite implementing similar policies to catch up with international pharmaceutical leaders, experienced different outcomes. This unpredictability highlights the complex interplay of local conditions and strategic responses. WOPs are relative and temporary. Latecomers must maximize their potential quickly before others in the industry identify and exploit the same opportunities. Vértsey (2017) highlights the importance of predicting when a WOP will open. Due to information asymmetries, actors may perceive the value of WOPs differently, with some recognizing opportunities that others may overlook (Katila & Mang, 2003). This relative nature of WOPs means that identical opportunities can carry different implications for different actors, depending on their strategic positioning and readiness to act.

1.1.6 Synthesis of the catching up studies

The literature on technological catching up provides a comprehensive examination of how latecomers can close the gap with forerunners. This process is crucially dependent on technological advancement, which often precedes improvements in income, productivity, and market performance. Successful technological catching up can result in the convergence of latecomers with forerunners or even surpassing them.

The established literature on technological catching up includes several key theories and frameworks that explain how latecomers can close the gap with forerunners in terms of industrial and technological capabilities. These theories highlight various mechanisms, strategies, and factors critical to the technological catching up.

Convergence theory posits that over time, poorer economies will tend to grow at faster rates than richer economies, leading to a convergence in terms of income levels, productivity,

and technological capabilities. This theory suggests that latecomer countries can achieve similar levels of development as advanced countries by adopting and integrating existing technologies, improving their institutional frameworks, and leveraging global knowledge flows (e.g. Abramovitz, 1986). The focus is on reducing disparities through technological advancement, economic policies, and institutional development. In the technological catching up context, technological capabilities are seen as the cornerstone for achieving and sustaining technological advancements and competitiveness. Firms and countries must develop these capabilities to manage technological change effectively (e.g. Hobday, 1995; Kim, 1998; Kiamehr, 2017). SAP explores what catching up antecedents are and how latecomers engage in learning, knowledge absorption, and capability building through practical actions (e.g. Xiong & Monin, 2015). Meanwhile, Strategy Process is concerned with understanding the reasons and mechanisms behind strategic changes, including the evolution of formulation and implementation processes (e.g. Malerba & Lee, 2021). WOPs framework is highlighted in the literature review, which are often associated with technological discontinuities, market shifts, or policy changes that latecomers can exploit to accelerate their catching-up process (e.g. Perez & Soete, 1988; Lee & Malerba, 2017). Identifying and leveraging these windows is crucial for successful technological advancement and convergence. These theories collectively provide a robust structure for understanding the complex process of technological catching up.

Research on catching up is conducted at multiple analytical levels. At the macro level, strong governmental institutions, strategic policy interventions, and effective governance structures are pivotal for fostering economic growth and technological innovation (Han et al., 2004; Hobday, 1995; Kozlova & Noguera-Santaella, 2019; Miao et al., 2021). At the meso level, sectoral innovation systems and the role of technological sophistication across industries are crucial for understanding productivity gains and innovation dynamics (Goedhuys et al., 2013; Fagerberg & Srholec, 2005; Godinho & Ferreira, 2012; Intarakumnerd et al., 2002; Jung

& Lee, 2010; Lee et al., 2009; Malerba, 2002; Martin & Johnston, 1999; Mei & Zhang, 2022). At the micro level, the focus is on latecomer firms' strategies for capability building, including learning from forerunners through imitation and eventually developing independent innovation capabilities (Joo & Lee, 2010; Kiamehr, 2017; Kim & Lee, 2008; Malerba & Nelson, 2011; Spanos & Voudouris, 2009).

While the literature on technological catching up is extensive and provides valuable insights, several research gaps remain, addressing which can lead to a more comprehensive understanding of the mechanisms, strategies, and outcomes of technological catching up, with a specific focus on the process and WOPs.

The literature on technological catching up has extensively explored how latecomers can close the gap with forerunners in terms of technological capabilities (i.e. Fan, 2006; Guo & Zheng, 2019; Shin, 2017). However, a significant gap exists in understanding how technological uncertainty influences the catching up process. Technological uncertainty refers to the unpredictability in technological development, adoption, and diffusion, which can vary widely across different sectors (Fixson et al., 2017; Riillo et al., 2022). Each sector has distinct technological trajectories, market structures, and competitive dynamics, which can significantly impact the catching up process (Malerba & Nelson, 2011). There is a lack of integrated analysis that considers both technological uncertainty and process dynamics simultaneously. Most studies focus on either the general process of catching up, such as path-following, path-skipping/leapfrogging, and path-creating (Figueiredo & Cohen, 2019; Lee, 2013; Lee & Lim, 2001; Yu et al., 2022; Zhu et al., 2017) or the specificities of individual sectors (Kim & Park, 2019; Lee & Ki, 2017; Rui & Bruyaka, 2021), without examining the interplay between these factors. To address this gap, there is a need for research that combines an understanding of technological uncertainty with process dynamics. Such research should

focus on how these factors interact to shape the patterns of latecomer firms and countries in their efforts to catch up technologically.

WOPs are critical junctures where shifts in technology, market dynamics, or policies enable latecomers to catch up with or even surpass technological leaders (Perez & Soete, 1988; Lee & Malerba, 2017; Kwak & Yoon, 2020; Hansen & Hansen, 2021; Giachetti & Mensah, 2023). Institutional WOPs, in particular, can arise from regulatory reforms, policy incentives, public investments, and support for research and development (Kim et al., 2013; Oyarvide & Acuña, 2020). While existing literature acknowledges that institutional actions can initiate WOPs (Kim et al., 2013; Liu et al., 2017; Szczygielski et al., 2017), it often lacks a detailed exploration of how these initial opportunities can trigger additional WOPs across different dimensions, such as technology and markets. There is a need to understand how policies can proactively influence the timing, scale, and accessibility of WOPs. Additionally, there is limited understanding of the synergies created when institutional WOPs interact with technological or market opportunities, potentially leading to an enhanced capacity for catching up. Few empirical studies document the processes through which institutional WOPs lead to cascading effects that benefit emerging industries (e.g. Lema et al., 2020), highlighting a significant gap in the current research. Addressing this gap requires a focused examination of the interactions and feedback loops between institutional, technological, and market WOPs to develop a comprehensive framework that can guide strategic decision-making in emerging industries.

The existing literature does not adequately explore whether and how crises can induce WOPs that catalyse rapid innovation and transformation. Most studies focus on predictable environments where opportunities emerge gradually (Yap & Truffer, 2019), overlooking the potential for crises to create sudden and transformative WOPs. Turbulent contexts, characterized by economic volatility, political instability, rapid technological changes, or

global crises, present unique challenges and opportunities for leveraging WOPs (Wan & Yiu, 2009; Zhang et al., 2023). In such unpredictable environments, traditional strategies may not be applicable, requiring organizations to adopt agile and adaptive approaches to navigate uncertainty effectively (Lim et al., 2009; Wan & Yiu, 2009; Wu et al., 2010). There is also a lack of comprehensive analysis of how the impact of crisis-induced WOPs varies across different sectors and entities. We know little about the differential impacts and outcomes of WOPs, particularly regarding how they influence competitive dynamics and technological advancements in various industries. That is to say, the disparity in how entities leverage these opportunities remains underexplored, especially in a turbulent context.

1.2 Epistemological foundation

1.2.1 Epistemological considerations

Epistemology, the study of knowledge and how it is acquired, is a critical consideration in research as it underpins the methodologies and frameworks that guide research inquiry (Reihlen & Schoeneborn, 2022). Understanding epistemology offers an opportunity to clarify the foundations of our work, allowing us to articulate how knowledge is constructed, justified, and validated within our study.

Epistemology is fundamental to research because it influences every aspect of the research design, from the formulation of research questions to the interpretation of data (Boisot & MacMillan, 2004; Denzin & Lincoln, 2008). By engaging with epistemological questions, we can critically evaluate the assumptions that underlie our work, such as what constitutes valid knowledge, the role of the researcher, and the nature of reality we are investigating (Gephart, 2004; Lincoln & Guba, 1985). This critical reflection enhances the credibility and reliability of research findings by making the research process more transparent and robust. Furthermore, considering epistemology encourages us to be aware of the limitations and biases inherent in different knowledge paradigms (Knights, 1992). This awareness allows us to choose

methods and approaches that are best suited to our research questions, facilitating a more comprehensive understanding of complex phenomena (Johnson & Duberley, 2000). It also enables us to position our work within broader academic discourses, contributing to the development of knowledge in a way that is informed, critical, and reflective (Boisot & MacMillan, 2004).

Several epistemological approaches guide research in the social sciences, each offering distinct perspectives on how knowledge is constructed and understood. Positivism is an epistemological stance that emphasizes the use of scientific methods to study social phenomena (Bryman, 2016). It is based on the belief that reality is objective and can be observed and measured independently of the observer. Positivists prioritize quantitative methods and seek to identify patterns, relationships, and causal connections through empirical data collection and analysis. This approach assumes that knowledge is derived from observable and measurable phenomena, leading to generalizable and predictive conclusion (Reihlen & Schoeneborn, 2022). In contrast to positivism, interpretivism focuses on understanding the subjective meaning and experiences of individuals within their social contexts (Geertz, 1973). It emphasizes the role of the researcher in interpreting social phenomena, recognizing that knowledge is co-constructed through interactions between the researcher and participants (Goldkuhl, 2012). Interpretivists prioritize qualitative methods, such as interviews and ethnography, to explore the depth and complexity of human experiences and the meanings individuals attach to them (Denzin & Lincoln, 2008; Yin, 2003). Constructivism posits that knowledge is not discovered but constructed by individuals based on their experiences and interactions with the world (Blaikie, 2007). This approach emphasizes the active role of individuals in creating meaning and understanding, suggesting that multiple realities exist depending on individuals' perspectives. Constructivist research often employs qualitative methods to explore how people construct and make sense of their realities (Denzin & Lincoln,

2008). Critical realism acknowledges the existence of an objective reality while recognizing that our understanding of this reality is mediated by social, cultural, and historical contexts (Easton, 2010). It emphasizes the importance of exploring the underlying structures and mechanisms that shape observable phenomena. Critical realism often combines qualitative and quantitative methods to provide a more comprehensive understanding of complex social issues, seeking to uncover the deeper causes and contexts that influence events and behaviours (Danermark & Ekström, 2019). Pragmatism is an epistemological approach that focuses on the practical consequences and applications of research. It suggests that the validity of knowledge is determined by its usefulness and applicability in addressing real-world problems. Pragmatists are flexible in their choice of methods, using both qualitative and quantitative approaches to address specific research questions and objectives (Shah & Corley, 2006). Table 1.1 provides an overview of the epistemological foundations discussed in this thesis, highlighting the different perspectives on how knowledge is constructed and understood within social sciences.

Table 1.1 An overview of the epistemological considerations

Epistemological Approaches	Main Authors	Key Contributions	Key Concepts
Positivism	Bryman (2016), Reihlen & Schoeneborn (2022), etc.	Emphasizes the use of scientific methods to study social phenomena. Reality is objective and can be observed and measured independently of the observer.	Empirical Observation, Objectivity, Hypothesis Testing.
Interpretivism	Geertz (1973), Goldkuhl (2012), etc.	Focuses on understanding the meaning of human experiences and social phenomena. Emphasizes subjective interpretation and the role of context.	Subjectivity, Contextualization, Qualitative Methods.

Epistemological Approaches	Main Authors	Key Contributions	Key Concepts
Constructivism	Blaikie (2007), Denzin & Lincoln (2008), etc.	Knowledge is constructed by individuals based on their experiences and interactions. Emphasizes the active role in meaning-making.	Knowledge Construction, Social Interaction, Active Learning.
Critical Realism	Easton (2010), Danermark & Ekström (2019), etc.	Acknowledges an objective reality, but understanding is mediated by social, cultural, and historical contexts. Explores underlying structures shaping phenomena.	Objective Reality, Social Mediation, Causal Mechanisms.
Pragmatism	Shah & Corley (2006), etc.	Focuses on the practical consequences and applications of research. The validity of knowledge is determined by its usefulness in addressing real-world problems.	Practicality, Flexibility, Real-World Application.

1.2.2 Epistemological approach

This thesis adopts an interpretivist epistemological orientation, emphasizing the importance of understanding the subjective and contextualized experiences of stakeholders involved in technological catching up and WOPs. Interpretivism, or epistemology of interpretation, focuses on the meanings and interpretations constructed by individuals within their social contexts and rejects the notion that social sciences should strive to represent reality in an objective manner (Reihlen & Schoeneborn, 2022).

In the context of interpretivism, knowledge is a construct that emerges from human interactions and social contexts (Gephart, 2004). The focus is on understanding the processes and meanings that individuals and groups ascribe to their actions and interactions within the technological catching up process. The capacity for knowing extends to individuals and communities engaged in interpreting and making sense of their experiences (Johnson &

Duberley, 2000). This includes industry experts, policymakers, and organizational leaders whose insights are derived from their contextual understanding. These actors provide valuable perspectives that inform the research findings, as their interpretations and experiences are crucial for understanding the dynamics of technological catching up and WOPs. The extent of what can be known is therefore bounded by the richness and depth of the qualitative data collected, recognizing that knowledge is always situated and context dependent. Sources of knowing in this thesis include interviews, case studies, and ethnographies (Hyett et al., 2014). These methods capture the meanings and interpretations of individuals within specific contexts, providing a deep and contextualized understanding. Based on these premises, the best knowledge, from an interpretivist perspective, is that which provides deep insights into the subjective experiences and meanings constructed by individuals and groups (Gephart, 2004; Johnson & Duberley, 2000).

This thesis also incorporates the epistemology of collective action, which argues that management research should be responsive to practical needs and provide actionable insights (Hatchuel, 2005). This approach aligns with the goal of understanding how latecomer firms can strategically leverage WOP to catch up with forerunners, thereby contributing both theoretically and practically to the field of management. The epistemological consideration of this thesis also draws on the insights of Knights (1992), which emphasize the disruptive impact of new epistemological locations in management studies. Understanding catching up requires a consideration of how technological, institutional, and market factors interact over time and across different contexts. This approach challenges the static and linear models often found in traditional management theories, advocating for a more fluid and context-sensitive understanding of catching up processes. The work of Reihlen & Schoeneborn (2022) provides a broad overview of the epistemological foundations in management studies. Their contribution highlights the necessity of understanding the philosophical underpinnings of management

practices and how they shape research methodologies. This perspective informs the methodological choice in this thesis, ensuring that this is grounded in a coherent epistemological framework.

By adopting the epistemology of interpretivism, this thesis ensures that its findings are not only theoretically robust but also practically relevant. It provides actionable insights for policymakers and managers in latecomer firms, contributing to both academic research and practical decision-making (Hatchuel, 2005).

1.3 Methodology in a nutshell

Building on the interpretivist epistemology, which emphasizes the subjective and contextualized nature of knowledge, this thesis adopts qualitative research methods to explore the experiences and perspectives of stakeholders involved in technological catching up and WOPs. The chosen methodology aligns with the interpretivist approach by prioritizing depth, richness, and contextual relevance in understanding the phenomena under study (Goldkuhl, 2012).

Case studies enable a detailed examination of specific instances of technological catching up and the exploitation of WOPs. They provide rich, contextual insights that are essential for understanding the unique circumstances and strategies of different firms and countries. (Eisenhardt, 1989; Yin, 2003) Technological catching up involves complex interactions between technological, institutional, and market factors. Case studies allow researchers to capture these complexities and the contextual factors that influence the success of catching up strategies (Noor, 2008). By focusing on specific cases, this methodology can illustrate broader theoretical concepts and mechanisms in action. This helps to bridge the gap between theory and practice, providing actionable insights for policymakers and managers (Hatchuel, 2005). Case studies are flexible and adaptable to various research settings, allowing

the researcher to explore phenomena in real-world contexts where boundaries between phenomenon and context are not clearly evident (Baxter & Jack, 2008).

Cases are selected based on their relevance and significance to the study of technological catching up and WOPs. The selected cases include industries and firms from different sectors that have demonstrated notable catching up trajectories. This selection is guided by theoretical sampling principles, aiming to maximize the variation in contexts and outcomes (Guest et al., 2006). Data is collected from multiple sources, including industry reports, policy documents, and interviews with key stakeholders. Semi-structured interviews are conducted with key stakeholders, including industry experts, policymakers, and organizational leaders. These interviews provide rich, qualitative data on the participants' experiences, interpretations, and strategies related to technological catching up and WOPs. The semi-structured format allows for flexibility in exploring relevant themes while maintaining a consistent framework for comparison (Hyett et al., 2014). This ensures a rich and diverse dataset that captures various perspectives and dimensions of the catching up process (Tellis, 1997; Yin, 2003). Table 1.2 outlines types of data collected in different chapters for the empirical studies.

The findings from the case studies and comparative analysis are integrated to provide a holistic understanding of technological catching up and WOPs. This involves synthesizing the insights from different cases to identify overarching themes and principles (Gehman et al., 2018). The research findings are interpreted in the context of existing theories and literature on technological catching up and WOPs which helps to refine and extend theoretical frameworks, contributing to the academic discourse on these topics.

Table 1.2 Types of data collected for empirical chapters

Study	Type of Data Collected	Data Sources	Collection Methods
Chapter 2	Industry reports; Interviews; Field observations.	Industry databases; Government reports; Interviews with industry experts; etc.	Archival research; Semi-structured interviews; Factory visits.
Chapter 3	Policy documents; Company performance reports; Interviews.	Government policy documents; Industry reports; Company annual reports; Interviews with industry experts; etc.	Archival research; Semi-structured interviews; Factory visits.
Chapter 4	Data on digital transformation initiatives; COVID-19 response measures; Consumer behavior changes.	Reports on digitalization trends; Government reports on COVID-19 policies; Market research reports; etc.	Archival research; Process tracing.

The theoretical framework of this thesis is structured to provide a comprehensive understanding of technological catching up, with a particular focus on how different types of WOPs and technological uncertainty influence this process across various contexts. This framework serves as the foundation for the empirical investigations conducted in the three core chapters of the thesis.

The three papers presented in this thesis have been carefully selected and organized to build a coherent narrative that progressively deepens the understanding of technological catching up, particularly in the context of Chinese industries. Each paper addresses a distinct but interconnected aspect of the catching up process, allowing the thesis to explore the phenomenon from multiple angles and provide a comprehensive analysis. The order of these papers is strategic, enabling the reader to first grasp the broader concepts and challenges before delving into more specific cases and complexities.

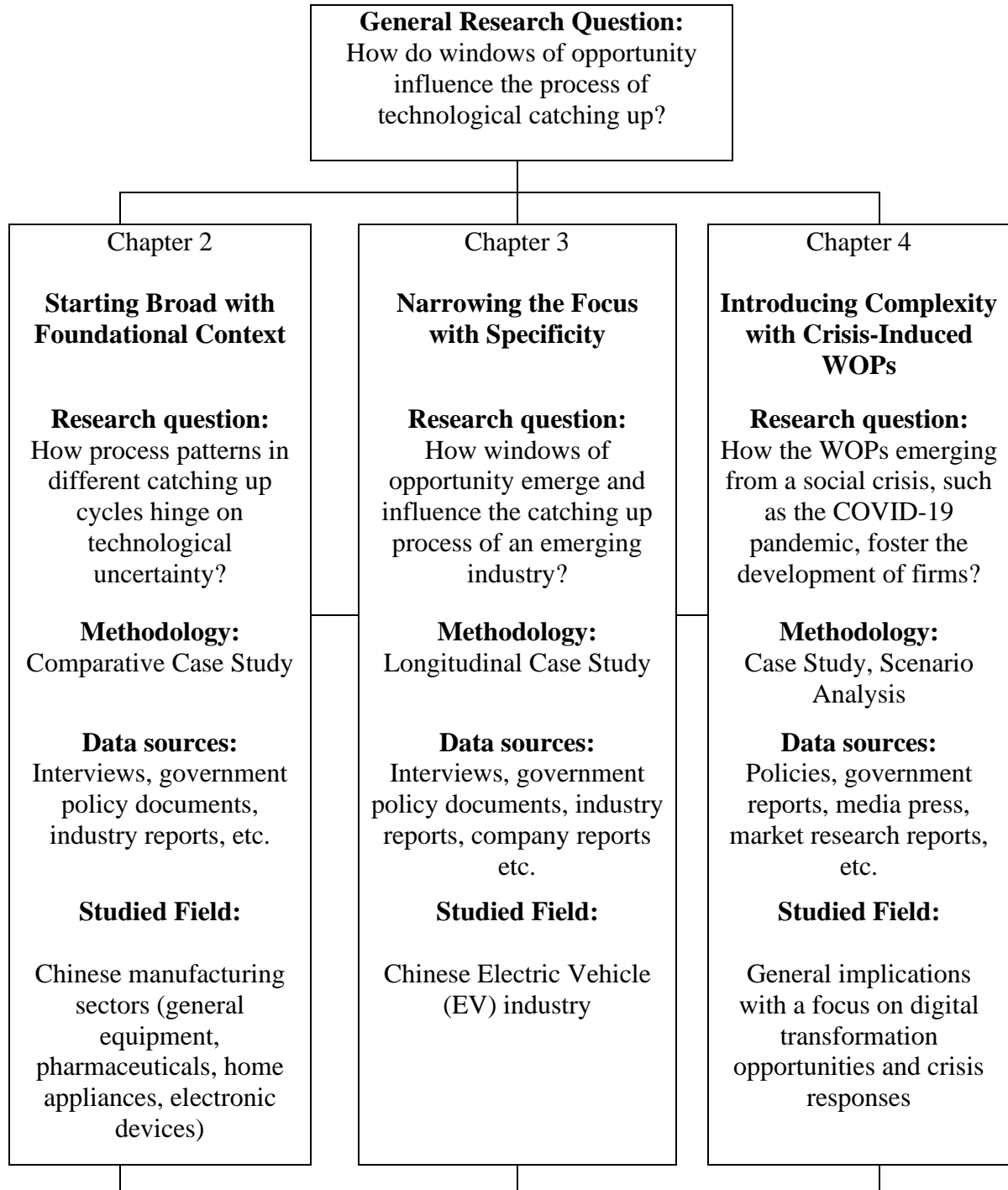
The first paper provides a broad overview of how technological uncertainty influences the catching up process across multiple industries. It introduces key concepts such as the variability in technological trajectories and the importance of sector-specific dynamics. This foundational analysis establishes the context for the more focused studies that follow.

The second paper narrows the focus to a single, highly relevant industry, EVs. Placing this paper second allows the thesis to dig deeper into the mechanisms of institutional support and its critical role in shaping industry-specific catching up.

The third paper introduces an additional layer of complexity by exploring how external shocks, such as the COVID-19 pandemic, can create unique WOPs that accelerate technological catching up. By positioning this paper last, the thesis culminates in an analysis of the most dynamic and unpredictable aspect of catching up, showing how external forces can disrupt traditional trajectories and offer new pathways for development.

In summary, the order of these papers is designed to gradually transition from a broad, multi-sectoral perspective on technological uncertainty to a more focused examination of policy-driven opportunities in a specific industry, and finally to the exploration of crisis-induced opportunities in a rapidly changing technological landscape. Figure 1.2 shows the general logical structure of the empirical studies in this thesis and the key elements behind the order of the three articles.

Figure 1.2 Overview of Chapters 2, 3, and 4



Chapter 2 Technological uncertainty and catch-up patterns: insights of four Chinese manufacturing sectors

This article studies the technological uncertainty and the patterns of industrial catching up within the context of China's manufacturing sector. As China continues its rapid industrialization and economic growth, understanding how different sectors respond to varying levels of technological uncertainty becomes increasingly vital. This study focuses on four distinct manufacturing sectors in China: general equipment, pharmaceuticals, home appliances, and electronic devices. These sectors were selected for their differing levels of technological complexity and market dynamics, providing a rich comparative analysis of how technological uncertainty shapes the trajectory of catching up. The research applies process theory to examine the cyclical nature of catching up and how firms within these sectors navigate periods of high uncertainty. This article contributes to the broader literature on technological catching up by highlighting the sector-specific dynamics that influence how latecomer firms in emerging economies like China can bridge the gap with global leaders. By exploring the unique challenges and opportunities presented by technological uncertainty, this study provides valuable insights into the strategic management of innovation and industrial development in diverse manufacturing contexts. The findings of this article are particularly relevant for policymakers, industry leaders, and scholars interested in the mechanisms of technological advancement and the factors that drive successful catching up in emerging markets. The study underscores the importance of adaptive strategies and responsive policy frameworks in navigating the uncertainties inherent in high-tech industries, offering a nuanced understanding of the pathways to industrial leadership in a rapidly changing global landscape.

Xu, L., Xiong, J., Yan, J., Soparnot, R., and Yuan, Z. (2024) ‘Technological Uncertainty and Catch-Up Patterns: Insights of Four Chinese Manufacturing Sectors’, *IEEE Transactions on Engineering Management*, 71, p.4876-4888. Available at: <https://doi:10.1109/TEM.2022.3228114>.⁷

2.1 Context

This article is the first in the main body of this thesis for several key reasons. First, this article provides a broad, sector-specific analysis of how technological uncertainty influences the catch-up process in different industries. By starting with this study, we set a foundational context for understanding the various dynamics at play across sectors, which is essential for the subsequent more specialized case studies. Second, this article introduces critical concepts such as technological uncertainty and sector-specific dynamics, which are recurrent themes in the following chapters. By addressing these first, it allows us to grasp the essential theoretical and empirical frameworks that will be built upon in later studies. Third, by comparing four different Chinese manufacturing sectors, the article highlights the diversity and variability in catching up processes. This comparison serves as a baseline for the more focused analysis in later chapters, such as the study on the electric vehicle industry. Last, regarding thematic continuity, starting with this article allows for a logical progression in the thesis, where we move from a broad analysis of sectoral patterns to more detailed case studies (such as the Chinese electric vehicle industry) and then to the impact of exogenous shocks (like the COVID-19 pandemic). This creates a coherent narrative that flows from general to specific, providing clarity and depth to the overall argument.

⁷ This work was supported by the National Natural Science Foundation of China under Grant #71772142.

The bumpy publication journey of this paper began in 2019 when the initial draft was completed and submitted to Research Policy. The original manuscript aimed to investigate industry change from a process theory perspective, utilizing a comprehensive dataset of Chinese manufacturing sectors. Despite the interesting topic, the paper received criticism from the reviewers and was ultimately rejected. Specifically, reviewers highlight several key issues: the introduction needs more clarity on the significance of research gaps, the theoretical background could be more comprehensively reviewed, the findings should include further explanation on paradigm combinations, and the theoretical contribution was unclear. In response to these inspiring critiques, the manuscript underwent significant modifications. This approach allowed for a more focused and robust analysis. This revised manuscript draft eventually formed the prototype of this chapter. Despite the improvements, it faced desk rejections from subsequent submissions to Industrial and Corporate Change and Technovation, indicating the need for further refinement.

The prototype of this article was presented at the European International Business Academy Conference, Poster Session, in Madrid, Spain, in December 2021.

Taking editors' and colleagues' suggestions into account, this prototype was resubmitted to IEEE Transactions on Engineering Management.

Initially submitted to this journal under the title "Technology trajectories catch-up cycles and patterns of process: insights of four Chinese manufacturing sectors", the paper was first submitted in March 2022. After the initial review, the reviewers provided insightful comments, suggesting several areas for improvement. The key feedback focused on refining the typology presentation and illustration, improving the framing and expression of key concepts, and enhancing the discussion of technological uncertainty.

In response to the first round of major revision feedback received 28/06/2022, we undertook a comprehensive revision of the manuscript. Major updates included a more detailed elaboration on technological uncertainty, better justification of the sampling reasons, and clearer presentation of interview details. Additionally, the contributions of the study were more explicitly articulated. We also engaged a professional language expert to improve the overall composition and clarity of the manuscript. These efforts resulted in a more coherent and polished version of the paper, which was resubmitted on 26/08/2022.

We received the minor revision decision on 23/10/2022. The second round of revisions focused on further enhancing the discussion section, particularly the intersection of technological uncertainty and the catch-up cycle. We added detailed explanations of the different patterns identified and their transitions. This included addressing the reviewers' suggestions to add more detail to the illustrative figures and to ensure that the manuscript was reader friendly. We also refined the abstract to make it more concise and directly reflective of the study's key findings. The manuscript was resubmitted for its third time on 15/11/2022.

The iterative process of revision has greatly improved the manuscript, making it a valuable contribution to the literature on technological catching up and process theory. It is eventually accepted for publication on 23/11/2022. We are grateful for the constructive feedback from the reviewers and editors, which has significantly enhanced the quality of our work. We hope this chapter provides meaningful insights into the dynamics of technological uncertainty and its impact on catching up in the context of Chinese manufacturing sectors.

This chapter was presented as a poster during la Journée de l'École Doctorale des Sciences Economiques, Juridiques, Politiques et de Gestion, UCA, at Clermont-Ferrand on 16/06/2023.

Abstract:

Existing literature highlights the relevance of technology uncertainty and processes in latecomers' catch-up but largely ignores the potential interplay between the two as well as the catch-up cycle. Thus, the purpose of this study is to answer the research question of how process patterns throughout the various stages of the catch-up cycle hinge on technological uncertainty. Based on observations of the manufacturing industries of general equipment, pharmaceuticals, home appliances, and electronic device manufacturing in China, our findings reveal that the patterns differ in the early and late stages of the catch-up cycle, due to different technological uncertainties. We demonstrate the features of patterns in conjunction with the catch-up cycle: predictive or explanatory patterns as fundamental ones in the early stage; and convergent and divergent hybrid modes comprised of the aforementioned fundamental patterns in the late stage. Our results provide fresh insights into the catch-up process literature and offer valuable practical implications for latecomers.

Keywords: Catch-up cycle; Technological uncertainty; Process patterns; Predictive; Explanatory; Hybrid.

Managerial relevance statement

This study provides the following managerial applications: Policies and regulations are not the only instruments for regulating industrial standards. The institutional window of opportunity rejuvenates industries where technology is monotonous and invigorates those enterprises that embrace it. Technological regimes are dominant forces that govern and influence the occurrence and velocity of catch-up. Policymakers should construct an agile and efficient response mechanism for detecting technological uncertainty and formulating supportive regulations. Latecomer firms' executives must accurately assess their companies' situations and forecast future technological trends. When technology uncertainty is high,

managers should plan and implement better-designed strategic initiatives with foresight. Therefore, anchoring WOPs whilst leveraging internal resources to incubate capabilities and create a peerless path. In contrast, when technological uncertainty is low, managers should maintain vigilance over fast-moving or strategic followers on familiar paths.

2.2 Introduction

Strategic management scholars have demonstrated a long-term interest in sustaining their organizations' superior performance over competitors (Campbell-Hunt, 2000; King & Zeithaml, 2001). Thus, one surpassing another is ubiquitous across all levels of strategy research. The portrayed phenomenon is that of latecomers' or new entrants' catch-up with forerunners' or incumbents' leadership (Xu et al., 2018).

The convergence between the laggards and the frontier, or catch-up, is a gap-closing process (Yang et al., 2021). Some studies emphasize leadership turnover during continual catch-up attempts (Kang & Song, 2017), whereas other research focuses on the segmentation of phases in catch-up processes. Typically, technological catch-up begins with introducing externally advanced technologies and/or products. Thus, experience from imitating introduced technology or implementing production could be accumulated. This is accomplished by seizing the window of opportunity (WOP), which refers to "*discontinuities in the dynamic of a sectoral system*" (Lee & Malerba, 2017, p.339), in order to eliminate latecomer disadvantages while raising and creating latecomer advantages to forge ahead (Cho et al., 1998; Dosi, 1982; Lee & Lim, 2001; Malerba & Nelson, 2011; Perez & Soete, 1988).

Hobday (1995, p. 19) distinguishes original equipment manufacturing (OEM), original design manufacturing (ODM), and original brand manufacturing (OBM). According to Kim (1997), technological internalization and development are achieved gradually through duplicative imitation. This is subsequently modified or creatively imitated until it evolves and becomes an endogenous innovation. Other studies describe catch-up process models, such as

leapfrogging (Cho et al., 1998) or path-following, path-skipping, and path-creating (Lee & Lim, 2001). These patterns vividly present catch-up sequences by visualizing them in discernible and intelligible forms. Some recent research has focused on latecomers' WOPs, thus further stimulating the catch-up cycles' evolution (Landini et al., 2017; Lee & Malerba, 2017).

Various WOPs emerge in the constantly changing external environment during catch-up cycles. This could be attributed to the “*phenomena of successive changes in industrial leadership*” (Lee & Malerba, 2017, p. 338) during the early prologue, interim development, or final complement. Therefore, latecomers manoeuvre their capabilities by building and learning mechanisms with diverse permutations (Figueiredo & Cohen, 2019). Technology, market demand, and policy concerns influence latecomers' catch-up path choices. When building research capabilities and during periods of policy uncertainty, organizations tend to eliminate negative effects and risks. Therefore, they are more likely to follow their industry's leaders. Industry forerunners are believed to have greater foresight into the influences caused by policy changes (Amore, 2020). Government initiatives introducing institutional WOPs may reshape technological paradigms and breed technological WOPs (Xu et al., 2023), thereby encouraging latecomers to pursue a novel approach to catch up with path-breaking innovation (Gao et al., 2021). When demand uncertainty is high, market information is rapidly revealed. Thus, enterprises may eventually enter the market simultaneously. Stackelberg's leader-follower behaviour may be more appropriate (Hirokawa & Sasaki, 2001). When the followers observe their industry leaders to determine the profitable amount, production decisions are made (Hirokawa & Sasaki, 2001). Thus, even in one predesigned catch-up process, phases fluctuate as WOPs evolve and the actors' responses vary. In this study, we focus on technological catch-up cycles, where technological uncertainty is the primary component of the catch-up cycle process patterns. We define technological uncertainty as “*the difference between the amount*

of information required to complete a task and the amount of information already possessed” (Galbraith, 1977, p. 5).

At the early stage of catch-up, latecomers usually focus on technology-driven learning and the accumulation of experience and capital. In South Korea, the electronic industry began with foreign technology implementation and production to learn product design and its operational mechanisms (Kim, 1980). Electronic industries’ efforts to catch-up with the economies of the Asian Tigers (South Korea, Singapore, Taiwan, and Hong Kong) begin with OEM contractors learning technology for turnkey manufacturing. They were then able to build ODM capabilities (Hobday, 1995). The catch-up cycle began exponentially for some industries. For example, in the mid-1960s, the global camera industry’s leadership shifted from German to Japanese (Kang & Song, 2017). This rare opportunity required the simultaneous integration of technological, institutional, and demand WOPs. Consequently, most latecomers benchmark incumbents in the early stages of catch-up. For instance, South Korea’s camera industry expedited its catch-up by evaluating the Japanese experience (Kang & Song, 2017). Latecomers’ capabilities to consolidate, imitate, or outsource operations were upgraded to creative development, innovation, and original brand establishment (Hobday, 1995; Kim, 1980).

Catch-up mechanisms are affected by differences in various industry sectors, structures and norms, value chain links and demands, research, financial, and political institutions. (Malerba & Nelson, 2011). Established catch-up process research mainly focuses on high-tech industries, such as the Korean electronic industry (Kang & Song, 2017; Kim, 1980; Lee & Lim, 2001). Low-tech industries such as retailing and wine production have received less attention (Morrison & Rabellotti, 2017; Xiong & Monin, 2015), with even less given to cross-industry comparisons (except for Malerba & Nelson, 2011). However, technological uncertainty varies between sectors, and catch-up processes are heterogeneous (Miao et al., 2018).

Over the last few decades, China has embraced globalization's division of labour to become a worldwide manufacturer. China's rapid economic expansion is built on the essential pillar of manufacturing. However, this growth has been uneven across diverse industries. Some industries, such as telecommunications (Guo et al., 2019), have already become leaders in the international arena. Meanwhile, the mass expansion of low-end production capacity in other sectors demonstrates that Chinese companies remain followers.

The catch-up process differs between industries with various technological uncertainties (Park & Lee, 2006). However, in empirical research on catch-up strategy, the catch-up cycle stages and technological uncertainty are not yet linked. Thus, we focus on this study's pivotal question and investigate how process patterns in catch-up cycle stages hinge on technological uncertainty. The Chinese manufacturing industry serves as the study's research context. Sectors with different technological uncertainties and catch-up cycles are included. We selected four Chinese manufacturing sectors: general equipment, pharmaceuticals, home appliances, and electronic devices (unmanned aerial vehicles, i.e., UAVs). These four latecomer industry scenarios are based on the previously mentioned catch-up cycles and technological uncertainty. This study demonstrates that process patterns differ in the catch-up cycles' early and late stages and that technological uncertainty is crucial to their formulation and hybridization.

2.3 Literature review and theoretical development

2.3.1 Stages of catch-up cycle

Strategy Process and Strategy-as-Practice share some common propositions and theoretical resources but differ in practice (Kouamé & Langley, 2018). The catch-up process is described by several models, such as leapfrogging (Cho et al., 1998) or path-following, path-skipping, and path-creating (Lee & Lim, 2001). However, from the Strategy-as-Practice perspective, it merely defines distinct processual forms. This study recognizes the catch-up

strategy as a Strategy Process. (Van de Ven, 1992) examines organizational processes and summarizes three widely accepted definitions: (1) explaining the logical relationship between variables; (2) a concept or variable segment involving individuals or organizational behaviour; and (3) a series of phenomena describing how things change over time. Process is defined as “*a sequence of events, activities, and interactions over time*” (Kouamé & Langley, 2018, p.561) and is related to developing and implementing processes to gain competitive advantages by emulating competitors, mainly forerunners. Process theories are categorized according to their commonalities and differences. (Van de Ven, 1992) classifies process theories into four groups: life cycle, teleology, dialectic, and evolution. Life cycle and teleology are predictive because they incorporate initiative conditions and equifinality. While dialectic and evolution are more concerned with emergent changes and their occurrence, they also have fewer anticipatory changes but have more explanation. Cloutier & Langley (2020) discover a similarity between four process-theorizing methods: Linear and Parallel are predictive with regularities, whereas Recursive and Conjunctive styles demonstrate the merits of a generative mechanism. We begin our study by following this logic and delving into the catch-up process. We divide the processes into two pattern categories: predictive and explanatory. The predictive pattern’s evolution follows a completely or partially established or anticipated trajectory. Meanwhile, the explanatory pattern’s evolution is where dynamic constructs lead to unpredictable development alternatives.

In the catch-up cycle, four major phases are identified. They are the entry, gradual catch-up, forging ahead, and leadership transition. The first two are the early stages, and the latter two are the late stages (Lee & Malerba, 2017). WOPs indicators identify key developmental constructs in industrywide catch-up cycles. Thus, WOPs emerge as potential alternative forms and are identified from technological, institutional, and market demand perspectives (Lee & Malerba, 2017). In this study, the successful WOPs response is a threshold

or essential period to distinguish a catch-up cycle between the early (entry and gradual catch-up) and latter stages (latecomers forging ahead and incumbents falling behind).

2.3.2 Predictive catch-up process

Catch-up strategy research focuses on the forging ahead phases of the technological trajectory. Kim (1980) summarizes three phases of technological capability development for the South Korean electronics industry's catch-up since the 1970s. Local latecomer enterprises imported and implemented cutting-edge foreign technology and gained valuable product design and operational knowledge. This enabled the absorption of foreign technology. Local workers' competencies improved as domestic and foreign market competitiveness intensified. These factors consolidated and strengthened South Korea's domestic electronic industry's assimilation of foreign technology.

The Japanese semiconductor industry's catch-up evolved initially by developing its demand internally, improving its manufacturing capabilities, and eventually catching up technologically and establishing industry standards in 1986 (Cho et al., 1998). Since 1992, South Korea's subsequent rise resembles this logic. Despite a lack of internal demand on which to base initial designs, family ownership provided Korean companies with sufficient resources to act quickly and jumpstart manufacturing. This "*sequential competence-building*" mode (Cho et al., 1998, p. 497) of the Japanese semiconductor manufacturing industry builds capacity with experience. Other latecomers, like India and China, can use the Japanese and South Korean examples as benchmarks to eliminate latecomer disadvantages and take advantage of latecomer benefits.

Latecomers can evolve as forerunners by engaging in these developmental capabilities (Lee & Lim, 2001). This process begins with becoming familiar with R&D's end phase, product assembly using imported parts, learning its structure and mechanism via practice, duplicative or modified imitation, and finally designing and inventing its own products. During

these distinct phases and to reach their goal of forging ahead, latecomers have followed different paths with varying patterns. Some follow identical technological trajectories as their forerunners, while others leapfrog by skipping a few steps to save time or through invention (Hobday, 1995). According to Lee & Lim (2001), the catch-up strategy's three models are path-following, path-skipping, and path-creating, with the first two leading to equifinality and the last yielding unexpected results. Hence, path-following and path-skipping are predictive patterns, whereas path-creating is interpreted as explanatory.

2.3.3 Explanatory catch-up process

The dialectic and evolution process theories are examples of explanatory processes that attentively observe how change and development transpire (Van de Ven, 1992). An explanatory process explains how events with diverse values are selected, mediated, and retained during development. This differs from a predictive process's unitary or plural cumulative sequence toward equifinality. WOPs increase the likelihood of these events occurring. They are also customized to suit specific conditions, making fixed pathways less common.

Pharmaceutical industry advancements in India and Brazil share certain similarities. (Guennif & Ramani, 2012) share insights and discuss how the three phases of production, re-engineering, and creation are managed. These two countries have achieved much over the past fifty years, and the perception of their institutional WOPs has varied. In Brazil, they were underexploited, but in India, they were seized up by private sector domestic latecomer firms. This disparity of unforeseen responses results from their accumulation of capabilities alongside distinct technological trajectories. This shaped the Indian pharmaceutical industry into a successful latecomer and a fulfilled catch-up enterprise. However, the Brazilian pharmaceutical industry continues to lag behind in its own market. Domestic demand in the indigenous market is critical to local industry and domestic companies' catch-up.

Since World War II, global steel industry leadership has shifted from the United States to Japan and then to South Korea, with various WOPs dominating the catch-up process (Lee & Ki, 2017). Japan initially caught up by riding the new technological wave, while the United States was stuck in the 1980s incumbent trap. South Korea subsequently capitalized on the 1998 industrial crisis to equip its low-end entry with advanced technology at a lower cost. This enabled a transition from path-following to path-skipping and was attributed to time efficiency and technological upgrading.

Not all catch-up cycles result in leadership changes. Latecomers may gain market share from dominators, but they cannot overtake them. This can be explained by sector specificities; for instance, the wine industry is less susceptible to technological and economic changes. As a result, incumbents have sufficient time to react and adjust to the disruptions caused by new entrants. They also have time to adapt to the newly formed path in the same way new entrants did while meeting market demands (Morrison & Rabellotti, 2017).

2.3.4 Technological uncertainty and catch-up

Technological uncertainty, which is one determinant of the catch-up process, is also known as the difficulty of forecasting technological development (Riillo et al., 2022). Shenhar & Dvir (1996) distinguish technological uncertainty as low, medium, high, and super high.

Type A refers to low technological uncertainty. All industry players in this category have easy access to the necessary production technologies, which are readily available and mature. Due to technological parity, rivals expand economies of scale to gain competitive advantages. In this case, technological catch-up can be achieved through path-following (Lee & Lim, 2001). However, homogeneous competition has become a common phenomenon, creating price wars that deplete the company's surplus. Even if a latecomer catches up with the forerunners, forging ahead by replicating established practices and remaining an OEM will still be difficult to achieve (Hobday, 1995). This is relevant except where WOPs such as

institutional interventions, policy tilts, or the emergence of new market preferences are present (Giachetti & Marchi, 2017).

Type B refers to medium technological uncertainty. In this instance, the producer can incorporate a small amount of mature, technology-based innovations. These new technologies are available to competitors in the industry and are designed to incrementally improve the performance of existing technologies. Latecomers can compete by introducing new technologies or features and improving or modifying the existing development trajectory. This enables fast movers to bypass some conventional steps in the catch-up process and forge ahead of the forerunners (Lee & Lim, 2001). By pioneering the single-lens reflex (SLR) mechanism, the Japanese camera industry caught up and created a new path. Mid-1990s German rangefinder companies ignored this new technological advancement (Kang & Song, 2017). Meanwhile, WOPs of market demand and policy promotion occurred. In the decades following, the digital SLR camera was launched. This upgraded version with additional functionalities sustained Japan's dominance. The development of the mirrorless camera revolutionized the camera market in South Korea and Japan until the 2000s. Thus, leapfrogging is necessary to address the new market demand for lightweight devices that create high-quality images. Thus, the process's predictability is weakened.

Type C refers to high technological uncertainty. A larger share of new technologies continues to raise technological uncertainty. High levels of technological uncertainty are created by new technologies' initial use and appearance, as well as their initial integration of new technologies and/or multiple existing technologies. In that situation, designing and testing technological catch-up paths is vital. This process barely refers to or depends on the development trajectory of existing forerunners. Although path creation makes the catch-up process less predictable and independent exploration of technology deployment enhances differentiation competition, we can still interpret it as an explanatory pattern. Since the early

2000s, Jin & von Zedtwitz's (2008) research has examined the Chinese mobile manufacturing sector. Their research identifies a recessive phase that occurs when latecomers adopt new technologies and combine them with existing features. This leads to technological obsolescence in advanced countries and is considered an extension of Kim's (1980) three-phase evolution. In the high-tech industry, Almudi et al. (2012) present a dynamic industrial catch-up model that captures how emerging firms transform pricing advantage into technological convergence. This is achieved through accessing global cutting-edge technology, investigating innovative gaps, investing in organizational R&D, convergent scientist salaries, managing personnel inflows, and investing in education. In high-tech enterprises, recombining existing knowledge generates WOPs in an open innovation framework (Guo & Zheng, 2023). When faced with high technological uncertainty, enhancing and strengthening acquired knowledge is critical for early-stage firms in a sector where knowledge modularity is minimal (Fixson et al., 2017).

Type D refers to super high technological uncertainty. This is generally estimated in industries without radical technology prior to the start of a project. Such unprecedented technological developments are innovative in the industry. The great uncertainty that determines a project's risk is that it is often unpredictable. Therefore, individual enterprises frequently avoid such radical approaches to their development. Such endeavours, such as aerospace exploration, are usually government initiatives. Due to its unpredictable nature, the technological path can only be figured out gradually through trial and error, correction, calibration, and debugging. Proposing new ideas, testing them, eliminating non-conforming solutions, and retaining appropriate solutions are analogous to the logic of evolution as an explanatory pattern (Van de Ven, 1992). Due to science's immaturity globally, the gap between emerging and industrialized economies is decreasing. For instance, in the early 2010s, the regenerative medicine industry was a rarity in the field because it involved multiple branches

of high-end expertise. This kind of cutting-edge technology is new to both developed and developing countries (McMahon & Thorsteinsdóttir, 2013). Under such circumstances, organizations endeavour to compete and collaborate to standardize in order to mitigate the risk associated with extraordinarily high technological unpredictability (Riillo et al., 2022). When foreign technology or reverse engineering cannot be introduced to the global regenerative medicine industry, catch-up in an emerging economy relies on endogenous factors such as capital investments, socio-cultural support, and market and economic consequences. As these factors are difficult to capture by traditional catch-up process models, a more comprehensive tool with greater explanatory and predictive ability is required.

Technological uncertainty results in divergent capability-building approaches, leading to various catch-up processes (Park & Lee, 2006). Mowery & Nelson (1999) assert that an industry's leadership can be measured by the performance of its leaders in the global market. Following this tradition, industry leaders were used as examples. Established studies also revealed that the catch-up and leapfrogging of a sector can be revealed by the leading firms' innovation and technological capability (Hain et al., 2020). Our analysis presents leading firms in diverse industry sectors to illuminate their catch-up process. As a result, our research scope is at the industrial level. In this study, and based on Shenhar & Dvir's (1996) typology, technological uncertainty is divided into two groups: low and high.

2.4 Methodology

The High-tech Industry (Manufacturing) Classification of China⁸ (hereafter HIMC) classifies four sample sectors into two segments: high-tech and low-tech. This is based on **the National Economic Classification of Industries of China**⁹ (hereafter GB/T 4754-2017) and reclassifies activities connected to the high-tech manufacturing industries' features. We do not

⁸ www.stats.gov.cn/tjsj/tjbz/201812/t20181218_1640081.html

⁹ www.stats.gov.cn/tjsj/tjbz/hyflbz/201710/t20171012_1541679.html

arbitrarily match technological intensity (high or low-tech) to technological uncertainty. Instead, the technological uncertainty typology criteria demonstrate that HIMC sectors have increased technological uncertainty (Shenhar & Dvir, 1996).

Case selection follows two key principles: the sample should be representative with theoretically diverse dimensions (Seawright & Gerring, 2008). The selection of the four representative industry sectors is based on the following criteria: (1) The catch-up cycle phase(s) are visible in its development trackway; (2) two are in the high-tech segment and two are in the low-tech segment; and (3) in each segment, one is in the early catch-up phase and the other is in the late phase. Table 2.1 presents China’s empirical context. These diverse cases are the primary study samples that depict the diverse catch-up cycle stages and technological uncertainties. Business partners, industrial experts, and government officials also provided information for triangulation purposes (Yin, 2003).

Table 2.1 Information of sample sectors

Sectors	Codes (HIMC)	Codes (GB/T4754-2017)	Market scale in 2017 (billion CNY)
General equipment	N/A	34	312.54
House appliance	N/A	385	1510
Electronic device (UAV)	03 (0383)	3963	7.9
Pharmaceutical	01	27	2454.44

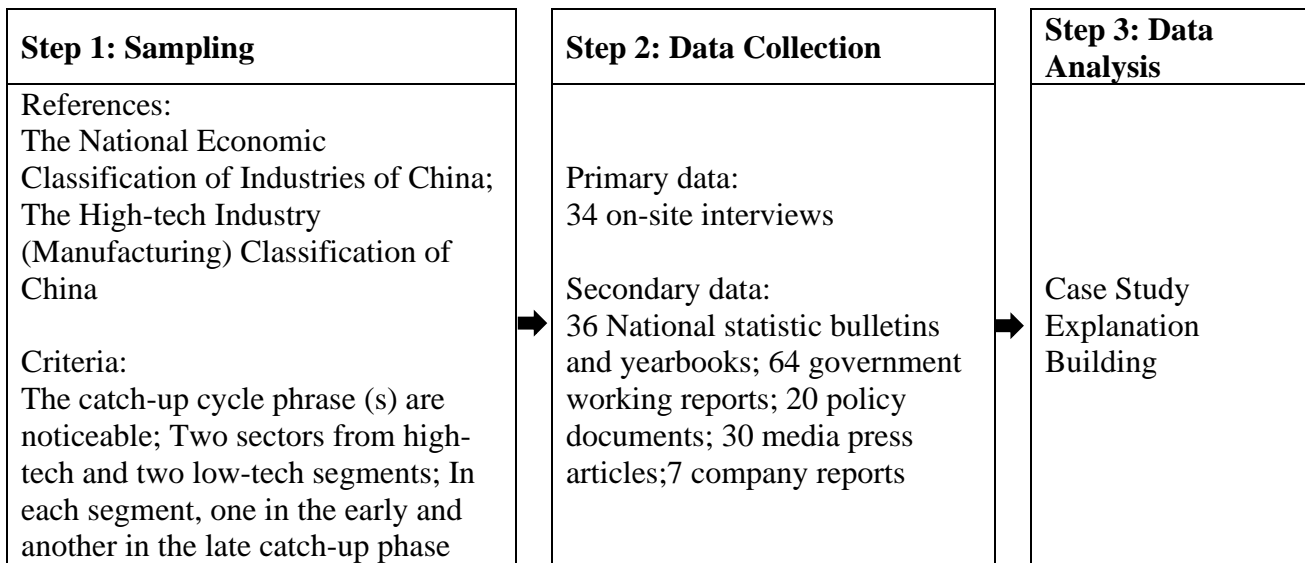
Source: The High-tech Industry (Manufacturing) Classification of China (2017), The National Economic Classification of Industries of China (2017), and The National Development and Reform Commission of China (2017).

In total, 34 onsite interviews were conducted in China between July and August 2017. Interviewees consisted of managers and executives from the four selected industries: business partner organizations (e.g., key raw material suppliers and distributors); industry experts (e.g., directors of consulting firms with close ties to the manufacturers); and government officials

who supervise the interviewed manufacturers. Interviewees had to meet the following criteria: experience, tenure, position, and knowledge of the technological catch-up within their company and industry sectors. With the interviewees' permission, interviews were recorded and transcribed. The average interview lasted 78 minutes, with the longest lasting 128 minutes, and the shortest only 15 minutes. To support the interview transcripts, nine field observation notes were taken by interviewers who visited informants onsite. These are included in the database. Thirty-six national statistical bulletins and yearbooks; sixty-four government working reports; twenty policy documents; thirty media press articles; and seven internal reports were also collected. Public websites and companies' intranets provided additional information. These secondary data sources helped us rectify informant cognitive bias and facilitate triangulation analysis (Yin, 2003).

Explanation building is carried out in a succession of revisions and is based on the interpretation of primary and secondary data (Yin, 2003). This involves proposing the original view, comparing the findings with theoretical propositions of catch-up concepts, revising the theoretical view, and applying the revised view to case details, after which the process is repeated. Model-matching logic is used to compare empirical data models and attributes to theoretical concepts. Patterns from process theories coordinate with catch-up patterns in the general equipment and pharmaceutical sectors. However, the other two sectors' cases are more complicated. Therefore, we revised theories, mediated case details, and proposed the possibility of hybrid patterns. From this premise, we returned to the theoretical perspective to elucidate the hybrid patterns.

Figure 2.1 Research Method Flow Chart



2.5 Findings

The board Chairman of company SX presents a brief overview of the Chinese manufacturing development scenario by stating that *“Depending on the manufacturing segment, the current situation and development trajectory differs from one to another in China.”* Our empirical findings and the literature both support his point of view.

Our findings are based on the technological catch-up of the four selected Chinese industries, which exhibit diverse patterns in catch-up’s early and late stages and also acknowledge technological uncertainty. Depending on the level of technological uncertainty, in the early phases of the technological catch-up, industries demonstrate either predictive or explanatory patterns. Meanwhile, two industries indicate late-stage hybrid patterns. These are a mélange of predictive and explanatory models, with each having distinctive pattern sequences. Next, we summarize our results and present our findings on patterns in the early and late stages of catch-up in the chosen industries.

2.5.1 Patterns in the early stage

2.5.1.1 Predictive Pattern

Industries that emerge from predictive patterns may have straightforward and rudimentary technical trajectories and/or endpoints. Three representative manufacturers of bearings, electrical machinery and equipment, and metal forgings align with the development of general equipment manufacturing, which is in its early stages of catch-up. According to a Company HC informant, *“this is a highly standardized industry in China, making it easy to produce on a large scale. It is suitable for wide use, and it is convenient in order to control costs (in mass production).”*

One industry report states the current situation of China’s bearing manufacturing as follows:

“The problems of low production concentration, weak R&D capabilities, and low technical level in China’s bearing manufacturing still exists.... There is a big technical gap between domestic bearing production and its foreign competitors. Urgent improvement of indigenous production is needed.” (IndRep-PS2014-014, 2014).

In hindsight, China’s growth and development in manufacturing bearing gear rotary components from 2003 to 2011 saw tremendous infrastructure investment. Consequently, the manufacturing sector saw an increase in equipment demand. From 2008 to 2013, Chinese wind power technology developed exponentially. This brought a WOP for the bearing sectors’ development. At the current level of technological development, no bearing substitutes or replacement products exist. Some new designs are still in the conceptual design phase but have not yet been popularized. *“At the moment, there are no other products that can replace bearings. New products such as magnetic levitation or vacuum bearings appear, but they do not make a revolutionary technological change in the field of traditional bearings.”* (SFL,

2017). Therefore, the key focus of core competitiveness is improving product structures and materials through internal design.

An informant describes his company's main business and production position, which is typical of Chinese electrical machinery and equipment manufacturing companies: *"We are technically an OEM, and purchase parts according to demand and assembly. We also manage after-sales technical support, but we do not produce particular components, such as capacitors or display screens"* (HC, 2017). The main business is handling and assembly. Thus, under computerization's influence, its transformation and upgrading still depend on changes in the product chain's upstream technology and are impacted by downstream market demand. It seizes the path-following catch-up strategy.

According to a report on the Chinese forging industry,

"From the Chinese Forging Association's survey of 34 forging parts companies' operation status, [...] more than 60% of forging parts manufacturers chose to compete through homogeneous low-price competition to capture market share, which intensified the market competition" (IndRep-20150108, 2015).

After a price war in the low-end forging market, forging and other metal manufacturers sought to transform and upgrade to strengthen their core competitiveness and escape vicious competition. The general manager of PK reveals,

"Previously, there were more than 300 low-end forging enterprises in the Wuxi area. These had limited technological resources with no research and development. [The rivalry] is entirely dependent on the price war, which caused the formation of vicious competition. Now our transformation is toward high-end changeover."

The creation and development of talent teams have become the current focus. This involves technical experts who collaborate with academia and industry in the production, research, and development of top talent.

2.5.1.2 Explanatory Pattern

The explanatory pattern depicts China's pharmaceutical manufacturing sector's catch-up. Through reverse engineering and independent chemical medicine exploitation, it modernizes traditional Chinese medicine and biopharmaceutical research and development. Currently, this sector is ascendant, and *“since 1978, the average revenue of China's pharmaceutical market has increased by more than 17%, much higher than that of 8% to 10% of the world market. The amount of domestic demand is the driving force for the development of China's pharmaceutical industry”* (YMKD, 2017). The government also acknowledges this development as rapid growth: *“in recent years, the pharmaceutical industry has shown moderate and rapid growth, and the results are gratifying”* (GovRep, 2009).

Based on diverse product structures and development paths, China's pharmaceutical sector has fragmented into three sub-industries. These are chemical pharmaceuticals, Chinese patent medicine, and biopharmaceuticals. The chemical pharmaceutical industry is the result of foreign direct investment spillovers and indigenous R&D. Chinese patent medicine combines traditional Chinese medicine with contemporary medicine technologies. The Chinese domestic market is vital for pharmaceutical products. Following China's 2003 accession to the World Trade Organization, an essential shift transpired where multinational pharmaceutical companies increased their production mobility. This generated increased business and profits for Chinese pharmaceutical companies and also raised international standards, advanced technologies, safety and quality concepts, and increased awareness of patent production. These factors enhanced the Chinese pharmaceutical industry's international status and competitiveness. The Wall Street Journal (Chinese edition) describes the Chinese pharmaceutical sector's development as follows:

“In reality, China's pharmaceutical industry started at the beginning of this century and experienced the development from scratch; from the use of traditional fauna and

flora materials and crafts to the large-scale application of modern technology, such as biotechnology” (cn.wsj.com, 2018).

These three Chinese pharmaceutical manufacturing segments provide an evolutionary picture of alternation and integration across product generations and segments. Chinese pharmaceuticals have caught up to chemical medicinal products through reverse engineering. This has been achieved by imitating leading companies, implementing advanced production lines, digesting and absorbing advanced technologies, before finally localizing. The Chinese pharmaceutical manufacturing industry is experiencing a turbulent rise, especially in the biopharmaceutical sector. A senior engineer from YMKD stated, *“We have just started the biopharmaceutical R&D in recent years. We have invested substantial capital in this segment. However, development is costly because talents are very scarce due to the industry infancy.”*

2.5.2 Hybrid patterns in late stage

2.5.2.1 Convergent Hybrid: from the Predictive to the Explanatory

When an industry matures to a late stage of catch-up, both predictive and explanatory patterns are necessary to fully comprehend its process. Chinese home appliance manufacturers demonstrate a convergent hybrid pattern of catch-up that evolves from predictive to explanatory. Strategically, their leadership position is maintained. As it retreats from the Red Ocean, this industry sector explores potential opportunities in the Blue Ocean market. According to a senior engineer from the Chinese home appliance manufacturing sector,

“This company is well known for its consumer electronics. Now it is in a transitional period. [...] It wants to take the high-end of the industrial chain. [...] At the time, vicious competition was shrinking in the mobile phone, DVD, television, and monitor industries” (PL, 2017).

The Chinese home appliance sector initially exploited the import substitution strategy to compete in the market. This includes the introduction, imitation, digestion, and absorption

of foreign-related products and experiences before arriving at a state of innovation. This strategy's major flaw was extensive product homogenization in the market, which eventually led to a price war. A senior manager from PL stated that, *"In the domestic market, it was once the phenomenon of bad money driving out good."* The low-end market saw competition from domestic products, while foreign brands still dominated the high-end market. The overall development and output of China's home appliance manufacturing industry have steadily increased and gained scale advantages under the market economy's momentum and advanced foreign production technologies and equipment. After entering the mature phase, the expansion rate slowed, factor input-output ratio decreased, and market capacity became saturated. During this period, businesses paid more attention to cost and quality due to increased competition. Modern equipment such as machine learning, big data, and artificial intelligence have expedited the speed of industrial restructuring. According to a recent article, the current ecology of the Chinese home appliance sector is focused on data and algorithms. The article states that,

"The appliance industry has entered a period of slowdown and needs to find new growth drivers. Emerging Internet home appliance companies, represented by Xiaomi, are changing from product-centric to consumer demand-centric. This is based on consumer big data, integrating traditional IT information technology with AI, Internet of Things, cloud computing, and other innovative technologies to improve efficiency and effectiveness at the production and retail end. Thereby, providing consumers with a good and convenient smart home experience, driving lean growth. Also, channel providers such as Suning seek to vertically integrate upstream to enhance competitiveness." (MedPre-20019835, 2020).

As home appliance popularity increases, the industry begins a recurrent evolutionary cycle with a progression of intelligent products through diversity, selection, and retention. The

focus of this new round of intelligence in home appliance production will be value-added services. These are centered on building an interconnected eco-system with intelligent home appliances. Based on generated usage data, the operation and interaction of established appliances are continuously refined and improved.

2.5.2.2 Divergent Hybrid: from the Explanatory to the Predictive

In the electronic device manufacturing UAV subsector, we observe a diverging hybrid pattern. This type of catch-up begins with an explanatory pattern and progresses to a predictive pattern. The consolidation of drone and camera technologies, as well as the maturity of domestic electronic component manufacturing, has enabled Chinese UAV companies to respond to productization more expeditiously than their foreign counterparts. In so doing, they maintain their global leadership. This recently expanding sector has absorbed upstream manufacturing qualities. National policies promoting smart hardware and intelligent manufacturing encourage local governments to facilitate and develop consumer UAV companies. According to one report,

“In July 2017, the State Council of China released the New Generation Artificial Intelligence (AI) Development Plan. The aim of the plan is to guide China to become a world leader in AI by 2030. The development of AI has been raised up to the level of a national strategy. The UAV is one of the focus sectors” (MedPre-20191-c6, 2019).

Since its inception, fundamental technology, manufacturing capability, and rigorous legislation have underpinned the Chinese consumer and commercial UAV sectors’ saltatory growth.

Client groups are expanding exponentially from niche to public as commercial UAVs mature and costs continue to fall. Commercial drones’ gradually derived functions have transformed them into intelligent and efficient production tools. Their uses include aerial photography, administrative inspection, logistical operations, and so on. The chairman of DE explains,

“From the perspective of the overall industry, the pace of product innovation is increasingly faster and faster, and intelligent functions are becoming more powerful. There are many supportive voices in the plant protection drone sector from society, and many favorable policies and regulations continue to be introduced. Consequently, the entire industry is in a period of rising, just like farming machinery in the last century, and plant protection drones are also in the process of being accepted.”

The industrial UAV market, as opposed to the consumer UAV market, demands greater technical performance and specialized industrial applications such as agricultural irrigation and pesticide spraying, remote sensing, photogrammetry, and 3D modeling. China is still in the early phases of the manufacture and application of industrial UAVs. Commercial UAV success reflects a developmental trajectory that originates from commercial technological retention. This demonstrates that these two unique UAV applications share homogeneous technology.

2.6 Discussions and conclusions

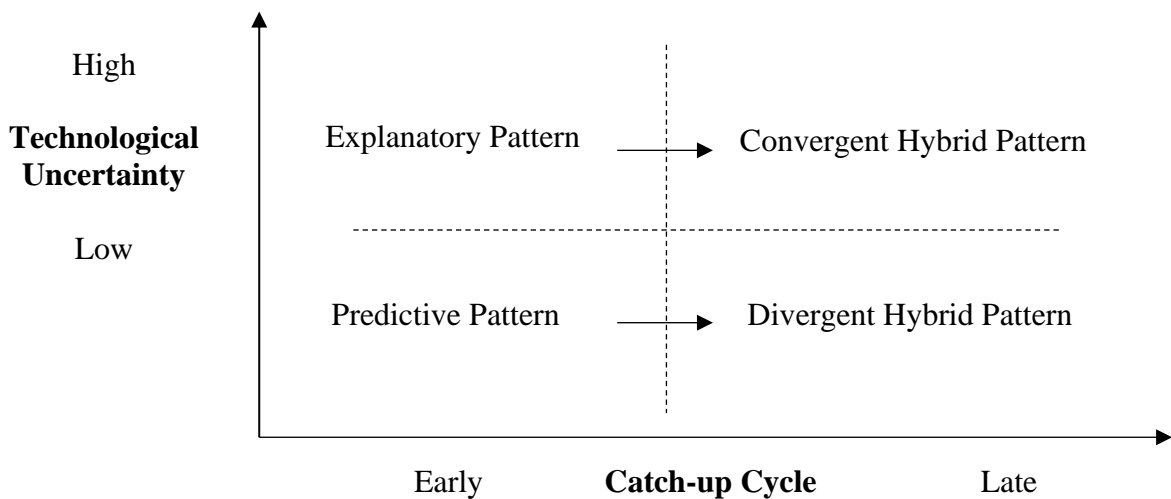
2.6.1 Discussions

2.6.1.1 Typology of Catch-up Patterns

Figure 2 depicts a typology that translates the findings into a matrix with two dimensions: catch-up cycle phases and technological uncertainty. This figure shows the selected manufacturing sectors in distinct quadrants according to their respective catch-up patterns. As the catch-up cycle evolves, WOPs serve as the demarcation line between the early and late stages of the catch-up cycle. From this perspective, the classification is based on the sectors' current catch-up progress. Among the four catch-up patterns, the predictive and explanatory patterns are congruent with Van de Ven's (1992) observations from the organizational transformation processes, while the other two are variants of the combinations (hybrid patterns) of the first two patterns. When technological uncertainty and catch-up cycle stages are low, latecomers transform from a predictive pattern to a divergent hybrid one. The

early predictive pattern represents the seriality of catch-up process phases and equifinality orientation. When technological uncertainty is low, technological trajectory is more predictable, and incumbents can be benchmarked. Latecomers' technological trajectories resemble those previously practiced by forerunners (Lee & Lim, 2001). Thus, latecomers can reduce trial-and-error costs and benefit from economies of scale. It can also prevent latecomers from achieving transcendence due to a lack of momentum, or they can be stuck in the catch-up cycle stages for a long time. After late-stage entry, latecomers with more accumulated resources and experience can better react and seize external opportunities (such as changes in market demand and institutional policies). To improve on or overtake incumbents' leading positions, latecomers must adjust their strategies and choose a more flexible exploratory pattern, such as innovation and differentiation. In Figure 2.2, this situation is labelled as a divergent hybrid pattern and the transition logic is indicated by the lower arrow.

Figure 2.2 Process Patterns in Catch-up Cycle Under Technological Uncertainty



However, when technological uncertainty is high, along with the catch-up cycle stages, latecomer industries transform from an explanatory pattern to a convergent hybrid one. The explanatory pattern's focus is to explain the emerging event's opportunities and challenges. As it is a more dynamic, flexible, and customized approach, path skipping or path creation (Lee & Lim, 2001) are the main demonstrations. High technological uncertainty makes the

technological trajectory less predictive. Consequently, latecomers must explore possibilities and pathways to improve. Latecomers may have distinct resources and experiences at the start of catch-up, and their development pathways may differ from incumbents and from one another. Such an explanatory pattern in the early catch-up cycle stage may need updating in the late stage. Latecomers can safeguard a few best practices in the late stage after gaining some latecomer advantages or overcoming latecomer disadvantages. These can eventually become references for others, such as the dominant design. Latecomers may subsequently adopt the predictive pattern for their own strategies. Consequently, in the catch-up cycle's late stage, latecomers show a convergent hybrid pattern. In Figure 2, such transition logic is indicated by the upper arrow.

Being in the early or late stages of the catch-up cycle is different from being in the early or late stages of the industrial life cycle. For instance, China's general equipment manufacturing sector is mature in terms of its industrial life cycle. However, in its catch-up cycle, it is stagnant in terms of economies of scale other than upgrading technology to a higher level. There were no exogenous nor endogenous WOPs open, thus hindering this sector's growth. In contrast, Chinese UAV manufacturing is at the forefront, with large global market shares, cutting-edge technologies, and outstanding product performance. This demonstrates late-stage maturity in its catch-up cycle, while the global UAV market is still in its growth phase. Accordingly, new entrants continue to flow in, and long-term, tenuous players remain.

Early Catch-up Stage and Pattern Monotony

The catch-up cycle's early stage involves macroenvironmental factors, such as political regulation and law, economic attributes, socio-cultural elements, and the ecological environment (Lee & Malerba, 2017). For example, labour costs drive latecomers' entry and growth, enabling them to absorb the technology through operational procedures, earn profits, and invest in R&D activities. Similar to the steel sector, Chinese general equipment

manufacturers' initial market share catch-up occurs in the inferior segment (Lee & Ki, 2017). Policy, culture, and industrial structure encourage Chinese pharmaceutical manufacturing's entry and expansion.

General equipment manufacturing in China is a technologically stable, low-tech-dominated industry that is transitioning from OEM to OBM, which is in the catch-up cycle's early stage. This OEM production enables indigenous enterprises to associate production with international orders and technological learning (Hobday, 1995). Inertia from technological maturity can hinder latecomers' transition from the established trajectory experienced by their forerunners. By pursuing a predetermined course and to catch up with the forerunners' pace, this sector may increase its capabilities and benefit from economies of scale, scope, and the learning curve effect. In so doing, they strive to dominate a market with enormous manufacturing capabilities. Nevertheless, market leadership is distinct from technological leadership (Lee & Lim, 2001). Unless latecomers respond quickly to the opening of exogenous WOPs or build endogenous ones, this is considered unattainable and unrealistic. A predictive pattern represents a conventional catch-up process with obvious and recognizable technological trajectories. Latecomers create technologies and capabilities based on slavishly followed paths, such as the industry life cycle or forerunners' path. In manufacturing industries, duplicative imitation is ubiquitous in the catch-up cycle's initial period (Kim, 1997; Lee & Lim, 2001).

When contradictory values collide, subjective initiatives enter an explanatory catch-up process. China's pharmaceutical industry has a very high level of technological uncertainty. Chemical medicines, traditional Chinese medicines, and biopharmaceuticals all evolve simultaneously. Among these, Chinese chemical medicine's catch-up begins by importing active pharmaceutical ingredients to obtain formulation abilities. This is followed by large-scale vertical integration of upstream production. As a result, economies of scale and cost

efficiency are achieved. Through collaboration with foreign firms, technologies are absorbed and assimilated, experience is accumulated, and their own R&D capabilities are progressively developed. This process resembles that of India (Guennif & Ramani, 2012). Even though traditional Chinese medicine has long dominated Chinese healthcare for centuries, it is still considered controversial from some modern pharmaceutical science perspectives. Along with the modernization of traditional Chinese medicine, independent chemical medicines, and biopharmaceutical R&D coexist and benefit from an exceptional synergy. Traditional Chinese medicine's thousand-year use of flora and fauna is a vital source of heuristic and evidence-based knowledge for advancing biopharmaceutical technology. Currently, in developed and underdeveloped countries, there is no established tracking technique for this emerging field of regenerative medicine (McMahon & Thorsteinsdóttir, 2013). China has favourable policies and regulations, significant capital investments, and tremendous domestic market prospects, allowing it to dominate in the biopharmaceutical sector. As global biopharmaceutical categories are still in the early stages of development, dominant technologies or industrial standards have yet to be determined. Consequently, during this period, leadership is often decided by manufacturing capabilities or based on controlled market share (Binz et al., 2020). These are all core competencies that Chinese biopharmaceutical categories can build by leveraging their resources and orchestrating capabilities.

2.6.1.2 Late Catch-up Stage and Pattern Hybrid

Late-stage leadership transitions are characterized by a dynamic in which a latecomer's forging ahead causes the incumbents to lag behind. While cost efficiency may initially yield competencies, maintaining the advantages and moving forward requires efficient and timely responses to WOPs. Latecomers who are more adaptable to radical innovations and disruptive technologies may capitalize from technological discontinuity (Kang & Song, 2017). Notably, latecomers are leading radical industrial innovation initiatives (Cabral, 2003). Novel and

innovative market preferences generate new consumer demands, requiring the development of market-favourable businesses by new entrants. Incumbents must pivot or modify current structures to readjust to the marketplace (Morrison & Rabellotti, 2017). The importance of institutional WOPs is reinforced and confirmed by empirical studies of catch-up in diverse industries and economies (Malerba & Nelson, 2011). After successfully forging ahead, new leaders should be cautious of the lessons learned from incumbents who lagged behind.

Chinese manufacturers may demonstrate superior efficiency and competitiveness in sectors with highly standardized mass production (Nahm & Steinfeld, 2014). Home appliance manufacturing has followed a conventional catch-up process (Kim, 1980). This sector initially captured leadership by dominating the domestic and foreign mass markets with highly standardized products. While leaders forge ahead in the catch-up cycles, early followers may experience growth, which can threaten their dominant position. To maintain leadership, incumbents must react to newcomers' catch-up symptoms and adapt innovations in response to changes in demand (Morrison & Rabellotti, 2017). Chinese home appliance manufacturers are increasing customized value of their products in the high-quality indigenous market by leveraging new technologies such as the Internet of Things and artificial intelligence. This is a pre-emptive tactic to gain the initiative in a prospective catch-up cycle and to avoid the technological obsolescence dilemma. When technological uncertainty is introduced, the resulting divergent hybrid pattern shifts from predictive to explanatory, and alternative trajectories emerge.

The Chinese UAV's saltatory catch-up with a convergent hybrid pattern has interpretations from several perspectives. One determinant is that China's electronic device manufacturing has the necessary infrastructure and expertise (Jin & von Zedtwitz, 2008), which enables an innovative architectural approach to drone manufacturing. Another determinant is that the three primary WOPs (Lee & Malerba, 2017) are open simultaneously. This boosts and

accelerates Chinese UAV manufacturers' development incrementally. Due to Chinese enterprises' significant impact on incumbents in the global UAV market, UAV technology valuation systems may become standardized. (Binz et al., 2020). When standardized followers are oriented along clear trajectories, predictive patterns are more likely to occur. Likewise, incumbents tend to adhere to industrial agreements and evolve in accordance with the industry's life cycle logic. Incumbents should be concerned that some fast-developing followers may exploit their outdated technology to incubate novel technologies and industries in order to catch up (Jin & von Zedtwitz, 2008). When the underlying strategy or technology is inflexible and cannot meet constantly changing environmental demands, the success trap should be perceived and treated with caution (Kang & Song, 2017).

2.6.2 Conclusion

Based upon the Chinese manufacturing industry and through the lens of Process Theory, this study endeavours to answer the research question of how process patterns throughout the various stages of the catch-up cycle hinge on technological uncertainty. Empirical data from primary and secondary sources is applied to a case study covering four Chinese manufacturing sectors. This analysis demonstrates that the sectors' development exhibits divergent patterns in the catch-up cycle's early stage. As the catch-up process matures, two hybrid patterns emerge as two types of pattern conjunction, and the transition from one pattern to the other is the result of the industry's response to changing technological uncertainties. This is observed in the responses to the major WOPs that arose. In addition to contributing to catch-up strategy and Process Theory research, this study has insightful implications for practitioners.

2.6.3 Theoretical contributions

The aim of this study is to contribute to catch-up and process theories at the industrial level. First, by introducing Process Theory's perspective, this study enriches the connotative concepts of catch-up cycles and transitions in industrial leadership (Kouamé & Langley, 2018;

Van de Ven, 1992; Cloutier & Langley, 2020). We define the periodical characteristics of catch-up procedures through Process Theory's predictive and explanatory patterns. This adds an innovative taxonomy of catch-up patterns to conventional patterns (Kim, 1980; Lee & Lim, 2001). Prior research found that the catch-up process was not inherently dominant, and scholars mostly interpreted it from the Strategy-as-Practice perspective. The extant literature on the catch-up process has primarily focused on describing its stages (such as phases) rather than examining and summarizing its structural nature. The categorical logic of Process Theory families is applied to the catch-up strategy to clarify the more detailed implications from a Strategy Process standpoint.

Second, this study expands previous research on the catch-up cycle's early and late stages (Binz et al., 2020; Lee & Ki, 2017; Lee & Malerba, 2017). It also identifies the determining factor that differentiates patterns in the catch-up cycles' early and late phases. Initially, latecomers develop either predictive or explanatory patterns, while hybrid patterns are recognized as two combination variants in the late stage. These are known as convergent hybrids (from explanatory to predictive) and divergent hybrids (from predictive to explanatory). Successful WOP manoeuvres determine the catch-up cycle's stages. For enhanced analysis of each stage and to clarify their developmental diversity, we combine Process Theory with catch-up. This is another significant validation and conclusion from well-established literature-based empirical studies.

Third, after long-standing debates among technology catch-up scholars, this study empirically defines and establishes the technological uncertainty function as a dominant catch-up pattern formulation (Miao et al., 2018). It contributes to the ongoing discussion on how technological uncertainty affects strategic management (Fixson et al., 2017; Riillo et al., 2022). Alternatively, it offers insight at an industrial level and supports the notion that technological uncertainty influences latecomers' catch-up patterns. Low technological uncertainty

encourages latecomers in their early catch-up stage to follow a predictable path that involves exploiting tedious technology while incubating their capabilities. When faced with technological uncertainty, latecomers must explore and consolidate fundamental technology across several trajectories. This is undertaken while leveraging other variables, such as institutional precedence and market preferences (McMahon & Thorsteinsdóttir, 2013). Furthermore, standardization occurs at catch-up's late stage due to high technological uncertainty. These two scenarios reinforce the proposition that higher technological uncertainty drives standardization (Riillo et al., 2022).

Fourth, Process Theory's implementation broadens the explanatory power and application scope of this industrial-level study. This enriches the process literature, which has previously been dominated by organizational studies (Van de Ven, 1992).

Finally, empirical data collected from four Chinese manufacturing sectors reveals representative catch-up situations in an emerging economy and takes into consideration the catch-up cycle stages and technological uncertainty. When technological trajectories are used as one catch-up indicator, this provides referential models for both latecomers and incumbents. This is especially true for those living in impoverished countries.

2.6.4 Practical applications

In addition to engaging in and contributing to theoretical debates, we believe our study addresses some practical applications for executive managers and policymakers. A strong awareness and comprehension of the industry's trends and technological uncertainty supports managers in developing successful catch-up patterns and adopting an efficient developmental approach in catch-up's early stages. In catch-up's later stages, it is essential to gain insight and knowledge into the extent of the industry's technological standardization. It is also critical to know its competitors' objectives in order to decide on differentiation or cost leadership as a competitive strategy. Policymakers should highlight the necessity of macro regulation and

implement incentive-based technology development policies for industries with low technological uncertainty. They should also encourage standardized modularization measures for industries with high technological uncertainty.

As a fast-developing emerging economy, China has experienced catch-up in a variety of industries. These include retail, (Xiong & Monin, 2015) telecommunication, (Fan, 2006) electric vehicles, (Xiong et al., 2022) and so on. Our knowledge of the Chinese catch-up process can be generalized to formulate recommendations for emerging economies in the preliminary stages of their catch-up process. Furthermore, because the catch-up cycle captures incumbents that fall behind, the latecomer forging ahead may teach the declining pioneer how to launch a comeback. In addition to the catch-up approach, industries in different countries are guided by technological uncertainties in each sector.

2.6.5 Limitations and future research

The prospect of interactions among various technologies dictating their catch-up patterns in one particular industry remains unexplored. A catch-up cycle at the macro level (i.e., national level) demands further extensive research that embraces and incorporates additional markets and institutional risks. Research at various levels may compensate for research scope limitations. In addition, path dependency hinders other emerging economies from flourishing on the same scale and scope as China. Consequently, patterns at various stages are not directly transferable to other contexts; thus, further research in diverse contexts may validate the general application and relevance of this study's findings. As we have only recently revealed the process's patterns, our understanding of the process's underlying mechanisms, such as the specific constructs, relationships, and influencing factors, remains insufficient. In future studies, longitudinal research that focuses on one company's catch-up may provide more precise information at an organizational level, where capability-building theory and a resource-based view may enhance our understanding. Notably, not all latecomers who succeed in

catching up do so through the use of technology. Instead, these latecomers may forge ahead by taking advantage of institutional and/or market WOPs, and they merit further investigation. Their expertise may also serve as an inspiration to those enterprises in sectors that are less technologically advanced. With regard to catch-up patterns, the impacts of technological uncertainty are demonstrated. Future research may also focus on other uncertainties from various perspectives that affect catch-up patterns, such as policy and demand uncertainties. Furthermore, our findings did not reveal other potential patterns when the level of technological uncertainty may vary with the stages of the catch-up cycle, such as transformations from predictive to convergent hybrid patterns or from explanatory to divergent hybrid patterns. Thus, additional research into the potential transformation of catch-up process patterns may not have to exclude those alternatives. Even though the triangulation technique mitigates informant retrospective bias, it can rarely be eliminated. This study's validity and reliability could be strengthened with longitudinal research supplemented with quantitative data.

Chapter 3 How latecomers catch up to build an energy-saving industry:

The case of the Chinese electric vehicle industry 1995–2018

This article provides a detailed exploration of how China, a latecomer in the global automotive industry, has leveraged windows of opportunity (WOPs) to rapidly advance its electric vehicle (EV) sector. The study examines the interplay between government policies, technological innovation, and market dynamics that have collectively facilitated China's rise as a significant player in the global EV industry. Focusing on the Chinese EV industry, the paper studies the evolution of policy frameworks that have created and sustained WOPs, enabling Chinese firms to overcome their initial disadvantages and achieve substantial technological and market advancements. The article also investigates the role of technological and market WOPs, highlighting how these factors have driven the rapid growth and development of the EV sector in China. This research contributes to the broader understanding of how government intervention and strategic policymaking can accelerate the industrial catching up process, particularly in sectors critical to sustainable development. The findings underscore the importance of a coordinated approach that integrates technological, institutional, and market-driven WOPs to foster innovation and competitiveness in emerging industries. The insights provided in this study are important for both scholars and practitioners, offering a comprehensive analysis of the factors that drive successful catching up in high-tech industries. By focusing on the case of the Chinese EV industry, the article offers valuable lessons on the strategic management of innovation, the role of government in industrial development, and the mechanisms through which latecomer economies can achieve sustainable growth and technological leadership.

Xiong, J., Zhao, S., Meng, Y., **Xu, L.***, and Kim, S.-Y., (2022) ‘How latecomers catch up to build an energy-saving industry: The case of the Chinese electric vehicle industry 1995–2018’, *Energy Policy*, 161, p. 112725. Available at: <https://doi.org/10.1016/j.enpol.2021.112725>¹⁰

3.1 Context

After the broad, multi-sectoral analysis provided by the first paper, the second paper narrows the focus to a specific industry, EV within China. This shift allows for a more detailed examination of how technological and market-specific dynamics play out in a single, strategically important industry. It dives deeply into how government policies and institutional frameworks create WOPs that facilitate the catching up process in the EV industry. This discussion builds on the theoretical concepts introduced in the first paper but applies them more concretely to the role of state intervention and policy evolution in a high-tech, emerging industry. Placing this paper second creates a logical progression from a broad analysis of sectoral patterns under technological uncertainty to a focused case study that explores these dynamics within the context of a specific industry. This allows us to see how the general patterns discussed earlier manifest in a real-world, high-stakes industry that is crucial for sustainable development.

The publication journey of this chapter was notably smoother compared to other chapters in this thesis. The initial draft of the manuscript was completed and submitted to the journal *Energy Policy* on 16/11/2020. The paper aimed to investigate how various WOPs -

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technological, institutional, and market - emerged and influenced the catching-up process of the Chinese electric vehicle (EV) industry.

On 02/04/2021, the paper received a major revision decision from the reviewers. The primary feedback highlighted the need for a clearer methodological approach, a more detailed discussion of policy evolution, and the interplay of different types of WOPs in the catching-up process. Additionally, the reviewers suggested enhancing the theoretical grounding and providing a more robust analysis of the empirical data.

In response to the reviewers' comments, significant improvements were made to the manuscript. The methodology section was thoroughly revised to better articulate the case study approach. This included the addition of 15 new interviews conducted in June and July 2021, which provided a richer dataset and more updated and clear insights into the Chinese EV industry's development. The theoretical framework was refined to focus more on the interplay of different WOPs. The empirical analysis was updated to include a detailed examination of how government policies evolved and interacted with technological and market demands to facilitate the industry's catching-up process. The findings section was completely restructured to present an accurate narrative on the evolution and impact of WOPs. The discussion was also expanded to highlight the implications of the findings for both theory and practice, emphasizing the dynamic interactions between different types of WOPs.

After resubmitting the revised manuscript on 02/09/2021, it was accepted for publication on 16/11/2021.

The efficient pace of review and acceptance can be partly attributed to the contemporary relevance and growing importance of the topic, As the development of the EV industry and sustainability issues are highly pertinent in today's global context. Practitioners are more curious about the mechanisms of the new energy era from all perspectives. Academics are also

interested because these topics align with current global challenges and trends, offering valuable insights into sustainable practices, technological innovation, and policy impacts.

Abstract:

This research identifies how windows of opportunity (WOPs) emerge and influence the catching up process of the Chinese electric vehicle (EV) industry between 1995 and 2018 by analyzing technological, institutional, and market demand elements of the WOPs. Our case study indicates that government policies play a vital role. Along with the development of Chinese EV industry, government policies evolve from initiation to consolidation and finally reposition. Meanwhile, WOPs emerge but diverge in their patterns, from institutional to technological and finally to the market demand WOPs. Our study further elaborates the interplay of the above-mentioned three kinds of WOPs, which provide feedback to the government authorities and work jointly to facilitate the catching up of Chinese EV industry. Based on the evidence of the Chinese EV industry, we continue the discussion of the emergence and interplays of WOPs during the industrial catching up in latecomer countries like China, who is eager to build an energy-saving industry. Our case study provides a fine-grained analysis of policy evolution and its role in opening the different kinds of WOPs, which eventually contribute to the successful catching up of a latecomer industry. It also offers new insights for policymakers when building a sustainable system.

Keywords: Windows of opportunity, Latecomers, Catching up, Electric vehicle industry, Emerging market, China

3.2 Introduction

Statistics from World Bank showed that 23% of global CO₂ emissions are from the transportation sector (Baeumler et al., 2012). There has been progress towards a consensus to reduce CO₂ emissions in the transport sector and improve its energy efficiency (United Nation Climate Change Conference, 2017). New energy vehicles, including electric vehicles (EVs) and other clean-energy vehicles, are seen as increasingly advantageous in light of energy conservation and environmental protection (Axsen, 2013). Developing new energy vehicle industry or EV industry is valuable and indispensable in reducing greenhouse gas emissions (IEA, 2019)

As China accounts for the most CO₂ emissions globally (Ritchie et al., 2023) , the Chinese government promotes the EV market to tackle the pollution problems arising from car emissions and supports progress towards a sustainable transportation system. Underpinning this policy there exists the additional issue of energy safety. The percentage of China's oil imports being much higher than the international security threshold (65%). Also, with over ten years development since 1995, China has become the world's largest EV market (50.40% of global EV volume). By 2050, EV vehicles are expected to become the dominant element of the Chinese car market (Sun & Wang, 2018). The evolution of the Chinese EV industry demonstrates successful catching up; the country gradually closed the gaps with international leaders in building energy-saving industries (Zhao et al., 2019).

The windows of opportunity (WOPs) play an essential role among the factors that accelerate the Chinese EV's catching up (Yap & Truffer, 2019). The concept of WOPs is defined as the industrial dynamic discontinuity and is categorized in technological, market, and institutional domains (Lee & Malerba, 2017, p.339). For successful catching up, latecomer companies' strategies and capabilities resulting from their understandings of and reactions to WOPs are critical in each domain (Lee & Malerba, 2017). Our study follows such

categorizations and examines how different kinds of WOPs emerge and how certain types may interact with each other to facilitate catching up. Yet, the contributions of the potential interplays of different kinds of WOPs to catching up remains unclear. Studies in how to respond to and utilize WOP to realize catching up — especially those in emerging industries — are insufficient. For instance, established literature on WOPs sheds light on the catching up of developed and newly industrialized economies, such as Japan and Korea (Malerba & Nelson, 2011; Shin, 2017). How WOPs might emerge and help latecomer countries in catching up is still unknown. Therefore, we selected the newly emerged electric vehicle (EV) industry in China and studied this research question: *how windows of opportunity emerge and influence the catching up process of an emerging industry?*

This paper focuses on the technological catching up of an emerging industry of a latecomer country. In particular, with attention to the potential interplay of different types of emergent WOPs. Studies on catching up strategies consider how latecomers close the gaps to leaders (Malerba & Nelson, 2011). In the selected automotive industry, the latecomers are a local group of firms in China, and the incumbents are an international group of automotive firms with industrial leaders operating in China. Furthermore, latecomer domestic firms and leading foreign entrants may benefit from preferential policies when working in China (Gao, 2015; Xiong & Monin, 2015). Thus, the institutional regulations would play a critical role in the Chinese EV sector's catching up. This research aims to identify how critical governmental policies related to EV may influence the emergence of the WOPs. It also analyzes how this WOP may interplay and jointly contribute to the catching up process of the Chinese EV industry. This study examines how different kinds of WOP emerge and lead domestic latecomers to respond to the evolution of the industry in China. So doing expectedly allows us to enrich our understanding about energy-saving policy decision-making. Our study provides new insights on policymakers' decision-making when constructing sustainable development,

not only for an environmental-friendly industry but also for building a reliable national system for the future.

3.3 Literature review

3.3.1 Catching up

Lee & Malerba (2017) define the catching up process as reducing the gap in market competence between domestic latecomers and foreign incumbents. The latecomer's market share dominance demonstrates its success in catching up. Existing studies on catching up mainly focus on learning perspectives (Guennif & Ramani, 2012) and capability evolution (Fan, 2006). At the industrial level, studies of catching up processes emphasize the role of WOPs (Kang & Song, 2017).

Capability building is considered to be essential for latecomers in seizing technological and market WOPs. Latecomers should consider the economic, institutional, market, and social factors to facilitate technological capability building. Leading incumbents can create barriers to prevent latecomers' catching up. Therefore, latecomers must develop technological innovation, maximize local advantages and learn from foreign incumbents to break the obstacles (Du et al., 2017). Other studies identify the importance of government support in the catching up process, such as: R&D support in the Chinese wind turbine industry (Qiu et al., 2013), policy design for improving Nigeria's renewable energy (Gungah et al., 2019), and preferential government policies in the Chinese hypermarket industry (Xiong & Monin, 2015).

3.3.2 Windows of Opportunity

WOPs have been widely applied in catching up studies. Perez & Soete (1988, p.460) state that "*catching up involves being in a position to take advantage of the window of opportunity*" created by technological transitions temporarily. Perez & Soete (1988) coined the term "Windows of Opportunity," referring to the transition of techno-economic paradigms in the process of latecomers forging ahead and catching up with forerunners by adapting the new

paradigm. Scholars have noted that the emergence of WOPs may generate from changes to the prevailing policy, technology, and market demand (Kang & Song, 2017; Lee & Malerba, 2017; Lema et al., 2020). Firms' responses and the evolution of sectoral innovation systems influence the opening and closing of WOPs (Lee & Malerba, 2017). Vértesy (2017) views government support, talent training, financial and technological capability as “preconditions” for catching up. These work alongside WOPs to influence the firms' catching up processes. Other scholars highlight the internal factors of firms when WOPs emerge, such as the agility of emerging firms (Lema et al., 2020) and capabilities to interact with the windows (Xu et al., 2014). The path-following catching up strategy can enhance the competitive advantages of latecomers in the early stages of industry evolution. But Lee & Lim (2001) also identify the disadvantages of technology imitation and believe that independent, innovative capabilities and a path-creating strategy will be more effective in attaining successful catching up. The taxonomy of Lee & Malerba (2017) organizes the various WOPs into three types relevant to their association, with institutional, technological and market demand factors.

Lee & Malerba (2017) further explain why latecomers can overcome the entry barriers, gradually catch up, and forge ahead and can potentially revert backwards. Early studies also demonstrate that those market opportunities that emerged along with the time and changes are vital in catching up processes (Malerba, 2004). During the evolution of the policy and contexts, abundant potential opportunities may exist within “the houses with windows”, and there needs to be “external or internal strengths” to “install” and “open” the “windows” and seize the potential opportunities inside the “houses” Lee & Malerba (2017). They further argue that the critical elements of the three different WOPs, namely technological, market demand, and institutional windows, are crucial to catching up.

3.3.2.1 Technological WOPs

The literature reveals that disruptive innovation may alter market positions if incumbents fail to adapt to new technologies (Chandy & Tellis, 2000). This failure may arise due to risk avoidance regarding the new technology or technology lock-in with the existing technologies. The latter being defined as an “incumbent trap” (Lee & Malerba, 2017). However, latecomers can adopt new technologies by learning from incumbents without the potential technology lock-in or inertia (Christensen, 1997). In this situation, technology-related WOPs may emerge, providing latecomers with the possibility to catch up (Lee & Malerba, 2017).

3.3.2.2 Market demand WOPs

New demand for innovative products and services can present opportunities to existing players (Mathews, 2005). Some industrial leaders fail to adapt to change due to a preference for remaining with current market positions. This creates a market window for latecomers to catch up (Mathews, 2005). In the interim, many multinational enterprises implement a global strategy with a low level of localization. This conduct leaves local latecomers’ market WOPs with local advantages (Malerba, 2004).

3.3.2.3 Institutional WOPs

Lee & Malerba (2017) explain institution-related WOPs as opportunities generated by governmental support, such as beneficial policies and incentive plans. Local governmental support (i.e., taxation and R&D budgets) can support latecomers in developing their capabilities in innovation, stimulating international collaboration, and deploying local market resources (Malerba & Nelson, 2011).

The opening of WOPs can bring forth different responses from incumbents and latecomers, thereby causing changes in industrial leadership (e.g., Kim et al., 2013; Malerba & Lee, 2020; Zhou et al., 2020). For instance, in the sectors where the characteristics of the

technologies are precise, explicit, and are easily embedded in equipment, the technological WOPs tend to occur. This can be seen in the case of the catching up of Korean firms to that of Japanese counterparts (Jung & Lee, 2010). Hence, this paper examines the signals of catching up and WOPs. This is achieved by comparing and analyzing the evolution of EV policies, the fluctuation of the number of EV patents, and sales volume between selected foreign incumbents and domestic EV latecomers.

3.4 Methodology

3.4.1 Method

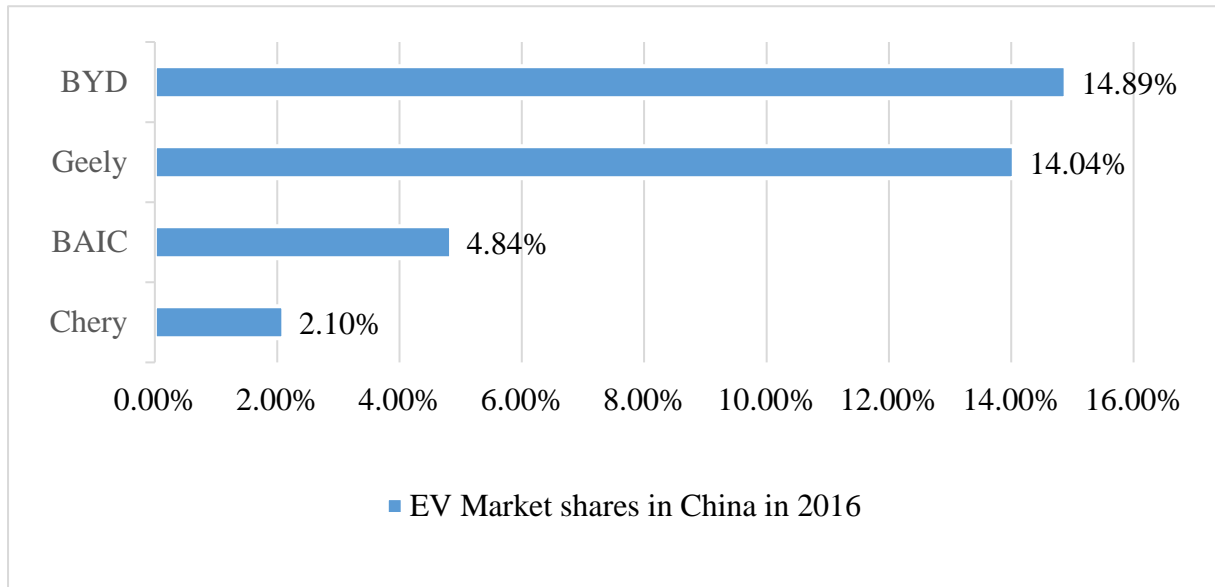
To analyze the catching up on the Chinese EV industry phenomenon in-depth and answer the research question of “how”, a case study approach is employed (Yin, 2003). This enables us to capture the contextual situation in the catching up of the Chinese EV industry and provides us with a better understanding of the interactivity between complex factors. We answer an explanatory question of “how”, which presents the need to trace the chronological sequence of interrelated events and identify their association (Yin, 2003). Therefore, the research question points to a case study investigating the current condition where relevant factors are not controllable.

3.4.2 Sampling

Faced with the growing market demand and the challenges arising from the problems of continuous increasing pollution, in 2012 the Chinese central government listed the Chinese electric vehicle (EV) industry as a strategic emerging industry (State Council, 2012). This action signifies that the local government is to provide financial and policy support such as tax credits and exemptions to EV automakers and EV purchasers (Technavio, 2016). This paper divides the Chinese EV industry into the Chinese latecomer group and the foreign incumbent group. The domestic latecomer group includes the local EV firms: BYD Auto, BAIC Group,

Geely Automobile, and Chery Automobile, based on the EV market share in 2016 (CATARC, 2016, Figure 3.1).

Figure 3.1 Top Domestic EV Firms in China (based on market shares of 2016)



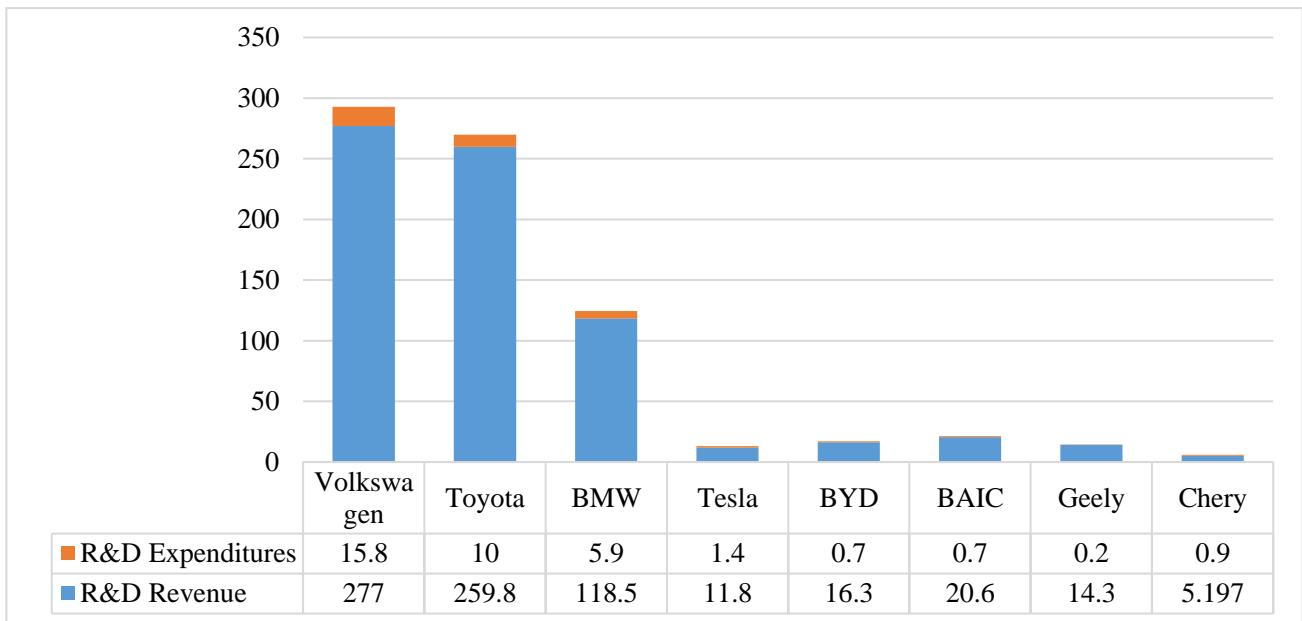
Source: Summarized from China Automotive Technology & Research Center, 2016

The foreign incumbent group includes BMW (Germany), Tesla (United States), Toyota (Japan), and Volkswagen (Germany). These two groups are selected because of the difference between the country-of-origin effect (Fortanier & van Tulder, 2009) and their technology level, market experience, and production capacity in each group. As Figure 3.2 demonstrates, a considerable gap exists in R&D expenditure between the domestic EV latecomers and the foreign incumbents. Since EV R&D programs come with high initial investment costs and long-time frames for returns on investments, domestic automakers may face the difficulty of technological catching up. Such an empirical setting meets the research question of this paper.

Figure 3.3 shows that the gap in R&D intensity between the sampled foreign and domestic firms narrowed between 2012 to 2018. To illustrate the general EV development of the country, we use the EV development of the leading domestic and foreign firms as representatives.

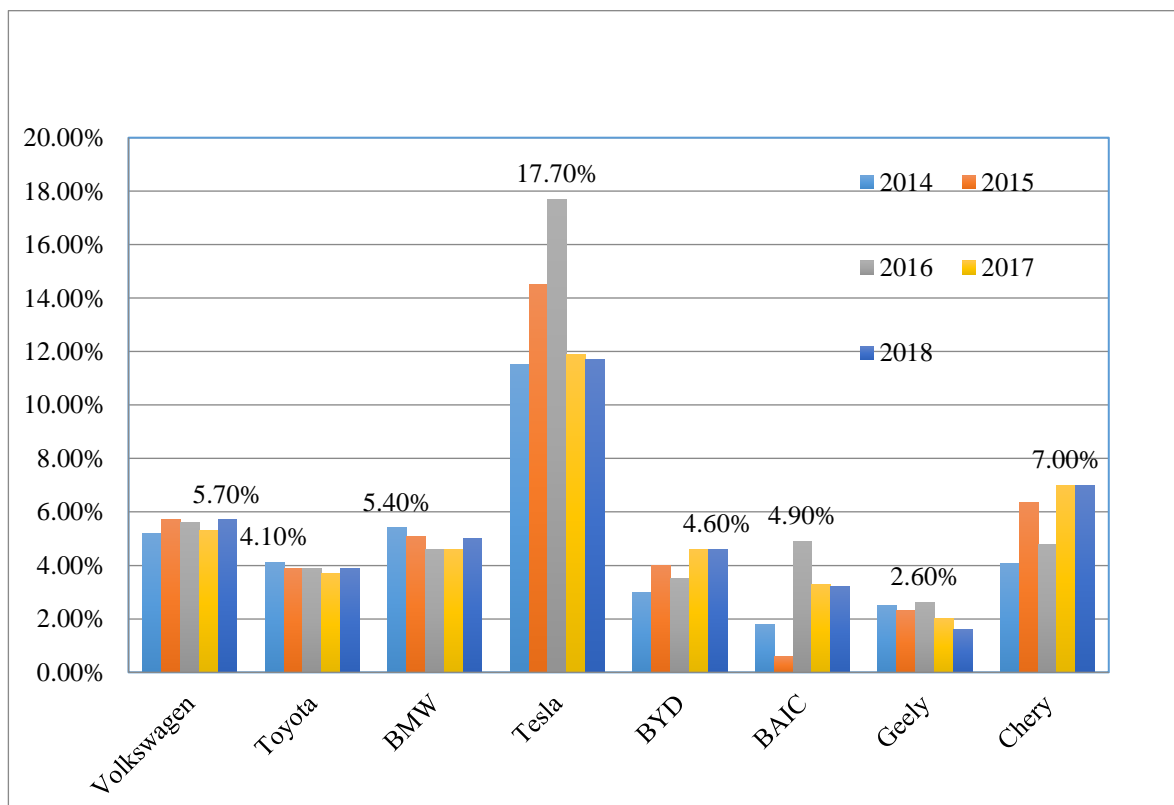
Figure 3.2 Selected Sampled Auto Firms' R&D Expenditure and Sales Revenues in 2018

(\$US Billions)



Source: Summarized from PWC, 2019. 2018 Global Innovation 1000 | Most Innovative Companies

Figure 3.3 Selected Sampled Auto Firms' R&D Intensity (2014-2018)



Source: Summarized from PWC, 2019. 2018 Global Innovation 1000 | Most Innovative Companies

3.4.3 Data source

As Table 3.1 demonstrates, the data comes from three sources: semi-structured interviews, archival data, and field observations. Data was collected via a two-stage process. 30 semi-structured interviews and secondary data from April to July 2018 were also collected. In this round, we first obtained the critical policies issued by the Chinese government, in order to understand the influences on the development of the Chinese EV industry, and the WOPs that emerged along with the industry evolution. For the second round, in June and July 2021, an additional 15 semi-structured interviews were conducted, as well as more secondary data. In this round, the data collection focuses on how different kinds of WOPs interact and work together to facilitate the catching up processes of the Chinese EV industry. In total, we collected 45 semi-structured interviews, 76 government and industry reports, other secondary data (such as literature and press reports), as well as field observations of selected Chinese EV firms.

3.4.4 Data analysis

Following the case study approach, we aggregated and classified the archival data and to analyze the periodical characteristics we utilized categorization and theme analysis techniques (Miles & Huberman, 1984). Assisted by NVIVO 12, we established coding terms to analyze the responses from the selected domestic EV firms and to set their current catching up strategies. The coding process included selecting initial codes, axial codes, selective codes and cited examples. Any errors and misunderstandings that appeared in the coding were carefully clarified and corrected. Similar to Zhao et al. (2019), we followed the national five-year plan announced by the central government of China and the development of the Chinese EV industry to examine how WOPs may emerge and interact alongside the industry evolution. We summarized the three critical stages of the Chinese EV industry as the policy initiation (1995 to 2005), policy consolidation (2006-2015), and policy reposition (2016 to 2018). This was followed with the analysis of the critical roles of WOPs as well as their interplays.

Table 3.1 Data Sources

Semi-Structured Interviews	Interview Time	First Round: April to July 2018, 30 interviews	Second Round: June to July 2021, 15 interviews
		2,085 minutes	
	Total Informants	45 Informants	
	Targeted Informants	EV firms' managers; Industry experts from both domestic and foreign EV firms	
	Language	Interviewed in Chinese and then translated into English	
Archival data	Existing literature and Reports	76 copies (Government reports, Industry reports, Firm reports, Media reports, and Literature on Chinese EV industry and EV firms)	
Field Observation	Selected fields	Record the selected EV maker's products and services in their marketing and sales departments	

3.5 Findings

3.5.1 Policy-leading catching up in the Chinese EV industry

In the past two decades, the Chinese EV industry has grown from its humble beginnings and has seen rapid development. Interview results indicate that EV development experienced three critical stages marked by policy evolution along with Chinese industry history. The three stages are policy initiation (1995 to 2005), policy consolidation (2006-2015), and policy reposition (2016 to 2018). Table 3.2 demonstrates an overview of policy evolution in the catching up process of the Chinese EV industry. This is also shown in Figure 3.4 that Chinese central and local policies have played crucial roles in each stage.

3.5.1.1 Policy initiation and industry emerging (1995 to 2005)

Similar to many other industries' catching up efforts, the catching up of the Chinese EV industry commenced from its attempt of duplicative simulation of foreign incumbents. During this emerging period, the government, enterprises, and institutions jointly demonstrated the concept of EV as a new automobile industry trend. The demonstration purpose held greater significance than its practical application. The main objectives of the Chinese government were to construct industry policy and approve new energy vehicle production qualifications for

automobile manufacturers in China. This production of new energy vehicles was mainly for some demonstrative and promotional projects in the public sector.

During this stage and from a policy perspective, the central government issued many favorable policies to facilitate the start of its domestic EV industry. The government formulated some epoch-making policies as shown below.

In the early 1990s, the Chinese government launched an international collaborated program with the United Nations called “*The Clean Energy City Plans*” to promote EVs. This move was considered to significantly affect market trends. It also announced that the traditional automotive industry in China, had entered the era of industry conversion. The promulgation of “*Policy on Development of Automotive Industry*” encouraged the domestic and foreign automobile industry to embark on various convenient ways of docking, promoting projects and expanding the scale of the industry. This policy also led to the launch of joint research and development projects between domestic and international automobile firms (Autohome, 2019). To fully exploit the EV market policy, guidance alone was not enough. In the 1990’s the crucial challenge for developing EV technology, was the problem of insufficient capital.

This challenge was mitigated to some degree as China joined the World Trade Organization (WTO) in 2001. “*The National 863 R&D Program*” commenced and reflected a more open and available Chinese market benefiting from a more precise direction of government investment and preferential policies than before. “*The National 863 R&D Program*” made financial support available to domestic firms, as well as opportunities for latent learning and technological collaboration with research institutions, universities, and foreign incumbents (Gov.cn, 2012). This program invested two billion CNY (approximate 242 million USD) in R&D to create three technical lines and three standard technologies. The technical lines were pure electric, hybrid electric, and battery. The three standard technologies were: power storage battery, drive motor, and powertrain control system (Tebon, 2020). These

efforts heralded the establishment of a comprehensive technology foundation of the Chinese EV industry. For example, BYD's disruptive innovation on the production processes and techniques of batteries signaled potential for creative imitation. BYD created semi-automation battery production lines in replacement of labor-operated machines. This turned the EV industry from capital-intensive to labor-intensive, thereby averting the problem of capital shortage associated with the advantages of sufficient and low-cost labor (Auto.ifeng.com, 2020).

In 2000's, the Chinese government proposed the development of energy-saving and environmentally friendly electric and hybrid vehicle technologies. The series of policies issued and implemented offered a solid foundation for further growth and development in the Chinese EV industry. For example, "***The National Policy on the Development of the Automobile Industry***" was announced and implemented in 2004. This policy prospected the automobile industry to become a pillar of the Chinese national economy.

As well as such policy endorsements, the Chinese EV latecomer firms also enhanced and accumulated the technology and its capabilities by imitation. Due to the favorable policies and technological development, the domestic EV companies began to increase their market share. Since then, "*China has been embracing the growth in automobile production and sales, yet the traditional energy vehicles were still the mainstream in the market*" as explained by a BYD manager (Interview#20210705, 2021). At this stage consumer recognition of the EV and its market demand were still trivial.

3.5.1.2 Policy consolidation and industry catching up (2006-2015)

During this stage, the Chinese EV industry witnessed rapid growth, boosted by a series of promoting policies. For instance, "***The New Energy Vehicle Production Access Management Rules***" in 2007 approved several new electric vehicles for mass production. Between 2009-2010, the government approved EVs for use as service cars. This procurement

implied that the government's financial investment into the EV industry was even greater than previously. To maintain their leading industry position and reduce the risks of imitation from local Chinese firms, international EV firms continued their strategic deployment of EV patents in China. In 2009, *The Ministry of Industry and Information Technology of China* issued "*The New Energy Vehicle Demonstration and Application Project*". This required Chinese firms to manufacture EV auto parts locally, and to master the core technology, thereby, playing the dual role of promotion for the domestic latecomers and resistance for the foreign EV firms. This policy sought to ease the foreign firms concerns about technological imitation from China as well as to foster Chinese local EV industry. For example, BYD's first EV, F3DM, was an outcome of the creative imitation, rather than a simple copy, of Toyota's Corolla (Auto.163.com, 2009).

After setting the development in motion by duplicating learning, the Chinese EV industry entered a launching stage where policies were enhanced and updated. Not only did the policies focus on EV production, they also facilitated the construction of relevant infrastructure. For example, for improving the convenience of charging EVs, the domestic EV firm Zhongxing Telecommunication Equipment (ZTE) invested in wireless charging technology. They were assisted by the Chinese government's infrastructure plans, such as "*The 2015-2020 Chinese Charging Infrastructure Construction Guidance*". Informants from Geely and BYD emphasized that the government-led construction plan decreased firms' financial hardship in the construction phase and increased the public awareness of EV via growing frequent exposure. A manager in BAIC also mentioned government support, stating that:

"We long for further government support or intervention in industry upgrading, collaboration stimulation, charging piles and points construction and sharing supplier network and so on, which could increase industry synergies." (Interview#20180600, 2018).

Fostering Chinese local EV industry required financial support from the government. The subsidy policies for new EV entered a phase of rapid promotion and application by the following report: “*The Interim Measures for the Management of Financial Subsidies for Private Purchase of New Energy Vehicles*” in 2010. Subsidies were allocated to the EV manufacturers, and accordingly, individual buyers or leasing companies could benefit by acquiring the EV’s at a reduced price. “Plug-in hybrid passenger cars are subsidized up to 50,000 CNY (approximately 8,070 USD) for each, and pure electric passenger cars are subsidized up to 60,000 yuan (approximate 9,684 USD) for each.” (Denza, 2013). “*The White Paper on China’s Energy Policy*”, announced in 2012, stated that China would unswervingly and vigorously develop new and renewable energy. As a result, a notice on the expansion of the demonstration and promotion of the hybrid bus was issued, with a goal of putting 3,000-5,000 energy-saving, low-emission buses into use. Consequently, 17 EV companies and 69 models of hybrid buses were offered subsidies and benefits (Caeshc.com.cn, 2013). Since then, the Chinese automotive industry has made the rapid switch from gas-burning to a new energy strategy, and with the benefits from government subsidies and policies, various types of new energy products emerged and entered the market (e.g., Cell to Pack technology by Contemporary Amperex Technology, Blade battery by BYD, etc.).

3.5.1.3 Policy repositions and industry forging ahead (2016 to 2018)

For the previous two stages, EV sales from domestic EV firms were mainly driven by Chinese government subsidies. During this next stage of policy reposition, the government reduced its subsidies to the EV industry. In 2015, *The Ministry of Finance of China* and four other ministries and commissions of China jointly clarified that, from 2017 to 2020, the subsidy standards for all EV models (except for fuel cell vehicles), would be appropriately regressed. “*The subsidy standard from 2017 to 2018 decreased by 20% on the basis of 2016, and the subsidy standard from 2019 to 2020 decreased by 40% on the basis of 2016.*” (Gov.cn, 2016).

In 2017, *The Ministry of Industry and Information Technology of China* issued “*The New Energy Vehicle Manufacturers and Product Access Management Regulations*” to clarify and reinforce the new EV production and product access requirements. From this date, the existing subsidy policy started to decline, and simultaneously the government lowered the threshold requirements (e.g., drivable range and battery energy density) for making pure electric passenger cars, thereby, allowing more players to enter the industry. The government also noticed that some new manufacturers started producing EV’s only to take advantage of generous policy subsidies. This could impact EV quality which may not be guaranteed. Consequently, *The Ministry of Industry and Information Technology of China* demanded high quality development of the EV sector and emphasized the establishment of a justice and competitive market order. They achieved this by abolishing discriminatory regulations, urging EV companies to compete with the advantages of technology, quality, price, and services.

This reduction in subsidies had shaken out incompetent companies and retained qualified ones. Such changes in the Chinese EV industry consolidated the technological competence of the domestic EV firms and their complementary assets, such as the EV-related infrastructures. One example was the battery sector of the EV industry. The number of electric vehicles urgently needing simultaneous construction of charging facilities was rising. This influenced the need to accelerate the pace of the power stations and charging pile constructions. When compared with electric motors and electronic control systems, power batteries were the main technological breakthrough for new energy vehicles. In the field of power batteries, a timeline of technological progress exists. This is similar to Moore’s Law — which indicated that energy density increases chronologically. Innovative battery technologies became commercially available. New energy vehicles range and safety was effectively enhanced; and their cost structure was optimized. Together with the battery technologies and other key technologies, Chinese EV companies endeavoured to construct the comprehensive industry

chain. For example, a government report introduced the achievement of a veteran domestic company as:

“BAIC Group’s has put 1,725 EV to commence its layout of intelligent logistics. And it deploys strategies in areas such as solid-state batteries, 5G and vehicle networking to lay the foundation for its technological innovation.” (Gov.cn, 2019).

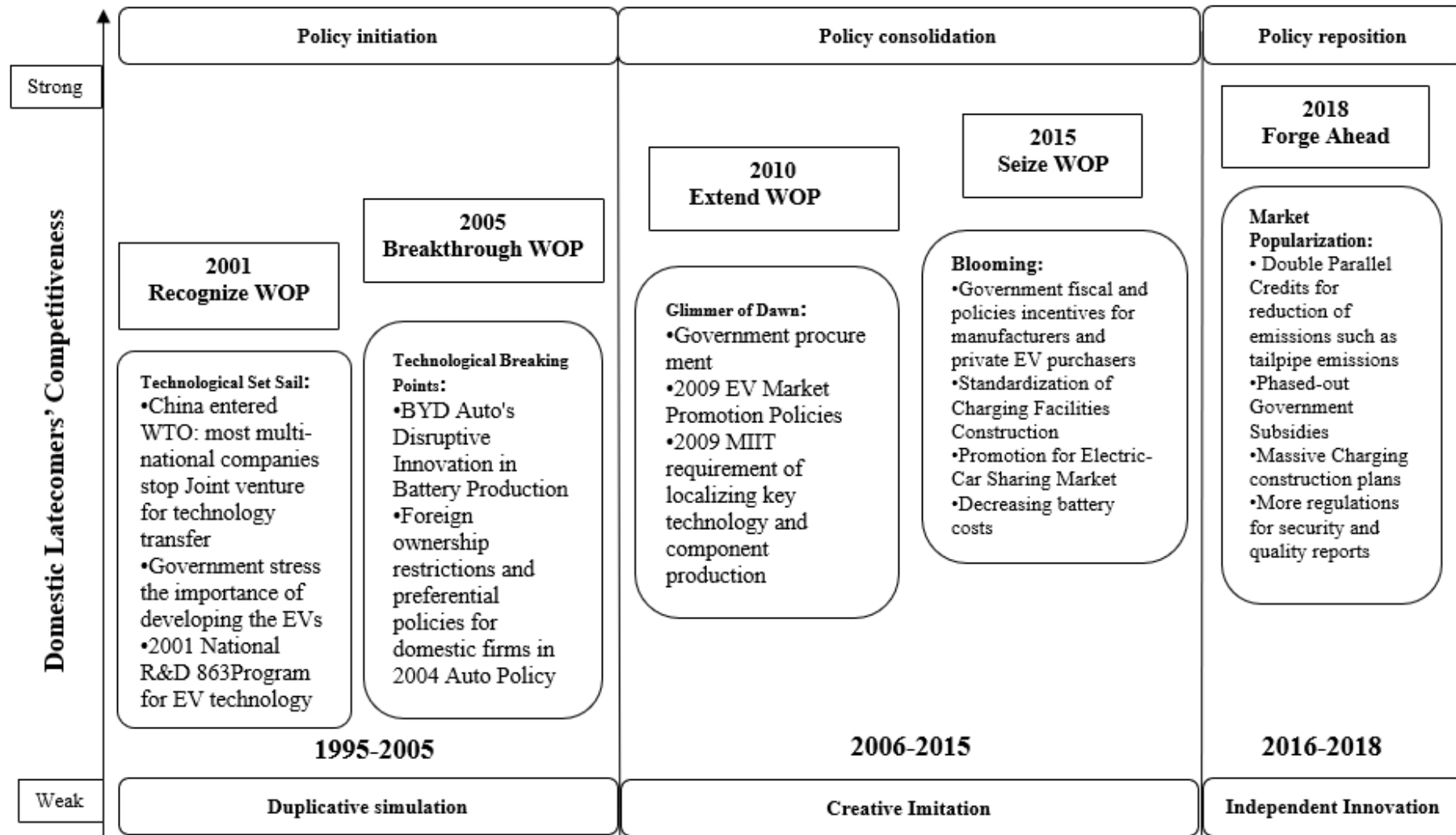
Due to technological advancement within EV firms and the enhancement of EV-related infrastructures in China, the EV market quickly expanded during this stage of policy repositioning. Consumers purchased an EV because of its energy-saving concept and its low cost. They also gained other benefits from owning an EV e.g., individual drivers could easily get a title of their cars if the car were an EV. In the Chinese domestic market, electric vehicles were mainly used in consumers’ daily lives, such as commuting to work or driving family and friends. EV users embraced the energy-saving and environmental protection that new energy cars (mainly EVs) provided and paid attention to the vehicle’s intelligence and of the advanced technological applications. In the critical EV technology field, China had established a holistic R&D structure to enable independent intellectual property achievements. For instance, the Chinese EV patents span all categories of EV production. These met the expectations and preferences of EV users and eventually contributed to the rapid development of the market in China. An industry report captured such technological advances driven by market demand:

“The majority (of Chinese EV patents) associates with automotive powertrain technology (B60L and B60K) account for 31.3%, followed by the power batteries category (H02J and H02M), which consists of 23.1%, and patents for electric motors account for 8.2%, marked as the third.” (Evpatner, 2016).

Table 3.2 Overview of policy evolution in the catching up process of the Chinese EV industry

Stage	Regulations	Authorities	Industrial theme
Policy initiating	<ul style="list-style-type: none"> -The Clean Energy City Plans (2001) -Policy on Development of Automotive Industry (1994) -The National 863 R&D Program (2001) -National Policy on the Development of the Automobile Industry (2004) 	<ul style="list-style-type: none"> -Instrumentalities of the State Council -State Development and Reform Commission -State Council 	Duplicative imitation
Policy consolidation	<ul style="list-style-type: none"> -The New Energy Vehicle Production Access Management Rules (2007) -New Energy Vehicle Demonstration and Application Project (2009) -The Interim Measures for the Management of Financial Subsidies for Private Purchase of New Energy Vehicles (2010) -The White Paper on China's Energy Policy (2012) -The 2015-2020 Chinese Charging Infrastructure Construction Guidance (2014) 	<ul style="list-style-type: none"> -State Development and Reform Commission -The Ministry of Finance -State Council 	Creative imitation
Policy reposition	<ul style="list-style-type: none"> -General Planning for Technological Innovations of Industries during the 12th Five-Year Plan Period (2011) -The Notice on Further Promoting the Pilot Program for Energy Conservation and New Energy Automobile Demonstration and Popularization (2011) - New Energy Vehicle Manufacturers and Product Access Management Regulations (2017) 	<ul style="list-style-type: none"> -The Ministry of Industry and Information Technology -The Ministry of Finance -The Ministry of Science and Technology -State Development and Reform Commission 	Independent innovation

Figure 3.4 Catching up progress in the Chinese electric vehicle industry



3.5.2 Emergence and interplays of Windows of Opportunity in the Chinese EV industry

The conception of China's EV industry began with China's strategic policy of building an automotive industry. This change from traditional automobiles to EV was crucial for combatting climate change and in promoting sustainable development. The government's vital concern and support for this industry made it possible for China to launch EV as an industry. For the purpose of developing the EV industry, many policies and regulations had been issued to provide support (directly and indirectly) for scientific and technological progress, and for market prosperity. Institutional, technological, and market demand WOPs opened up sequentially. Institutional WOPs were rooted in the policies and regulations that first allowed the EV industry to emerge and grow. The opening of institutional WOPs induced the beginning of technological and market demand WOPs, which jointly flourished the EV industry in China.

3.5.2.1 The heterogeneity of WOPs emergence

In the process of Chinese EV's catching up, the WOPs emerged from the promulgation of government decrees, the evolution of technology, and the transformation of market demand. In such a process, the importance of WOPs from different sources varied. For example, at the initial stage of development, institutional WOPs was considered the dominant WOPs and regarded as the essential WOPs. The technological WOPs and market demand WOPs were marginal or had not yet even appeared. We recognize these different sources and importance of WOPs emergence as the heterogeneity of WOPs emergence.

When reviewing the development of the Chinese EV sector, it was clear that the institutional WOPs triggered the technological and market demand WOPs. From a chronological point of view (i.e., horizontal comparisons), the critical change nodes in the evolution of policy, technology, and market demand reflected the opening of WOPs. From a dynamic point of view (i.e., vertical comparisons), the switches of the three aspects of WOPs influenced each other. For instance, during the late stage of rapid development (2006-2015),

investment into technological development of various emerging EV enterprises became overheated, and the industrial rules were unclear. The government, very quickly issued restraint and regulation of the industry, reacting to technological WOPs. During the process of the EV industry's catching up, the opening, maintenance, and interaction of all three aspects of WOPs were not independent but interacted and restricted each other. These interactions and correlation of institutional, technological, and market demand WOPs are summarized in Figure 3.5.

At the commencement of the Chinese EV sector, the rapid launch and development was credited to the guidance and support of policy and marked the opening of institutional WOPs. In 2001, the new energy vehicle research project was listed in "*The National 863 R&D Program*", marking the starting point of China's clear strategic and systematic development of the new energy vehicle industry. This was significant and symbolized the opening of institutional WOPs. Institutional WOPs were posed by supportive regulations; for instance, according to a national sales manager of one key supplier of BYD, "*The National Policy on the Development of the Automobile Industry*", was seen as the "*dominant driving force*" in the Chinese EV sector (interview#20210630). At the beginning of the Chinese EV industry, institutional WOPs significantly revealed its orientation function. Yet, the market, hardly responded to the new EV, which was likely due to customers having a wait-and-see attitude. The situation changed with the opening of the institutional WOPs, where regulations were set and sufficient capital was offered to the EV companies. Most importantly, this created favourable public opinion and sent clear positive signals for the companies to conduct R&D and increased confidence of EVs production. As a result, in 2009 the market responded to the EV products.

"The market introduction phase of the new energy vehicle industry began in 2009. In 2009, we organized and implemented the demonstration project of 'Ten Cities and Thousands

of EV'. In 2016, we carried out the pilot project of private EV." (*The National Development and Reform Commission of China*, 2010). Since then, many policies have been issued to powerfully boost the development of the industry so that institutional WOPs continue to expand. In the later stage of development (around 2015), the policies and regulations at the government level shifted from fiscal and tax support, and technological R&D to a regulation and management system — to better administer the development of the industry.

The government provided incentives for manufacturing EV, and the EV companies started a technological and production competition. The institutional WOPs opened in 2001, and simultaneously China entered into the WTO. In the early stage of catching up development of the EV industry, local Chinese EV enterprises began to absorb the foreign experience, technology, capital, and products, which allowed for imitation learning. Consequently, the technological WOPs immediately opened up. For example, in 2014 after Tesla lifted its patents, the quality and quantity of patented technology used in China's EV industry grew substantially. Hence, domestic EV enterprises had a more precise reference template for development. This rapid improvement brought in a discontinuity in the level of technical knowledge. The opening of the technological WOPs led to the emergence of more EV start-ups and advanced the EV technology.

Due to the convenience of using the lifted foreign technology patents, China's local R&D capacity weakened. As shown in Figure 4.1, when compared to 2011-2013, the number of EV patent applications filed in 2014 and 2015 decreased. This decline was not only caused by technological WOPs but also by governmental policy consolidation of industrial standard regulation.

The increased number of EV companies and their competition provoked incremental and radical technological breakthroughs. Chinese internet giants also entered the EV industry, which generated fierce competition. "*The rise of the EV is with the help of Internet enterprises.*

The new forces of car building generally have an Internet background, and in the process of growing up, they have reaped a lot of investment and financing from Internet giants. Internet companies have also repeatedly participated in the intelligent networking transformation of traditional car companies as intelligent solution providers.” (People.cn, 2021). Apparently, the opening of technological WOPs in the EV industry resulted in the continued increase of Chinese EV patent applications since 2016.

Market demand as an initially exogenous WOPs generated by the institutional WOPs, in turn, affected the technological WOPs. In 2009, the market demand WOPs opened when EVs were permitted to be traded in the Chinese market. This occurrence was the milestone for the demonstrating application period and the market introduction period of the EV industry. To expand the market demand, the Chinese government provided incentives for individual consumers encouraging them to purchase EVs. Manufacturers and standardized EV charging infrastructure construction sectors were also incentivized to increase production and related products. As a result, between 2014 and 2015, the key indicators of market condition and EV technology development (i.e., the number of charging points, sales and production, as well as patent applications) increased. The sales of Chinese domestic latecomers started to surpass those of international incumbents. In 2015, the technological gaps shrank significantly. Table 3.3 summarized these results. In addition, in this period, government was not the only force to lead the EV industry. EV companies largely developed their products (vehicles) and the whole EV industry accelerated, because they sensed huge buying power from individual consumers. Also, since 2015, the growth rate of the industry has slowed down. As the primary division for the promotion and application of new EVs, sales of the new energy passenger vehicles grew steadily. In contrast, the growth rate of commercial vehicle sales continued to decline (Sina, 2019). To realize virtuous growth, the Chinese EV industry must rely on the non-policy-driven market and technological advances. The purpose of manufacturing and developing EV was not

simply for receiving favourable government subsidies. Rather, EV companies focused on consumers and made numerous efforts to improve EV quality, safety, and endurance. Thus, the policy's action of stepping back may bring forth another technological WOPs.

Table 3.3 Total Number of EV Sales, Foreign Incumbents VS Domestic Latecomers in Chinese EV market

Year	Types of Groups	2005	2010	2015	2017
Total Sales (Units)	Foreign incumbents	175,700	403,200	148,939	270,365
	Domestic latecomers	N/A	7,181	104,023	343,373
Total Number of Patents applied for in China	Foreign incumbents	660	2,236	3,230	3,258
	Domestic latecomers	37	910	2,320	2,937

3.5.2.2 The dynamics of WOPs interplays

By vertically observing and comparing the timeline of the three WOPs (shown in Figure 3.5), we identified that the interaction among different opportunity windows was dynamic. Generally speaking, one window of opportunity created the next WOPs sequentially. The importance of varying WOPs changes as time progressed, and the WOPs' effects on catching up are different.

The characteristics of the early stage in Chinese EV development were institutional WOPs driven and technological WOPs empowering. After this stage, EV-related patent applications increased every year (See Technology Change in Figure 3.5). This trend indicated that technological WOPs opened following the influence of institutional WOPs. When the institutional WOPs opened, the government offered the industry financial subsidies and other supporting regulations. Accompanied by the technological achievements and product quality improvement, the market showed strong consumer purchase intentions towards EVs. These high-tech industrial advancements can create technological WOPs, attracting various players

to enter the EV sector. Traditional and emerging car manufacturers, Internet companies, third-party service companies, and various service providers flocked to the telematics industry. This saw its market scale increase and its technology advance. The telematics platform made interconnectivity possible among cars, drivers, and urban infrastructure. *“The addition of more technology companies or other new forces will also further enrich the supply of EV products and bring more and better driving and service experiences to consumers, which is beneficial to the cultivation and growth of the EV market.”* (Xinhuanet.com, 2021).

The rocketed development in the EV industry contained noises in the company foundation, industrial chain operation, vehicle registration, and market. The original policy of direct financial support had been tightened and replaced by regulatory measures of indirect support. Some policies were issued for adjusting and balancing the rapid development and disorders that were required for higher standard production processes and a higher quality end product.

“To further promote the healthy development of the EV industry, continuously improve the level of industrial technology, enhance the core competitiveness, and do a good job in the promotion and application of EV, the government has updated some items based on the original supportive policies. The aim is to ‘adjust and improve the subsidy policy for popularization and application, implement the responsibility of the main body of promotion and application, and establish a punishment mechanism’.”
(Gov.cn, 2016).

Policy triggered growth in market demand brings with it direct subsidies and sales profits to companies, so that EV company’s production and technology development receive considerable financial support.

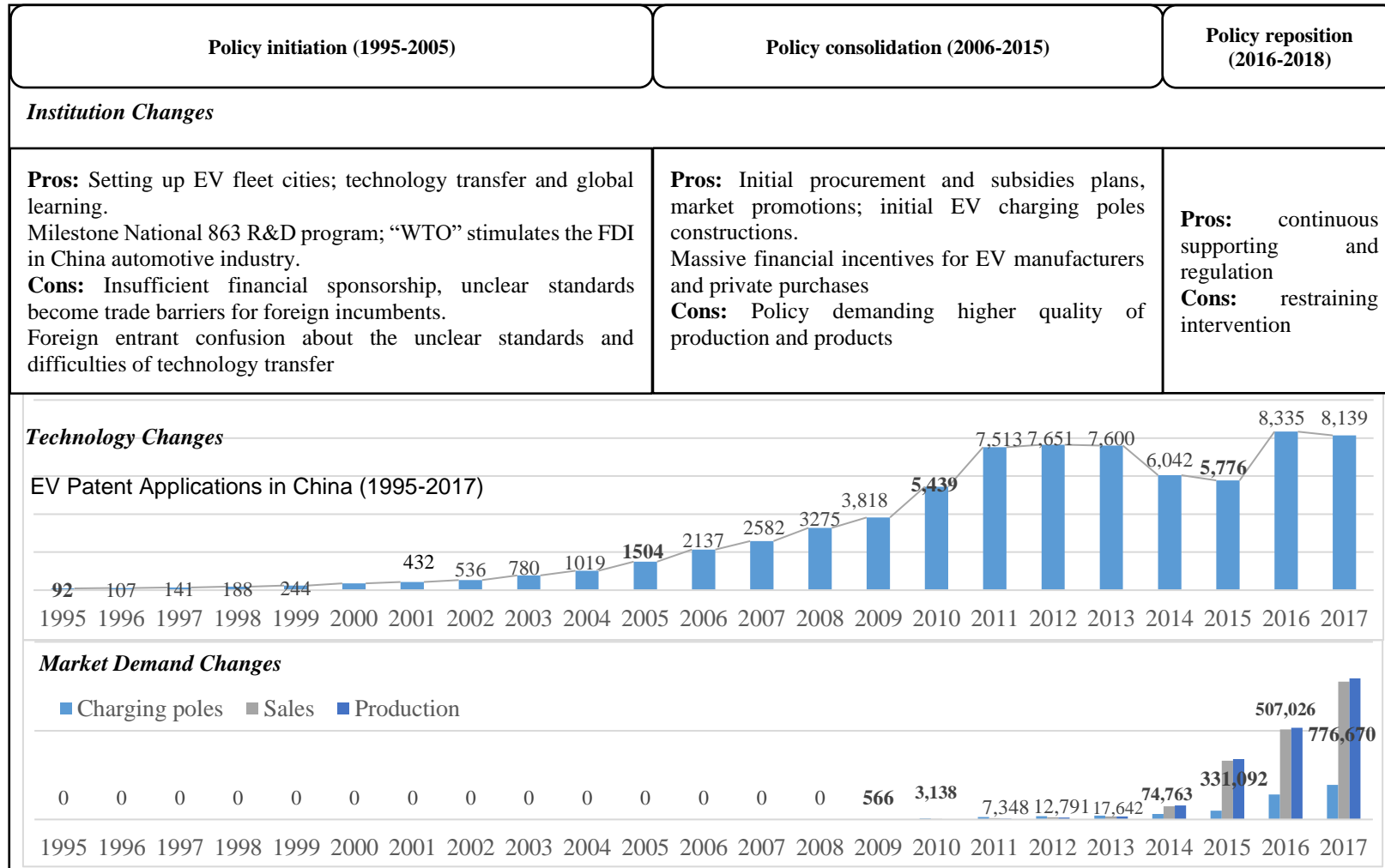
The change in subsidy policy resulted in the liquidation of the tail-end enterprises. At the outset, EV companies needed their own funds to complete production and sales before they

were eligible to apply for subsidies. This procedure brings financial pressure on the EV companies.

“When focusing on the domestic EV market, EV manufacturers are influenced by the decline of the subsidy policy. The growth rate of the whole market slows down, and the industry enters a reshuffle acceleration period. Some products having not met the market demand are gradually eliminated. In this context, how to further promote the marketization of domestic EV has become one of the main issues facing the whole industry.” (People.com.cn, 2020)

From this case study, we summarized the characteristics of WOPs emergence and interplays. WOPs emergence has heterogeneity, and WOPs interplay presented dynamics. Prior to the formation of China’s EV market, the cultivation and encouragement of the Chinese government stimulated the industrial R&D and supply of this emerging industry. Policy-led Institutional WOPs, laid the foundation for this newly conceived and unformed industry, drew a blueprint, guided the direction, and provided support. Technological R&D and production then benefited from policy support, showed their varieties in development through imitation and assimilation, and created technological WOPs. Under the joint action of industrial-technological progress, improved production efficiency, and the government’s preferential subsidy policies, the market demand gradually increased. Excellent market performance and a new consumer atmosphere formed market demand WOPs. This market demand WOPs reflected the production side, encouraged increased excellence in R & D investment, and induced a new technological WOPs. When chaos existed in the development of the emerging markets, policies came into play in time to regulate. Thereby, pushing the industry to be independent to subsidies and to be market-tested. The successive opening of each window of opportunity, progressive iteration, and mutual coordination were critical for the sustainable development of China’s EV industry in catching up.

Figure 3.5 Changes in Institutional, Technological and Market Demand WOPs in Chinese EV Industry from 1995 to 2018



3.6 Discussions

Our case study on the catching up of the Chinese EV industry shows that government policies have always been the significant factor dominating the development of a latecomer industry. This domination endogenously generates institutional WOPs. Institutional WOPs accompanied industrial evolution together with the sequentially triggering of the emergence of technological and market demand WOPs, which in return influence the institutional WOPs.

In the industry emerging stage (policy initiation), the government issued various policies and that led to the institutional WOPs. The opening of institutional WOPs brings forth the embryonic period of the Chinese EV sector. Thus, forming the fundamental industrial standard, constructing infrastructure and providing financial resources. Thereby providing technological WOPs with emergent possibilities. In the stage of industrial catching up (policy consolidation), the policies benefit technological progress, promote the development and production of Chinese EV companies, and incubate the market demand in China. Direct subsidies, e.g., purchase subsidies, insurance and tax reduction; and indirect incentives e.g., dedicated parking spots and exemption from traffic restrictions — have significantly increased consumer recognition and purchase intention. Then at the stages of industry forge ahead (policy reposition), the market demand WOPs opens, which, in turn, led to increased revenues for EV companies and further investment in technological progress. As new EV companies came flooding in, the market became overheated and industry expansion became frenzied, EV companies were motivated by beneficial governmental subsidies rather than decent production. This resulted in disorder for the EV sector. It provides insight and feedback to policymakers that further potential government interventions should take into consideration.

Our case of the Chinese EV industry demonstrates a clear pattern of how WOPs emerges heterogeneously and how local latecomer EV firms seize the different types of WOPs. The year 2001 was significant and marked the window opening when Chinese EV firms became involved in government-led R&D programs. Later, 2005 represented a breakthrough with the WOPs due to the disruptive innovation of battery production in China. 2010 was the starting point of extending the market window. This was mainly triggered by Chinese government purchases. Within the various technological, market, and policy factors, 2015 demonstrated the catching up and indicated that the Chinese EV market had become the largest globally. By taking advantage of the WOPs, domestic latecomers can catch up by maximizing their economic benefits and learn from the leading foreign EV companies.

Our study of the Chinese EV industry as a strategic emerging industry in latecomer countries complements the existing literature, mainly focusing on the high-tech sector (e.g., the telecommunications industry of Fan (2006)) and the traditional sector (e.g., the regional jet industry of Vértésy (2017)). Based on multiple sources, we provide a fine-grained case analysis of how latecomer countries catch up in building an energy-saving industry. We analyze how governmental policy evolves from initiation to consolidation and finally to reposition along with the development of the Chinese EV industry. The institutional WOPs, technological WOPs, and market demand WOPs open sequentially. Our results further demonstrate that the government policy and the interactions of the different types of WOPs can interact and eventually contribute to the rapid development of the Chinese EV industry.

Our evidence on the Chinese EV industry is consistent with the established literature (Lee & Malerba, 2017; Vértésy, 2017; Lema et al., 2020). The government policy, such as the monetary and non-monetary interventions on technology development and market systems, form the

preconditions for catching up — which drives the Chinese EV industry. More importantly, our findings complement the existing literature on WOPs, such as Lee (2005) who asserts that WOPs can appear simultaneously within the same industry. We further reveal that different types of WOPs emerge heterogeneously, and the dynamics of different kinds of WOPs along with the development of the Chinese EV industry led to its final catching up.

3.7 Conclusions and policy implications

Our results have important theoretical implications. First, our study provides new understandings of the government policy evolution and its influence on the latecomer industry's catching up. The evolving role of policy initiation, consolidation, and repositioning extends the previous literature on the critical part of government intervention (such as Gao, 2015). Second, this study advances understanding of the catching up process by highlighting the different types of WOPs that underpin it (Lee & Malerba, 2017). Our results indicate that different types of WOPs emerge heterogeneously throughout the stages of the catching up process. Also, the dynamics of the different types of WOPs facilitate the industrial catching up. Finally, we select the Chinese EV industry and conduct an in-depth case study based on multiple data sources. Our fine-grained analysis of the policy evolution and WOPs provides new understandings of latecomer countries such as China who are eager to build an energy-saving industry and achieve sustainable development.

Our study also demonstrated an essential consideration for policymakers and business practitioners when entering emerging industries. Policymakers should recognize and understand that government policy may evolve alongside industry development. In our case, governmental policy evolves from initiation to consolidation. Eventually, repositioning itself alongside the development of the Chinese EV industry. Attention should also be given to industry feedback,

such as the opening of WOPs in a heterogeneous manner. Business practitioners should seize the different types of WOPs, which are most often led by governmental policy. Yet, the heterogeneous nature of the institutional, technological, and market demand WOPs, such as those that have emerged in the Chinese EV industry, requires business executives to understand its dynamics in greater depth. The successful catching up of the Chinese EV industry reveals that the dynamics of the institutional, technological, and market demand WOPs might be more important than having only one type of WOPs' opening.

Our study also has its potential limitations. Although we analyzed closely the national policies on electric vehicles, we did not consider in detail the local policies. To date, there is no EV firm that has made a strong national presence. Future studies may consider both macro and micro policies on the energy-saving industry. Additionally, we did not differentiate the new EV venture from the EV firms transformed from the traditional automakers. Due to their differences, government policies, WOPs, and their contributions to the development of the EV industry should be considered in future studies.

Chapter 4 The Window of opportunity brought by the COVID-19 pandemic:

An ill wind blows for digitalization leapfrogging

This article explores the profound impact of the COVID-19 pandemic on digital transformation within various industries in China. The study examines how the unprecedented global crisis created unique windows of opportunity (WOPs) that enabled Chinese firms to leapfrog in their digitalization efforts, particularly in response to the urgent need for technological solutions during the pandemic. This paper introduces the concept of crisis-induced WOPs, highlighting how the pandemic accelerated the adoption of digital technologies across different sectors. It investigates the dynamic interactions between institutional, technological, and market-driven WOPs, providing a comprehensive analysis of how these factors collectively facilitated rapid digital transformation. This focuses on the varying responses of firms to these WOPs, emphasizing the role of adaptability and strategic innovation in navigating the challenges posed by the pandemic. By analyzing the digitalization leapfrogging during the COVID-19 crisis, this article contributes to the broader literature on technological catching up and crisis management. It provides valuable insights into how unexpected global events can reshape industrial trajectories and create new opportunities for technological advancement. The findings highlight the importance of flexibility, resilience, and proactive policymaking in enabling firms to capitalize on crisis-induced WOPs. This research is particularly relevant for policymakers, industry leaders, and academics interested in understanding the mechanisms of digital transformation during times of crisis. It offers practical implications for managing future disruptions and emphasizes the need for strategies that can quickly adapt to rapidly changing technological and market environments. The

study underscores the critical role of crisis-induced WOPs in driving innovation and maintaining competitive advantage in the face of global challenges.

Xiong, J., Wang, K., Yan, J., **Xu, L.**, Huang, H. (2021) ‘The window of opportunity brought by the COVID-19 pandemic: an ill wind blows for digitalisation leapfrogging.’ *Technology Analysis & Strategic Management*, 35(5), pp. 586–598. Available at <https://doi.org/10.1080/09537325.2021.1979212> ¹¹

4.1 Context

This third paper shifts the focus to the impact of an exogenous shock— the COVID-19 pandemic—on technological catching up. It introduces the concept of crisis-induced WOPs, which differs from the more traditional, policy-driven WOPs discussed in the previous papers. This paper examines how an unexpected global crisis can accelerate digital transformation and create new opportunities for catching up. By placing this paper last, the thesis moves from exploring ongoing, policy-driven catching up processes to analyzing how sudden, external disruptions can alter these processes. This evolution mirrors the complexity and unpredictability of real-world technological and industrial change, providing a comprehensive view of the different factors that influence catching up. It serves as a culmination of the thesis, highlighting the importance of adaptability and resilience in catching up processes. It ties together the themes of technological uncertainty,

¹¹ This work was supported by the National Natural Science Foundation of China under Grant #71772142.

sector-specific dynamics, and the role of government policy, showing how these elements interact in the face of a global crisis.

The inception of this paper was driven by the unprecedented global impact of the COVID-19 pandemic. Witnessing and experiencing the disruptions and the lockdowns firsthand in China, we began to contemplate the broader implications of such crises on technological and industrial transformations. Initially conceived as a viewpoint paper, the draft was completed in May 2020. In its early form, the paper was aimed at several special issue calls, including those from World Development and British Journal of Management focusing on the impact of COVID-19 on management and organization. Despite its relevance, the manuscript did not fully align with the scopes of these special issues and was consequently rejected. These rejections, however, provided valuable time to further refine and deepen the analysis.

Recognizing the evolving nature of the topic, we decided to submit the manuscript to a regular issue of Technology Analysis & Strategic Management. This allowed us to expand the scope of our study, incorporating more robust data and comprehensive theoretical insights. The paper underwent two rounds of rigorous revisions based on the reviewers' constructive feedback.

The significance and quality of this manuscript was recognised by the editor and reviewers and underwent two rounds of revisions. After the initial submission, we received a major revision decision on 25/11/2020. The reviewers suggested improving the methodological clarity, enhancing the theoretical grounding, and providing a more robust empirical analysis. We incorporated these suggestions, which included refining the research question, expanding the literature review, integrating more firm-level examples to illustrate the impact of WOPs on digitalization leapfrogging, much deeper discussed concept of Relative WOPs. The revised manuscript was resubmitted on 11/03/2021. Following this, we received a minor revision decision 04/05/2021. The

final adjustments were made to further clarify the methodological approach and better align the implications with the findings. The final version was then resubmitted on 19/05/2021 and was accepted for publication on 02/09/2021. Meanwhile, this paper was presented in the Emerging Market track at Academy of International Business Annual Conference (online) in July 2021.

Abstract:

We analyse how the COVID-19 pandemic crisis created the window of opportunity (WOP) in the digital industry and digital applications. These led to the leapfrogging of digital transformation in China. This was considered a major contribution to the pandemic recovery in early to mid-2020. By exploring this phenomenon, we examine alternatives for sustainable development during such turbulent circumstances mediating the destruction arisen from the crisis. We unveil the mechanisms that reveal the large-scale digitalization that emerged as part of the response to managing the crisis. We find that during this crisis in China, the WOPs from policy, technology and demand perspectives facilitated the leapfrogging of the digital transformation in numerous social and economic areas. More importantly, we also discover that the WOPs are unevenly distributed among firms, time, and locations. Based on these results, we put forth that the COVID-19 pandemic brings a relative window of opportunity (RWOP) to society, impacting industries and firms. However, these impacts are disproportionately distributed. To the best of our knowledge, this is one of the first studies to illustrate how a social crisis leads to WOPs enhancing digital transformation. Furthermore, this also ultimately provided a coping mechanism to deal with the pandemic.

Keywords: COVID-19; window of opportunity; leapfrogging; digital transformation; digitalization; China

4.2 Introduction

In late 2019, the outbreak of COVID-19 became a global crisis due to its rapid spread and enormous social, economic and ecological impacts. By December 31st, 2020, there were over 118 million cases confirmed globally. The wide lockdown in China and elsewhere created enormous impacts on human society. Business practices, public services and people's lifestyles were primarily affected. It is usually considered that such a crisis leads to an economic recession and social downturn (Nicola et al., 2020). However, the COVID-19 pandemic surprisingly facilitated a remarkable surge of digital transformation in China, which eventually aided the country's ability to cope with the pandemic. A wide variety of digital technologies such as cloud office, online education, smartphone apps of healthcare, public emotion consolation system, online entertainment, online public services, agile production, etc., were rapidly adopted. These actions significantly improved the social and economic climate for fighting against the pandemic. We consider the surge of the digital transformation nationwide as leapfrogging (Lee & Malerba, 2017) and observe that these WOPs were induced by the COVID-19 pandemic.

We also believe that the leapfrogging of digitalization is beneficial in tackling the COVID-19 pandemic. The established literature summarizes how successive changes in an industry's leading position are recognized as a "catch-up cycle" (Lee & Malerba, 2017). Incumbents are unable to maintain their advantages, thereby allowing latecomers to catch up. Scholars have gradually started to use the concept of "Window of Opportunity" in their research to refer to the definition, triggers, processes, and mechanisms of the catch-up cycle. Thereby, characterizing the opportunities arising from technological changes, changes in demand, institutions/policies, as well as other factors such as social movements. The recent research on the impact of the COVID-19 pandemic has focused on the reactions from business firms' such as resilience (van Hoek, 2020),

adaption of marketing strategy (Wang et al., 2020), and the restructuring of the global value chain (Verbeke, 2020). Yet, little research exists on how a social crisis might be an alternative source of building competitive advantage (Zahra, 2021) and how this can lead to positive benefits for firms (Teece, 2020). It was observed that a few firms outperformed others during the pandemic period. In particular, some firms were more successful in their digitalization process. Such divergent performance during the social crisis requires further investigation into the impact of social disturbance on business operations. Thus, in this study, we attempt to shed light on the question of how the WOPs emerging from a social crisis, such as the COVID-19 pandemic, foster the development of firms. To be specific, we focus on exploring how the WOPs led to the rapid digitalization of Chinese firms.

We conducted a qualitative analysis of the firms' behaviours during the COVID-19 pandemic to understand how social crises lead to differences in performance. In the catching-up literature, scholars use the leading firms' global production and market shares to measure the advancement of an industry (Mowery and Nelson, 1999). Also, the suggestion exists, that the leadership of an industry can be illuminated by the improvement of the leading firms' innovation and technology capability (Hain et. al., 2020). Therefore, we use multiple cases of leading firms to illuminate the outcome of industry digitalization. Our findings demonstrate that a social crisis such as the COVID-19 pandemic manifests itself as WOPs for business firms. Specifically, we illustrate how the pandemic resulted in different WOPs, namely political, technological and demand related. More importantly, rather than evenly distributed or absolute opportunities, we identify that the WOPs brought by external turmoil such as the COVID-19 pandemic provide relative opportunities for firms. Thus, we conclude our findings with a concept of the relative window of opportunity (RWOP) that emerged from the social crisis.

Our results have three major contributions. First, we contribute to the literature by extending the scope of WOPs from a one-dimensional to a two-dimensional concept with the idea of RWOP. The established literature on WOPs summarizes the contributory attributes of WOPs as, the orientations (endogenous and exogenous), the sources (policy-related, technology-related and market related), and the legibility (instant or repetitive ones) etc. (Lee & Malerba, 2017). Our findings of RWOPs extend the current studies of the WOP by identifying the significant core features of the relativeness. In so doing, our understanding of the WOP literature is enriched. Second, our study shows how RWOPs impact on firms during the COVID-19 pandemic period. This is demonstrated by the three key features of RWOP, namely, diversity, dynamism and complexity. Such results provide new insights into these three pillars of RWOPs. They also provide greater understandings of the divergent performance of firms, when facing WOPs as a result of social crises such as COVID-19. Finally, our observations of Chinese firms' performance following digitalization during the COVID-19 pandemic, responds to the call of crisis management. As China is one of the first pioneered countries experiencing the pandemic (and possibly also the first one recovered from the pandemic), the experience of China may provide practical guidelines for other regions. This is especially true to those still trying to grapple with the crisis, such as the United States, the European Union, and Latin American countries (Yu & Pang, 2020).

4.3 Literature review

4.3.1 The window of opportunity

Within the realm of the literature on WOPs, Lee & Malerba (2017) summarize how WOPs emerge from change or incongruity in the external environment and conclude that there are three types of WOP, i.e., policy-related, technology-related and demand-related. Business practices usually involve the interaction of these three main types of WOP and firm strategy. Together these

elements determine the success of less competitive firms and enhance their competence and capabilities (Kang & Song, 2017). WOPs can be further classified into being “major” or “marginal” (Lee & Malerba, 2017). When important WOPs are open, the potential for change in leadership is greater for those firms that engage in increasingly aggressive competitive behaviours (Guennif & Ramani, 2012; Lee & Malerba, 2017).

Policy or institutional changes are important factors that lead to the formation of WOPs, as was seen with the catch-up process of the Taiwanese and Korean high-tech industries in the 1980s and 1990s (Lee & Lim, 2001). This was also visible in the Indian pharmaceutical industry from the 1950s to 2010s (Guennif & Ramani, 2012). Lee & Malerba (2017) summarize these catching-up cases and formally propose the concept of an institutional (policy) window. Early studies indicate that WOPs primarily result from discontinuity in business environments, and thereby offer firms the potential to leapfrog alongside their technological capabilities. Landini et al. (2017) use simulation analysis to conclude that radical technological discontinuities create WOPs for latecomer firms and economies. Yet, the size of WOPs may vary depending on the extent of the technological discontinuity. Changes in demand, especially qualitative shifts in the business cycle, also contribute to the formation of WOPs (Lee & Malerba, 2017). Due to the business cycle development, incumbents may experience difficulties and the latecomers therefore are able to enter the market at a lower cost as compared with normal times (Mathews, 2005).

Existing studies on the WOP are based on the long-term evolution and developments of business firms and industries. Therefore, the focus of established studies is on the impact of WOPs on firm performance over a much longer duration. The underlying assumption is that the benefits of WOPs on focal firms are gradual and visibility of these benefits can take a long time. In other cases, such as during major social disturbances, little research exists as to how such external

disruptions may develop as WOPs. Other studies focus on how firms may take advantage of radical technological change to build competitive advantage (Coccia, 2017). However, those studies on disruptive technological change assume an expected positive influence on firms when confronted with the technological change. Yet, when regarding how negative external disturbances may lead to WOPs, less is known.

4.3.2 Windows of opportunity in a turbulent environment

The outbreak of the COVID-19 pandemic caused serious social and economic turbulence and many firms were led into and experienced a business crisis mode. Firms' strategies for dealing with environmental turbulence such as: financial crises, terrorist attacks, natural disasters, etc. have been studied in the strategic management literature. Environmental turbulence may deteriorate market order, restrain demand, disorder supply chain, and cause financial loss to firms. Therefore, firms often take a defensive retrenchment strategy that involves cutting unnecessary costs, for example, human resource redundancies, etc. (De Figueiredo et al., 2019). Some researchers think passively reorganizing business operations may not be an optimal strategy and consider this may magnify the negative impact of the crisis (Chakrabarti, 2015). Therefore, more researchers advocate the proactive strategy in order to deal with environmental turbulence (Lim et al., 2009). The uncertainty in the business environment caused by external crises may enable the firms' expansion (Reymen et al., 2015). New business models may emerge as a responsive solution to the crisis (Xiong et al., 2021). Environmental turbulence may become opportunities for firms to carry out mergers and acquisitions. Such can be the case, especially when target firms' difficult business position is due to the emergence of the crisis (Wan & Yiu, 2009). Based on the two alternative arguments, whether a firm sees digitalization as a solution to emerging business challenges depends on how the crisis is perceived as a WOP. This would necessitate prior

organization experience, top management teams' knowledge of the crisis, as well as insights into its characteristics (Oetzel & Oh, 2021). Furthermore, this would also involve the various strategic resources cumulated before the crisis (Kang & Song, 2017).

4.4 Methodology

We conducted a qualitative analysis, precisely, an intrinsic case study (Creswell, 2007) to thoroughly describe how a pandemic induces the leapfrogging of digital transformation in China, as well as its facilitating mechanisms. Our case selection followed the principle of theoretical sampling (Yin, 2003). The selected cases need theoretical development consisting of two broad categories: traditional sectors and internet-based industries. These two sectors had either limited business involvement in digitalization, or their development prior to the pandemic was very slow. Albeit, after the outbreak of the pandemic, both experienced dramatic growths. Our sample is of digital transformation in China since the outbreak of COVID-19 in late 2019. This is presented as the analysed sample and object. We only selected those industries actively and efficiently alerted to the WOPs that had resulted from the pandemic.

Our secondary data is derived from governmental policy, national and international press, and industry reports. Corroborating evidence from multiple sources of our data triangulate the accuracy of the outcomes of this study (Creswell, 2007). Our data ranges from December 31st, 2019 (when the first infected case was reported), to May 30th, 2020, being the date of the deactivation of the first-level public health emergency in China. This date was commonly viewed as the official signal of the end of the spread of the COVID-19 pandemic in China. Market demand for intelligent systems, computing and communication technologies, such as cloud computing, big data, 5G, AI, machine learning, computer vision, thermal, ultrasound, etc., rose sharply during the pandemic. This has been attributed to the social distancing and quarantine policies that were enforced during

this crucial time. The pandemic created the WOPs, which became the main driver of digital transformation development.

We conducted an embedded analysis (Yin, 2003) of various WOP types driven by digital transformation. After a detailed examination of a variety of reports, we commenced with a description of the case. We then highlighted significant statements. These enabled us to focus on key issues whilst analysing themes (Creswell, 2007). These are clustered accordingly into policy-related, technology-related and demand-related windows (Lee & Malerba, 2017). Chronological illustration, classification and comparative discussions collaborate to reveal the outcomes of the analysis. Following conclusions regarding the essence of the digital transformation leapfrogging in China, we interpret how WOPs are constituted against the backdrop of COVID-19.

4.5 Findings

The sudden outbreak of COVID-19 and the resulting institutional responses caused tremendous social turbulence and upheaval. This situation led to governmental interventions, technological discontinuity and changes in demand. This, in turn, developed into diverse and significant WOPs for fast digitalization in China. For instance, some new digital technology such as 5G, cloud computing and auto-driving benefited from these new conditions. Thereby, they could capitalize on such technological discontinuity acting as a critical factor towards leapfrogging.

4.5.1 Institutional windows

In response to the COVID-19 crisis, the Chinese government introduced a series of policies and regulations. In the early stage of the emergency, government policies focused on contagion prevention as well as diagnosing and treating patients. The first policy instrument was issued on January 23rd after the Wuhan lockdown to fight against the pandemic.¹² Facing the sudden cut-off

¹² http://www.gov.cn/xinwen/2020-01/23/content_5471751.htm

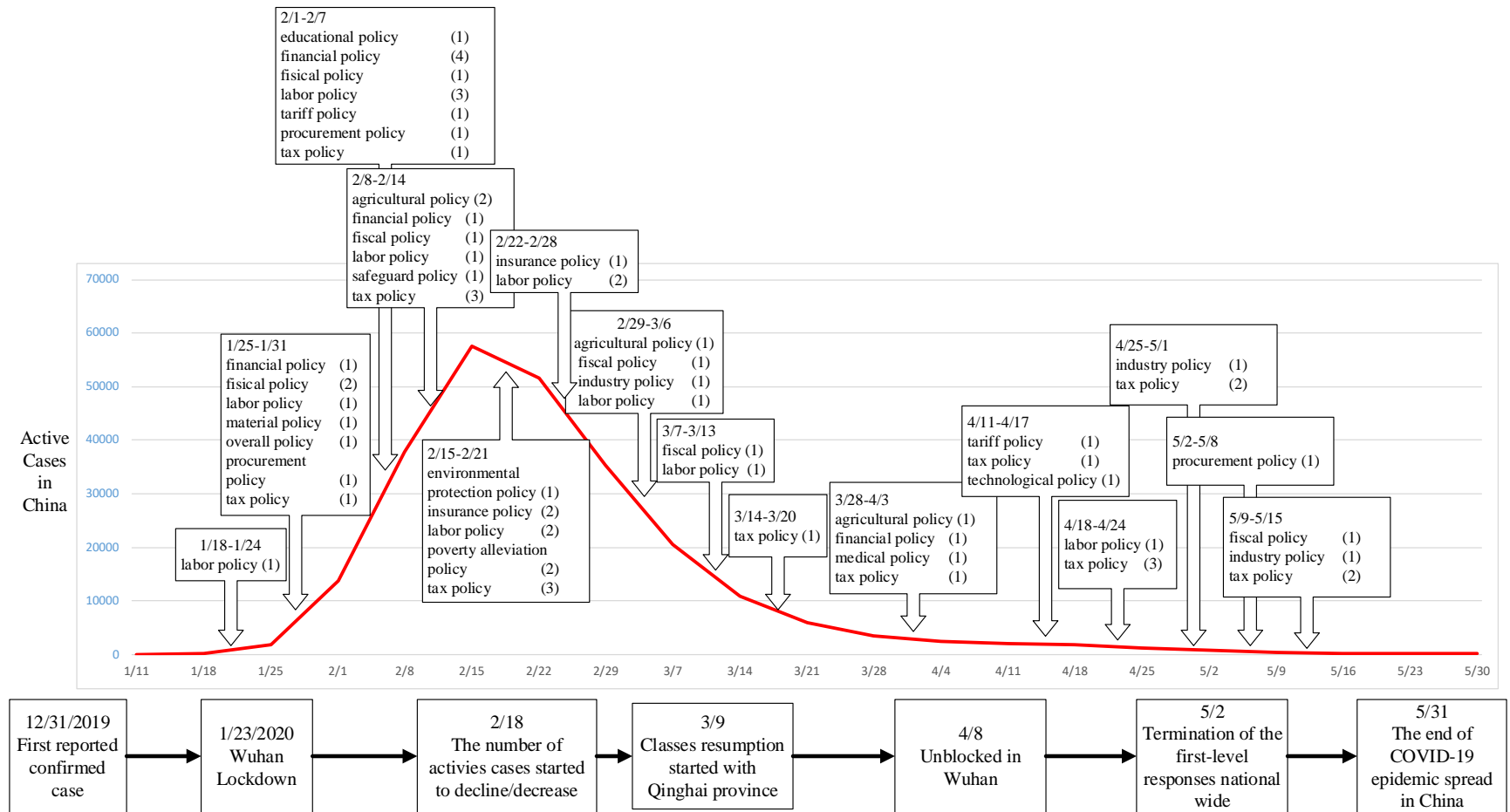
of transportation nationwide, firms were obliged to respond agilely with alternatives, especially for those whose operation relies on physical interaction. Between February 5-18, 6 Chinese governmental departments issued 26 policies and regulations related to COVID-19 treatment and prevention and over 100 billion CNY (around 14.5 billion USD) was directly allocated to healthcare organizations.¹³ The financial incentives mobilized the firms to tackle the urgent demand and contribute to the anti-pandemic endeavour. During the later stages of the pandemic, in addition to disease prevention and treatment, the government also paid attention to promoting the adoption of digital technologies. These technologies overcame the social distancing induced physical obstacle and enabled the firms to acquaint, develop and improve their capability of doing business remotely. Central and regional governments took effective actions through various policy instruments. For example, the Hangzhou Municipality in Zhejiang Province published a white book to guide and encourage the adoption of AI technologies in business operations and public services¹⁴. On April 16th, the Ministry of Science and Technology released a notice to promote the adoption of interactive technologies such as AI and big data in pandemic prevention and control¹⁵. These institutional contingencies boosted the development of digitalization rapidly in a pragmatic manner. Figure 4.1 illustrates the evolution of government interventions alongside the emerging COVID-19 crisis in China.

¹³ <http://www.gov.cn/fuwu/zt/yqfwzq/yqfkbtl.htm#1>

¹⁴ http://www.xinhuanet.com/money/2020-04/11/c_1210553501.htm

¹⁵ http://zc.gjzfwf.gov.cn/art/2020/4/14/art_8_17270.html

Figure 4.1 The evolution of policy interventions by the Chinese government during COVID-19 period



Note: The numbers in parentheses indicate the number of policy types issued in the specified week.

However, not all policies dedicated to the COVID-19 pandemic brought the expected positive outcomes. In response to negative impacts, 13 governmental departments in China issued documents encouraging webcasting in e-commerce¹⁶. While some companies successfully conducted webcasting, many other SMEs considered it cumbersome. Webcasting consists of two parts, the “actors” in the video content and the “story” in the live broadcast. The video contents of many well-known accounts were duplicated imitations. In the live broadcast, some of the key data, such as sales and user interactions (the number of followers, comments, likes, viewers, and interactions), were unable to be verified. Pursuantly, users and consumers showed their dissatisfaction of such disorder, which caused havoc and damage to the industry.

The multi-dimensional policies issued by the Chinese government not only put the domestic pandemic under control, but also induced the institutional WOPs which enabled the firms to accelerate and leverage digitalization technologies. Nevertheless, consistent with the point of view that WOPs may breed unexpected consequences (Guennif & Ramani, 2012), the firms lacking adequate resources did not benefit from the institutional WOPs. On that account, institutional WOPs were distributed inequitably among firms and locations, although the mutual objective nationwide was clearly shared by the instructions from the central governmental committee.

4.5.2 Technological windows

Developing digital technologies rode the wave of COVID-19 and the regulations and policies attached great importance to furthering the development of these technologies. On February 3rd, 2020, the Chinese Central Political Bureau hosted a conference addressing the need to increase scientific research efforts for coping with the crisis¹⁷. Following this, various government agencies

¹⁶ <https://new.qq.com/omn/20200718/20200718A0KHCG00.html>

¹⁷ http://www.gov.cn/xinwen/2020-02/03/content_5474309.htm

emphasized the use of advanced information technologies such as big data, cloud computing, AI, 5G and the IoT. For example, SenseCare, a leading Chinese AI firm, developed a COVID-19 module in lung CT imaging equipment to rapidly detect infection¹⁸. The tech giant Tencent, developed an integrated system actualizing multiple AI functions, including electronic pass, face recognition, and contactless temperature measurement for use at entry checkpoints¹⁹. Applications were developed based on cloud computing and 5G mobile networks, thereby ensuring stability and efficiency of real-time information transfer. The combinations of advanced digital technologies and traditional industries are employed to tackle the pandemic with three main efficacies, namely: medical support, public sentiment mediation, and maintenance of social order. In other industrial scenarios, for example, disease diagnosis, civil governance, telecommunications, etc., such equipment and technologies were further applied. Table 4.1 presents the details of these technologies.

It was observed that during the turbulent situation, large firms were stronger in transforming the institutional WOPs into technological WOPs. They could opt for more proactive strategies to enhance their competitive advantages (Reymen et al., 2015). However, small firms' market share risked being diluted by larger ones. We consider such divergence between large and small companies as part of the relevance of WOPs (Huang et al., 2021). The positioning of firms in the industrial value chain differed their responses to the technological WOPs caused by the asynchronous of digitalization that cast the uneven distribution of WOPs in the time axis.

¹⁸ http://www.cs.com.cn/ssgs/gsxw/202002/t20200221_6028215.html

¹⁹ <https://cloud.tencent.com/developer/news/690648>

Table 4.1 Digital technology applied in different industries to cope with COVID-19 crisis

Industries	Application types	Implemented technology	Efficacies
Information sharing	Real-Time Monitoring, Information Collection and Broadcasting, Consulting, Prevention Material Management	AI, Big Data, Cloud Computing, Block Chain	Public sentiment mediation
Medical	Medical Diagnosis, Telemedicine, Hospital Management	AI, Big Data, Cloud Computing, 5G	Medical support
Government administration	Human Temperature Measurement, Population Monitoring, Regional Management, Digital Government	AI, Big Data, Cloud Computing, Block Chain, Internet of Things, 5G	Social order maintenance, Public sentiment mediation
Online education	Live Stream, Online Courses, Platform and Solution Support	AI, Big Data, Cloud Computing, 5G	Social order maintenance
Telecommute	Instant Communication, Co-Working Integrated Solutions, Document Sharing, File Transfer, Task Management	AI, Big Data, Cloud Computing, 5G	Social order maintenance
Finance	Loan Management, Customer Service, Supply Chain Finance	AI, Big Data, Block Chain	Social order maintenance
Logistic	Unmanned Distribution, Logistics Deployment, Contactless Delivery	AI, Big Data, Cloud Computing, Internet of Things	Social order maintenance
New retailing	Cashier-less Stores, Instant Delivery, Streaming Retailing	AI, Big Data, Cloud Computing, 5G	Social order maintenance
Social media	Pandemic Surveillance Mapping, Interactive Media, Social Network	AI, Big Data, Cloud Computing, 5G	Public sentiment mediation

As a negative consequence, the abundant application of digital technologies might violate users' privacy and raised serious concerns among the public. For example, the health code system developed by Alibaba was implemented throughout the country by the government forces as an essential means of pandemic control. Based on the instant reading of personal health information and big data technology, the system identifies the population into three categories: the green code corresponds to those who tested negative to COVID-19, the yellow code is for suspected cases,

and the red code is for those who tested positive. It enabled the government to execute stricter control over people's traveling and even outdoor activities. Besides the serious concerns about privacy violation, people also worried that the system might be misused by the service providers and government for their own benefit.

4.5.3 Demand-related windows

The suspension of business activities and related lockdown of most cities caused a discontinuity of demand. This eventually led to demand-related WOPs, *viz.* demand transitioning from offline to online platforms. Table 4.2 shows where demand changed significantly for industries due to the COVID-19 crisis. Following the outbreak of the pandemic, the Chinese government required all schools to follow the “school gate closed study” rule. Shortly, more than 270 million students in primary schools, secondary schools, and universities shifted from in-class lessons to online classrooms²⁰, although online education was rarely implemented before. Since the beginning of January to May 2020, the demand of online/virtual classes, sky-rocketed and created more than 20,000 newly registered online education companies. In the first half of 2020, the total financing for online education providers was 14.34 billion CNY (about 2.22 billion USD), around a 48.3% increase than that of the previous year.

In embracing the WOPs created by the emergence of the online education market, some firms experienced rapid growth and development. For example, Tomorrow Advancing Life (NYSE: TAL) offers after-school education for students with offline schools in a few main cities as well as an online education platform targeting students nationwide. In early 2020, after the breakout of the pandemic, TAL merged with an online English training institute, Dada ABC, and exponentially expanded its online service. Even though the number of offline students drastically declined

²⁰ <http://edu.sina.com.cn/1/2020-02-09/doc-iimxyqvz1397372.shtml>

because of the pandemic, the surge of online courses led to a dramatic increase in financial return. In the first three quarters of 2020, TAL provided after-school courses to 3.4 million students. When compared with the same time period of the previous year, this is hugely significant with an increase of 46.5%.

Table 4.2 Demand change during COVID-19 crisis

Decline in demand		Increase in demand		Examples
Type	Rate	Type	Rate	
Shopping malls	○○○	Online shopping	●	In Q1 2020, the revenue of Wangfujing department store, a leading retailer in China, showed a 78.79 % like-for-like decrease; while the net income of Jingdong, a leading online retailer in China, is expected to grow by at least 10% year-on-year.
Cinemas	○○○	Online videos	●●●	The total national box office showed an 88 % year-on-year decrease in Q1 2020; while the demand for online videos outstripped supply.
Restaurants	○○○	Catering & Take away	●●	In January and February of 2020, the national catering revenue showed 43.1% like-for-like decrease.
Medical services	○○	Online medical care	●●●	During the Spring Festival of 2020 in late January, the number of visits of DXY.com, an online medical consultation service utilizing smartphone APPs, increased to 4.6 times compared to the period before COVID-19 pandemic. However, 94.1 % of hospitals experienced a like-to-like decline in cash flow during the pandemic.
Schools	○○○	Online education	●●●	270 million students used online education platforms for their studies.

Notes: 1. The symbol ○ indicates a decline in demand, and ● indicates an increase in demand.
2. The number of ○ or ● indicates the magnitude of the change.

Not all education firms benefited from this virtual education wave. Top online education companies such as Yuanfudao and Zuoyebang received investments to develop their products and services. These were substantial, amounting to 1 billion USD and 750 million USD. Some firms were slow to respond to the new market demands and were too late to adapt and transition their

services online. The WOPs related to institutional, technological, and market demands are open to all companies. Meanwhile, those firms that have increased resilience to deal with the pandemic, are those that exhibit greater agility in their digitalization capabilities and processes.

The emergence of the COVID-19 pandemic as a public health crisis causes changes in the manner and structure of consumer demands. It was a process of virtualization of the traditional offline business. Firms lacking in strategic sophistication were filtered out from the competition. Nevertheless, for the firms acting and shaping strategies agilely, the turbulence of the external environment is a WOP enabling faster growth. We see this as the asymmetrical characteristic of WOPs (Huang et al., 2021), which enhanced the irregular distribution of WOPs among firms.

4.5.4 Summary of findings

From the above case studies, we capture the integral characteristics of WOPs emerging from the social crisis caused by the COVID-19 pandemic. Institutional WOPs played a dominant role in the leapfrogging of digitalization in China. Contingency policies were the principal force in responding to the crisis and induced the institutional WOPs. The lockdown policies changed the consumption modes and business practice, and further led to the change of customer demand in the market. Shifting to novel business practices based on remote operations entails a solid technological foundation, without which the chaos could deteriorate rather than being controlled. This induced the technological WOPs, which were seized by firms possessing better technological capability and agility. The lockdown policies also bred new needs of consumers and induced the demand WOPs. The institutional, technological, and demand-related WOPs enabled fast digitalization in the country, whilst also projected divergent effects among different industries, firms, and locations.

4.6 Discussions and conclusions

In order to understand the role of a strong social crisis as WOPs, we used Chinese firms' digitalization during the COVID-19 pandemic as a context. Our results indicate that the social crisis resulted in WOPs for business firms. Nonetheless, such opportunities are not equal for all firms, nor are they evenly distributed through time and spatial dimensions. Therefore, we argue that the WOPs that consequently transpired because of the COVID-19 pandemic are RWOPs. This is due to the three characteristics of the RWOP being diversity, dynamics, and complexity.

4.6.1 Diversity of WOPs

As with the organizational diversity of different organizational compositions, WOPs have multiple attributes. The established literature involves the study of five main perspectives of WOPs. These consist of level, size, importance, source, and relationship with the firm and reflects the WOP diversity. WOPs are able to transform in an uncertain context (Keats & Hitt, 1988). This demonstrates that WOPs in an erratic environment encounter more interactions contributing to the intricacy and formation of WOPs. Consequently, opportunities may become increasingly complex and dynamic. Further investigations are necessary, to show how extreme cases of social disturbance, such as the COVID-19 pandemic may affect business activities. In particular, WOPs during the pandemic might differ from existing studies on those time periods unaffected by such extreme social disturbance.

WOPs are highly correlated with timing. Mathews (2005) concludes that companies mostly enter during the downturn phase of different industry cycles, rather than enter during the recovery phase. Established literature also emphasizes the importance of geographical differences in WOPs rather than the spatial dimension of WOPs. Drawing on Hannan & Freeman's (1984) study of organizational inertia, we argue that WOPs may also have inertia; and a firm's prompt response to

WOPs is influenced by its routines and practices. Observations of inertia are scarce in the short-term when a crisis is being faced or when the post-crisis era commences.

4.6.2 Dynamics of WOPs

We also consider WOPs to be a dynamic rather than static concept. First, in the early stages of new technology emergence and before a dominant product is formed, the transformation of exogenous and endogenous WOPs confirms the metamorphosis from an exogenous to endogenous opportunity (Morrison & Rabellotti, 2017). During a period of instability, such possibilities can be catalysed into an increased state of arousal, i.e., endogenizing innovation and changes in demand. This is followed by a continuation of industry standard-setting (Lee & Malerba, 2017). Our study validates that similar WOPs in varied contexts lead to diverse outcomes (Guennif & Ramani, 2012). By seizing the WOPs created by the COVID-19 pandemic, (such as online education services), newly emerged or adopted technology can grow exponentially. Social crises can facilitate the potential interactions of the demand-related window with the technological window, which together benefit firms with digital transformation capabilities.

4.6.3 Complexity of WOPs

We find that WOPs are complex: for Duncan (1972) the greater environment complexity is, the more different elements to be handled are. The complexity of WOPs is manifested in the fact that the formation of WOPs requires the participation and interactions of multiple actors. When analysing the issue of WOPs, early studies of the national system of innovation recognize how this interaction of multiple players must be considered (Guennif & Ramani, 2012; Lee & Malerba, 2017). Our results on digitalization transformation during the COVID-19 period in China, demonstrates that the formation of WOPs requires the complex interaction of various types of organizations. These organizations include government authorities, business firms, non-profit

organizations as well as new ventures. Thereby, involving a vast array of participants throughout the entire business community. Hence, WOPs resulting from the social crisis have greater complexity than those in non-crisis times.

4.6.4 Relative WOPs

From the above-mentioned features of diversity, dynamics and complexity, we argue that WOPs induced by the COVID-19 pandemic are relative, as an extension of the established WOP studies. This novel concept emerged from our analysis of the measures against the COVID-19 pandemic in China. RWOPs possess a different intensity and degree in terms of time, space, and inertia. The first is chrono-relativeness. WOPs are not homogeneous in the time dimension and may have discontinuities. A firms' capability to recognize and seize the WOPs may vary. This is due to the heterogeneity of the firms' resources and the contrasting perceptual capabilities of the top managers — which eventually influences firms' performance.

The second is spatial relativeness. The extent of pandemic development differs greatly across countries and regions, leading firms to adopt a variety of strategies to address the WOPs. Even those countries or regions with similar initial pandemic development, for example, China and Iran, can lead to completely disparate outcomes as governments implement diverse policy responses.

Finally, there is the relativeness of inertia. Inertia refers to the fact that the previous WOP may influence a later WOP. Online education during the pandemic fully exemplifies the inertia of the related WOPs. Before the pandemic, the opportunity for the online education industry was driven by the development of information technology. However, after the COVID-19 outbreak, and regardless of the race to replace traditional offline teaching with online options, many parents and students reported their online education experiences as ineffective. This was described as falling far short of their expectations. It was also attributed to being the root cause of many new family

disputes. In other words, the online education industry was at first driven by technological WOPs. Yet, when faced with further market WOPs, it continued to follow its existing technology-focused developmental path, rather than one focused and based on users' needs.

4.6.5 WOPs during turbulence

Usually, process research focuses on the “sequence of events that describes how things change over time” (Van de Ven, 1992, p.169). However, we focus on a phenomenon snapshot during the COVID-19 pandemic where the induced WOPs promoted the wide adoption of digital technologies. Therefore, process research is beyond the scope of this study, despite it warranting further scrutiny and investigation. Therefore, we address this suggestion as one of the future research options.

From where we stand, the latecomer enterprises' response strategies to WOPs appear to be proactive and persevering. Generally, the combination of WOPs and a proactive capability building strategy explains the reason for retaining industry leadership (Lee & Malerba, 2017). When WOPs emerge, facilitating a path-creating strategy requires sufficient knowledge and capabilities from latecomers (Kang & Song, 2017). According to Ramani & Urias (2018) latecomers having insufficient capability should invest in absorptive capacity building and reverse engineering, thereby, enabling them to respond to emerging WOPs.

However, when encountering crises, firms may respond with both proactive and persevering strategies. For instance, Wan & Yiu (2009) emphasize that the emergence of crises evokes acquisition opportunities for firms. Proactive acquisition behaviours facilitate the accumulation of strategic resources for the acquirers. Conversely, in normal times, few firms respond to WOPs with persevering strategies, whilst these passive strategies might convert into WOPs during times of crisis. In an uncertain environment, when faced with constant change, firms adopting

persevering strategies may outperform rivals who engage in aggressive strategic renewal tactics. The reason lays in the fact that too many changes in direction may undermine the value of strategic renewal (Wenzel et al., 2021).

Therefore, when responding to WOPs during crises, firms are required to act with greater strategic complexity. When responding to crises, resources and capabilities are not given the same importance, so that leveraging a firm's core competencies is the strongest defence against the challenges.

4.6.6 Conclusion

The novelty of WOPs expounded in this study answers the research question twofold. Firstly, we reveal the mechanism of WOPs emerging from social crisis, taking the response of COVID-19 in China, and unfold the characteristics of WOPs in the turbulent environment. Secondly, we zoom into the digitalization leapfrogging in the anti-pandemic procedure, and present business firms' action to take advantage of the WOPs in terms of digitalization. Essentially, we answer the questions of "how" by our qualitative endeavour. We observed that the leapfrogging of digital transformation benefitted China's fight against the virus, maintenance of social life and order, as well as the resumption of business activities. The crisis created institutional, technological and demand-related WOPs. Cloud computing, big data, 5G, AI and other technologies found strong market demand and became the main force of digital transformation. In this wave of digitalization, the divergent performance of firms is strongly influenced by the relativeness nature of WOPs. Recognizing and understanding the relativeness of WOPs is important for both policymakers and decision-makers for improved management of social crises. Also, future actions to prevent other similar environmental turbulence can be carried out.

4.6.7 Practical Implications

Our study provides practical guidelines to government policymakers and to business executives. When tackling the social crisis, these actors should see through the situation and identify opportunities which have surfaced. They also need to be vigilant to those opportunities that have derived from the discontinuity of economic and social activities. Economic growth and social value are not irreconcilable when facing a social crisis. To be precise, keeping business activities running as usual is compatible with constraining some conventional operations. An appropriate regulation may not only reduce or eliminate the negative impact from the crisis, it can also create WOPs for future advancement. The relevance of WOPs recognized in the turbulent environment is the recessive gene which should have been studied and noticed. Recognizing the relevance of WOPs becomes more important for business executives. A radically changed environment in a short timeframe brings great challenges to business operations. However, the unevenly distributed opportunities may also push the executives to transfer or adapt to the turbulence with enhanced capability. The turbulent environment shakes up market demand structure, compelling actors to respond to erratic situations. For instance, policymakers issuing new regulations to control, and business executives leveraging resources and capabilities to adapt. In particular, the opportunity of digital transformation may emerge during the social crisis and may require further adaptations in the post-pandemic era. After the pandemic, society activities may return to normality, but digital technology as a practical tool always remains, being an alternative channel for maintaining the societal order. During such processes, both policymakers and business managers must be aware of the potential drawbacks of rapid digital transformation in society, i.e., the issues related to privacy, digital stress, digital inequality, and the governance of digital technologies.

4.6.8 Limitations and future research

The case study approach enables us to scrutinize the features of WOPs in an abnormal situation from multiple perspectives. This is less likely achievable through a quantitative approach. Although our case study provides a landscape of how the COVID-19 pandemic created WOPs and led to the leapfrogging of digitalization in China, we acknowledge several limitations that may provide avenues for further inquiry. First, we studied digitalization as a solution to the social and economic crisis caused by the pandemic and focused on illuminating the outcome of digitalization. The process and mechanism at the micro level by which firms responded to the WOPs, and actualized the digitalization need further exploration. Further study could explore the procedural mechanism by multiple firm case studies. Theoretically, the study of WOPs has yet to be interpreted in detail, let alone placed in the context of the dynamic time, space and industry inertia. This unacknowledged perspective entails cross-discipline communication along with quantitative and qualitative approaches in future studies.

Chapter 5 General Discussion

The outcomes of the sequential case studies presented in this thesis contribute significantly to the literature conversations on technological catching up and WOPs. This section reorganizes the discussion to examine how the empirical studies in Chapters 2, 3, and 4 align with or challenge existing theories and what new insights they contribute. By integrating these findings, the thesis provides a comprehensive analysis of the dynamics of catching up and the three pillars of WOPs, so as to contribute to the established literature and draw implications for practitioners.

5.1 Joining in the theoretical conversation

5.1.1 The visible hand

The institutional WOPs refer to the opportunities created by government policies, regulatory frameworks, and public sector initiatives that can significantly influence the technological trajectories of firms and industries. These WOPs created and/or shaped by the visible hand in the economy facilitate catching up from various perspectives.

Regulatory frameworks and standards set by governments can also create WOPs by establishing the rules and guidelines within which firms operate. These regulations can drive technological innovation by setting high standards for product quality, environmental sustainability, and safety. For example, stringent environmental regulations can compel firms to develop cleaner technologies and adopt sustainable practices, thereby opening up new technological and market opportunities (Lee & Malerba, 2017). In Chapter 2, in the pharmaceutical sector, characterized by high technological uncertainty and stringent regulatory requirements, firms must navigate a complex landscape of scientific advancements and regulatory challenges. The ability to comply with and even shape these regulations can provide significant competitive advantages and create new WOPs (Kwak & Yoon, 2020).

Chapter 3's empirical results show government policies play a pivotal role in creating and sustaining WOPs by providing the necessary support for technological advancement. These policies can take various forms, including subsidies, tax incentives, grants for R&D, and the establishment of innovation hubs. For instance, in the Chinese EV industry, government policies such as subsidies for EV purchases, investment in charging infrastructure, and stringent emissions regulations have been crucial in creating a conducive environment for technological innovation and market growth (Fagerberg & Srholec, 2005; Gao et al., 2021; Yap & Truffer, 2019).

The ability of institutions to adapt and respond to changing technological landscapes is critical for sustaining WOPs. Adaptive policies that evolve in response to technological advancements, market conditions, and external shocks can help maintain the momentum of technological catching up. For instance, the adaptive policy framework for smart urban resilience in China during the COVID-19 pandemic demonstrates how flexible and responsive governance can create new WOPs even in times of crisis (Kim, 1998; Lim et al., 2009; Wan & Yiu, 2009). The study on the adaptive policy framework in Chapter 4 highlights how proactive and responsive institutional actions can create new WOPs by addressing immediate challenges and leveraging emerging opportunities for technological innovation and resilience.

5.1.2 The invisible hand

In addition to the visible hand of institutional interventions, the invisible hand of market demand plays a critical role in shaping WOPs for technological catching up. Market demand WOPs arise from shifts in consumer needs/preferences, emerging market needs, and changes in global demand patterns.

As consumer needs evolve, firms that can quickly adapt and innovate to meet these demands are better positioned to catch up (Giuliani et al., 2011). This dynamic is particularly evident in industries where consumer preferences are rapidly changing due to technological advancements or social trends. The rise of environmentally conscious consumers has significantly impacted the automotive industry, driving demand for EVs, as discussed in Chapter 3. Companies that recognized this shift early and invested in EV technologies have been able to capitalize on this market demand WOP, leading to significant technological advancements and market share gains (Bohnsack et al., 2015). In the healthcare sector, emerging markets have a high demand for affordable medical technologies and services. Companies that develop cost-effective healthcare solutions tailored to the needs of these markets can rapidly advance technologically and gain a competitive edge (Guennif & Ramani, 2012). For instance, the development of low-cost diagnostic tools for rural areas in developing countries has opened up significant WOPs for firms specializing in frugal innovation. That also echoes to the Chinese domestic EV market's raising.

Black swan events also trigger rapid shifts of consumers needs and preferences (Mazzoleni et al., 2020). The surge in demand for personal protective equipment, sanitizers, and contactless technologies has created opportunities for firms in the healthcare and consumer goods sectors to innovate and expand their product lines. Companies that adapted their production to meet these new needs, such as those manufacturing masks and sanitizers, have successfully tapped into emerging market WOPs (Shin, 2017). In Chapter 4, we focus on the pandemic has significantly accelerated the adoption of digital technologies as consumers increasingly rely on remote and online solutions for work, education, shopping, and entertainment. The increased reliance on remote work and online education has driven demand for improved digital communication tools, cybersecurity solutions, and cloud services. Companies that were quick to innovate, both

technology and business model wise, and scale their digital offerings have been able to capitalize on this sudden market demand, illustrating the dynamic nature of consumer needs in response to the pandemic.

5.1.3 The gap-bridging brick

In the context of technological catching up and WOPs, technology serves as the brick that bridges the gaps constructed by the visible hand of institutional interventions and the invisible hand of market demand.

Technology advancement is the key criterium which gauges the gap in technological catching up and is the essential goal the latecomers aim at achieving. It provides the necessary tools and innovations that firms need to enhance their competitiveness and achieve technological parity or advantages with more advanced competitors. In the EV industry, studies in Chapter 3, advancements in battery technology, electric drivetrains, and charging infrastructure form the bricks that allow firms to build competitive EV products and ecosystems. These technological foundations enable firms to meet consumer demands and comply with regulatory standards, thereby bridging the gap with established industry leaders (Hain et al., 2020).

Facing different technological uncertainties, the efficient and effective approaches to achieve catching up differ, as discussed in Chapter 2. In industries with high technological uncertainty, such as pharmaceuticals, Chinese firms need to develop dynamic and flexible technological competitiveness and tend to adapt more explanatory catching up patterns. While in the general equipment sector, it benefits from stable and well-established technological foundations. Firms in this industry prioritize optimizing production processes, improving quality

control, and maintaining high standards of reliability, adapting a more predictable catching up pattern which aligns with preestablished the technological trajectory.

The technological WOPs are also often the ultimate WOPs in the catching up process, which are transformed/evolved from institutional WOPs and/or market demand WOPs. In China, government policies supporting renewable energy technologies provide the scaffolding within which firms can lay the technologies necessary for developing competitive solar and wind power solutions (Quitow et al., 2017). These policies include subsidies, R&D grants, and infrastructure investments that facilitate technological advancements and market entry (Caliendo et al., 2020; Gao et al., 2021; He et al., 2006; Xie et al., 2016). Likewise, in Chapter 3, in the automotive industry, there has been a notable increase in consumer interest in electric vehicles and other sustainable transportation options. This shift in consumer preference has accelerated the adoption of green technologies and provided a significant WOP for firms developing electric vehicles and renewable energy solutions (Zhou et al., 2020). In Chapter 4, in the context of the COVID-19, the proactive interventions of Chinese government accelerated investments in 5G infrastructure and smart city projects to enhance digital connectivity and resilience, created institutional WOPs. As consumers adapted to lockdowns and social distancing measures, their reliance on digital platforms increased dramatically, and it highlights the market demand WOPs. The combined effects of government policies and changing consumer behaviour have accelerated the pace of digitalization across various sectors.

5.1.4 Through a fresh lens

The catching up process paradigm is unnecessarily consistent thoroughly for the latecomer in its catching up cycle. Chapter 2, through the theoretical thinking of process (Kouamé & Langley, 2018; Langley, 1999; Van de Ven, 1992), investigates the periodic paradigms in the catching up

process, with more focus on the role of technological uncertainty (e.g., Park & Lee, 2006). This chapter regards the catching up cycle as a completed catching up process, and regroups the four phases of the catching up cycle (Lee & Malerba, 2017) into two stages, early and late (e.g., Binz et al., 2020). Doing this also allows carefully examining the role of the technological uncertainty along with the process of technological catching up, which may not be salient within or across the phases of catching up cycles summarized from the existing literature. More importantly, the periodical phases of the catching up cycle did not involve the potential influence of technological uncertainty but assumed that technological trajectories are predictable (e.g., Lee & Malerba, 2017; . However, it might not be applicable to scenarios when technological trajectories are less predictable. Thus, the distinction of stages in the catching up process turns out to be inevitable given the fact that divergent paradigms are distinguished respectively, in particular when technological uncertainty may play a key role but is less studied. Precisely, in the early stage, the process paradigm appears monotony. However, in the late stage, the paradigm hybridity is captured. This finding completes the prevalent taxonomy of catching up process patterns (e.g., Kim, 1980; Hobday, 1995; Lee & Lim, 2001) in a dynamic manner, which integrates the catching up cycle (Lee & Malerba, 2017). More importantly, paradigms' diversity in both early and late stages is affected by the industrial technological uncertainty, consequentially, when the technological trajectory tends to be stable, predictive and divergent hybrid paradigms are more likely to occur, in contrast, explanatory and convergent hybrid paradigms are more common.

5.1.5 Sector specific dynamics

Chapter 2 also emphasizes the sector-specific nature of technological catching up, challenging the notion that a one-size-fits-all approach can be applied across different industries. By comparing the four sectors, the study demonstrates that each industry has unique characteristics

that shape its catching up dynamics. This sectoral analysis is crucial for understanding the varied pathways through which firms can achieve technological advancement. In the electronic devices sector, the rapid pace of technological change and intense global competition necessitate a focus on cutting-edge innovation and international collaboration (Malerba & Nelson, 2011). Firms in this sector must continuously innovate to stay competitive, often requiring significant investments in R&D and forming strategic alliances with global partners (Ho et al., 2017; Seo et al., 2019). In contrast, the general equipment sector benefits more from leveraging local market demand and incremental improvements to existing technologies. This sector typically experiences slower technological change, allowing firms to focus on gradual enhancements and efficiency improvements rather than radical innovation (Yap & Truffer, 2019). The pharmaceutical sector, characterized by high technological uncertainty due to constant innovation and stringent regulatory requirements, requires firms to be highly flexible and responsive (Fixson et al., 2017; Riillo et al., 2022). Companies in this industry must navigate a complex landscape of scientific advancements and regulatory challenges, making agility and the ability to quickly adapt to new developments crucial for success. In the home appliances sector, technological changes are more incremental, allowing firms to adopt more stable, long-term strategies. The relatively predictable nature of technological advancements in this sector enables firms to plan and implement gradual improvements, focusing on cost reduction and incremental innovation rather than disruptive changes (Bouncken et al., 2018; Nemet, 2009).

5.2 Theoretical contributions

This thesis makes significant theoretical contributions to the field of catching up through a comprehensive analysis of case studies in Chinese manufacturing sectors, the EV industry, and digitalization during the COVID-19 pandemic.

5.2.1 Enriching the catching up literature

This study enhances the connotative concepts of catch-up cycles and transitions in industrial leadership by applying Process Theory's predictive and explanatory patterns. This approach provides a new taxonomy of catch-up patterns, extending beyond conventional stages (Figueiredo & Cohen, 2019; Hobday, 1995; Lee & Lim, 2001). By categorizing the catch-up process into distinct phases and examining their structural nature, the study clarifies detailed implications from a Strategy Process perspective. This integration of Process Theory with catch-up strategies offers a novel framework for understanding the dynamic and evolving nature of industrial catching up.

The study also expands on previous research by identifying the determining factors that differentiate the patterns in early and late stages of the catch-up cycle (Binz et al., 2020). Initially, latecomers develop either predictive or explanatory patterns, evolving into convergent hybrids (from explanatory to predictive) or divergent hybrids (from predictive to explanatory) in later stages. Successful WOP manoeuvres determine these stages, providing a deeper understanding of their developmental diversity. This clearer view of the catch-up process enhances the theoretical framework by linking the dynamic evolution of WOPs with catch-up cycles.

Chapter 2 empirically defines the function of technological uncertainty as a dominant factor in formulating catch-up patterns. It contributes to the ongoing discussion on how technological uncertainty affects strategic management at an industrial level (e.g. Gao, 2014; Riillo et al., 2022). The research shows that low technological uncertainty encourages latecomers to follow a predictable path, while high technological uncertainty necessitates exploration and consolidation of fundamental technologies. The relationship between technological uncertainty and

standardization in the late stages of catching up reinforces the proposition that higher uncertainty drives the need for standardization.

5.2.2 Opening up the black box of WOPs' dynamics

The thesis highlights that WOPs do not emerge uniformly but rather heterogeneously throughout the catching-up process. Different types of WOPs, such as technological, institutional, and market-driven opportunities, arise at various stages of industrial development. This finding challenges the linear models of catching up and suggests a more complex, multi-dimensional approach to understanding how latecomers can leverage WOPs at different phases (e.g. Cusmano et al., 2010; Dosi, 1982; Kang & Song, 2017). The research identifies distinct stages in the catch-up process, characterized by different WOP dynamics. Early-stage WOPs are often associated with basic technological adoption and capability building, while later-stage WOPs involve more advanced innovation and market expansion. By differentiating these stages, the study provides a clearer framework for analysing how latecomers can strategically navigate the catch-up process.

The thesis demonstrates the critical role of institutional WOPs created through government policy evolution. Policies such as subsidies, infrastructure investments, and regulatory changes are shown to initiate, consolidate, and reposition industrial growth. This finding underlines the importance of adaptive and responsive policy measures in facilitating technological catching up (e.g. Gao, 2015; Kim & Park, 2019; Mei & Zhang, 2022; Qiu et al., 2013). Market demand WOPs, driven by shifts in consumer preferences and emerging market needs, are pivotal in shaping technological innovation. The COVID-19 pandemic, for instance, significantly altered consumer behaviour, leading to increased demand for digital solutions and creating new WOPs for firms to exploit. This dynamic illustrates how market-driven changes can accelerate technological adoption and innovation (Landini et al., 2020; Nemet, 2009; Yu et al., 2020). The study reveals how

technological uncertainty influences the nature and exploitation of WOPs. In high-uncertainty environments, firms must develop flexible and adaptive strategies to navigate unpredictable technological landscapes. Conversely, in low-uncertainty settings, firms can follow more stable, incremental innovation paths. This insight adds a new dimension to the understanding of how technological uncertainty shapes the opportunities available to latecomers.

The research shows that the interaction between institutional and market-driven WOPs can create synergistic effects that enhance technological catching up. For example, government policies that support digital infrastructure development, combined with increased consumer demand for digital services during the COVID-19 pandemic, provided a powerful impetus for digital transformation. This interplay highlights the need for a coordinated approach that leverages both policy interventions and market signals (Buckley & Hashai, 2014; Chesbrough, 2003; He et al., 2006). The study finds that WOPs can occur sequentially or concurrently, influencing the strategic choices and trajectories of firms. Sequential WOPs, such as phased policy implementations, provide a structured path for catching up, while concurrent WOPs, like simultaneous technological and market shifts, require firms to manage multiple opportunities and challenges at once. Understanding these patterns helps in designing more effective strategies for leveraging WOPs.

5.2.3 Integrating crisis-induced opportunities into the catching up framework

This thesis makes a third significant theoretical contribution by integrating the concept of crisis-induced WOPs into the broader framework of technological catching up. The research demonstrates how exogenous shocks, such as the COVID-19 pandemic, can act as powerful catalysts for creating new WOPs that accelerate the catching-up process. This aspect has been

relatively underexplored in existing literature, which typically focuses on more stable, long-term factors such as technological advancements and government policies.

This study shows that crises can rapidly alter the technological and market landscape, forcing firms to adapt quickly to new conditions. This adaptation often leads to unexpected innovations and shifts in industrial leadership, as firms that can effectively leverage these crisis-induced WOPs gain a significant competitive advantage. By examining how the COVID-19 pandemic created unique opportunities for digital transformation in various industries, the thesis provides a new lens through which to understand the role of crises in industrial catching up.

Furthermore, this contribution highlights the need for firms and policymakers to develop strategies that are not only reactive but also proactive in anticipating and preparing for potential crises. The ability to quickly pivot and exploit emerging WOPs during crises can differentiate successful latecomers from those that fall behind. This research underscores the importance of resilience and agility in the catching-up process, offering a more dynamic and responsive approach to managing technological and market uncertainties (e.g. Binz et al., 2020; Teece, 2020).

By integrating crisis-induced WOPs into the catching-up framework, this thesis expands the theoretical understanding of how external shocks can influence industrial trajectories and offers new insights into the strategic management of innovation during periods of instability. Table 5.1 summarises the theoretical contributions of this thesis.

Table 5.1 Summary of Theoretical Contributions

Theoretical contributions	Aspects	Descriptions	Key Insights
Enriching the Catching Up Literature	Sector-Specific Dynamics of Technological Catching Up	Analyzed how different sectors respond to technological uncertainty.	Highlights the need for sector-specific strategies and policies.
	Catching up process patterns	Provides a new taxonomy of catch-up patterns by applying Process Theory to analyze cycles and transitions in industrial leadership.	Expands understanding of how latecomers can transition through different stages of the catch-up cycle.
Opening the Black Box of WOPs' Dynamics	Heterogeneity of WOPs Emergence	Examines the diverse ways in which different types. Of WOPs emerge	WOPs emerge from various sources at different stages. The significance of these WOPs varies across stages, emphasizing the need for context-specific strategies.
	Dynamics of WOPs Interplays	How different types of WOPs (technological, institutional, and market) interact over time to influence the sectoral development	Interplay between various WOPs can lead to sequential or concurrent opportunities, which can amplify or constrain industrial growth.
Integrating Crisis-Induced Opportunities into the Framework	Impact of Exogenous Shocks on WOPs	Investigated how crises like COVID-19 create unique WOPs for accelerated digital transformation.	How unexpected events can act as catalysts for innovation and change.
	Concept of Relative WOPs	Introduced the idea of relative WOPs, emphasizing uneven distribution of opportunities among firms.	How firms and regions can capitalize on crises-induced opportunities.

5.3 Practical implications

5.3.1 Lessons for practitioners

Practitioners must cultivate flexibility and agility to effectively respond to the dynamic nature of WOPs. This involves investing in R&D to stay at the forefront of technological advancements and fostering a culture of innovation that encourages continuous improvement and adaptation. Building adaptive capabilities is essential for organizations to pivot quickly in response to emerging opportunities and challenges. Allocating resources to R&D is crucial for developing new technologies and innovative solutions that can meet changing market demands. Practitioners should prioritize R&D efforts that focus on both incremental improvements and breakthrough innovations. Organizations need to develop systems and processes that allow them to respond swiftly to changes in the external environment. This includes implementing agile project management methodologies, enhancing supply chain flexibility, and investing in digital transformation to improve operational efficiency and responsiveness. Microsoft adopted agile project management methodologies, particularly in its software development processes, to enhance its responsiveness to market changes and customer needs. For example, Microsoft transitioned to a continuous delivery model for its Azure cloud services and Office 365, allowing it to release updates and new features more frequently and respond swiftly to customer feedback.

Tailoring strategies to the specific dynamics of each sector ensures more effective exploitation of WOPs. Practitioners need to understand the unique technological, market, and institutional conditions that shape their industry and develop strategies accordingly. Each sector has distinct characteristics that influence the nature and timing of WOPs. Practitioners should conduct thorough market research and industry analysis to identify key trends, challenges, and opportunities specific to their sector. Developing sector-specific strategies involves customizing

product development, marketing, and operational plans to align with the unique demands and conditions of the industry. For instance, organizations in high-tech industries may focus on rapid innovation cycles, while those in traditional manufacturing might prioritize efficiency and incremental improvements. Apple Inc. operates in the highly competitive consumer electronics market, particularly with its flagship product, the iPhone. Apple focuses on rapid innovation cycles by introducing new iPhone models annually. Each new model often includes significant upgrades in hardware, software, and design, such as enhanced cameras, new processors, and innovative features like Face ID or the introduction of 5G. This approach allows Apple to stay at the forefront of technology, maintain customer loyalty, and continue to drive sales growth, even in a saturated market. Their emphasis on innovation also sets industry standards and shapes market trends. Toyota operates in the traditional automotive manufacturing industry, where efficiency, reliability, and cost-effectiveness are critical. Toyota is renowned for its Toyota Production System (TPS), which focuses on continuous improvement (Kaizen) and lean manufacturing principles. Rather than drastic innovation, Toyota makes incremental improvements in its manufacturing processes to enhance efficiency, reduce waste, and improve vehicle quality. This focus on efficiency has made Toyota one of the most profitable and respected automakers globally. Their incremental improvements have led to high levels of reliability and customer satisfaction, which are key to maintaining a strong market position in the automotive industry.

Practitioners should actively seek out and capitalize on WOPs that are particularly relevant to their sector. This might include engaging in strategic partnerships, pursuing niche markets, or adopting advanced technologies that offer competitive advantages.

5.3.2 Takeaways for policymakers

Policymakers should design adaptive frameworks that can evolve in response to changing technological and market conditions. This includes providing consistent support for innovation and infrastructure development, as well as creating a regulatory environment that encourages experimentation and growth.

Government policies should provide sustained funding and incentives for R&D, particularly in emerging and high-potential sectors. This can involve grants, tax credits, and public-private partnerships that foster innovation and technological advancement. Investing in critical infrastructure, such as high-speed internet, advanced manufacturing facilities, and sustainable energy systems, can create a conducive environment for technological innovation. Policymakers should prioritize infrastructure projects that support the growth and competitiveness of key industries. Creating a flexible regulatory framework that can adapt to new technologies and business models is essential for fostering innovation. Policymakers should engage in continuous dialogue with industry stakeholders to ensure that regulations keep pace with technological advancements and market changes. The Chinese government launched the “Made in China 2025” initiative to transition the country from a manufacturing hub to a leader in high-tech industries like robotics, aerospace, and biotechnology. The government provides extensive R&D funding, subsidies, and tax incentives to companies in these sectors. This policy has led to significant advancements in China’s high-tech industries. For instance, companies like Huawei and DJI have become global leaders in telecommunications and drone technology, respectively, thanks in part to the government’s sustained R&D support.

Coordinating institutional and market-driven interventions can create more robust WOPs. Policymakers need to align regulatory measures, subsidies, and market incentives to maximize

their impact and support the technological catching up process. Policymakers should implement coordinated policy actions that align regulatory measures, financial incentives, and support programs to create a comprehensive support system for firms. This includes synchronizing efforts across different government agencies and levels of government to ensure consistency and effectiveness. The Chinese government has implemented policies to promote R&D, protect intellectual property, and create standards that foster the growth of emerging industries. The Strategic Emerging Industries Plan includes substantial government funding, tax breaks, and subsidies for companies working in targeted emerging sectors. The government coordinates efforts across different ministries and local governments to provide support through incubators, industrial parks, and talent development programs. This coordinated approach has enabled China to rapidly develop and scale its emerging industries, making the country a global leader in sectors like electric vehicles, biotechnology, and renewable energy.

Encouraging collaboration between public and private sectors can enhance the development and deployment of new technologies. Policymakers should facilitate partnerships that leverage the strengths of both sectors, such as joint R&D initiatives, innovation clusters, and shared infrastructure projects. Horizon 2020 was an EU research and innovation program which facilitated collaborations between public institutions, private companies, and research organizations across Europe. Horizon 2020 supported joint R&D initiatives, public-private partnerships, and innovation clusters across various sectors, including health, digital technology, and green energy. The program aimed to solve societal challenges, enhance European industrial leadership, and boost innovation through cross-border collaboration. The program funded thousands of projects, leading to significant technological advancements and innovations. Examples include advances in renewable energy technologies, digital infrastructure, and health

innovations. The program also strengthened the EU’s competitiveness and contributed to economic growth.

Implementing market incentives, such as subsidies for green technologies, tax breaks for innovative startups, and grants for digital transformation projects, can drive technological adoption and innovation. Policymakers should design these incentives to address specific industry needs and encourage sustainable growth. China offers direct subsidies to consumers who purchase EVs, as well as tax exemptions and incentives for manufacturers to produce more EVs. The government also provides grants to companies developing EV technologies and infrastructure, such as charging stations. These incentives have made China the largest market for electric vehicles globally, with domestic companies like BYD and NIO becoming major players in the EV industry. The subsidies have driven technological innovation, expanded EV production, and helped reduce the country’s carbon emissions, aligning with China’s broader environmental and economic goals.

Table 5.2 Summary of Practical Implications

Target Audience	Aspects	Recommendations
Practitioners	Cultivating Organizational Agility	Invest in agile project management, enhance supply chain flexibility, and focus on digital transformation to improve operational efficiency.
	Strategic Investment in R&D	Allocate resources to R&D that support both incremental improvements and breakthrough innovations.
	Seizing and leveraging WOPs	Develop plans and build capabilities to rapidly exploit emerging WOPs
	Sector-Specific Strategies	Conduct thorough market research and industry analysis to identify specific trends and opportunities, allowing for customized strategic approaches.

Target Audience	Aspects	Recommendations
Policymakers	Proactive and Adaptive Policy Development	Implement adaptive regulatory frameworks and support sector-specific innovation through tailored government interventions.
	Encouraging Inclusivity in Access to WOPs	Develop policies that promote equitable access to resources, training, and capacity-building programs, helping all firms to participate in technological advancement.
	Leveraging Crisis-Induced WOPs for Growth	Create emergency policies that facilitate rapid adoption of new technologies and support industries in leveraging crisis-induced WOPs for competitive advantage.
	Supporting Sustainable Industrial Growth	Promote green technologies and practices, enforce environmental regulations, and incentivize resource-efficient innovations.

Table 5.2 provides an overview of how both practitioners and policymakers can implement strategies to harness the potential of WOPs effectively, thus promoting technological catching up.

5.4 Limitations and future research avenues

While this thesis offers significant insights into the dynamics of technological catching up and the exploitation of WOPs, it also has several potential limitations that warrant further research. These limitations highlight areas where the study could be expanded or refined to provide a more comprehensive understanding of the phenomena.

This study emphasizes technological uncertainty but does not extensively explore other uncertainties such as policy and demand uncertainties that may also affect catching up patterns. Future research should broaden the focus to how policy and demand uncertainties interact with technological uncertainty can provide a more comprehensive understanding of the factors influencing technological catching up patterns. In the early 2010s, the solar energy industry experienced rapid technological advancements, with the cost of solar panels dropping significantly.

However, the adoption of solar energy varied widely across countries, influenced not only by technological uncertainty but also by policy and demand uncertainties. For example, in Spain, abrupt changes in government policy, such as the reduction of feed-in tariffs, led to a sudden decline in solar installations despite technological progress. Similarly, in the U.S., demand uncertainty due to fluctuating oil prices impacted the rate of solar adoption. Understanding how policy and demand uncertainties interact with technological uncertainty can provide a more holistic view of the factors influencing the adoption and development of renewable energy technologies. This could guide more resilient policy designs that support technological catching up in the renewable sector.

We did not differentiate between new EV ventures and EV firms that have transformed from traditional automakers. These two types of firms may face different challenges and opportunities, and thus, government policies, WOPs, and their contributions to the industry's development might differ significantly. Future research should examine the distinct pathways and strategies of new EV ventures compared to those of traditional automakers transitioning to EVs. Understanding these differences can provide more targeted policy recommendations and strategic insights for various types of firms within the EV sector. Tesla, as a new entrant, and GM, a traditional automaker transitioning to EV, represent different pathways in the EV market. Tesla has leveraged its startup culture to innovate rapidly, focusing on software integration and battery technology. In contrast, GM has had to transform its vast manufacturing infrastructure and re-skill its workforce to compete in the EV market. Tesla's challenges include scaling production and maintaining quality, whereas GM faces challenges in overhauling its legacy systems and managing internal resistance to change. Both types of firms require different policy supports and strategic approaches to succeed. Studying the distinct strategies and challenges of new EV ventures

compared to transitioning automakers can lead to more tailored policy recommendations. This differentiation could help governments design incentives that address the unique needs of startups and established firms, fostering a more balanced and competitive EV market.

While the case study approach allowed for an in-depth examination of WOPs during the COVID-19 pandemic, it is inherently limited in its ability to generalize findings. The focus was on the outcome of digitalization rather than the detailed process and mechanisms at the micro level by which firms responded to WOPs and achieved digital transformation. Future studies should explore the micro level processes and mechanisms through multiple firm case studies. This could involve longitudinal research to track how individual firms respond to WOPs over time, providing a more granular understanding of the procedural dynamics involved in digitalization and technological catching up. During the COVID-19 pandemic, retailers like Walmart and Amazon thrived by quickly adapting to digital transformation, implementing contactless delivery, and scaling up e-commerce operations. Smaller retailers also moved online, but their success varied widely. While macro level studies highlight the outcome of digitalization, such as increased online sales, they often overlook the micro level processes, such as how firms reorganized their supply chains, retrained employees, and integrated new technologies. Longitudinal case studies of how individual retailers navigated digital transformation during the pandemic could provide insights into the specific steps and decisions that led to success or failure. This research could inform strategies for other firms undergoing digitalization in response to sudden external shocks.

The findings of this study are primarily based on the Chinese context and may not be directly transferable to other emerging economies due to path dependency and contextual differences. The specific patterns observed in China might not apply universally. Future research should validate the findings in diverse contexts by examining other emerging economies.

Comparative studies across different countries can help determine the general applicability and relevance of the identified catch-up patterns and WOP dynamics. China's rapid technological catching up in telecommunications, driven by state-owned enterprises like Huawei and ZTE, may not be directly applicable to other emerging economies. In India, the telecommunications market is characterized by intense competition among private firms like Reliance Jio, whereas in Brazil, the market is influenced by a mix of public and private investments. Path dependency, regulatory environments, and market structures vary significantly between countries, affecting how technologies are adopted and scaled. Comparative studies between India, Brazil, and other emerging economies could help validate or challenge the patterns observed in China. Such research could provide a more nuanced understanding of how different contexts shape technological catching up and help policymakers design interventions that are contextually appropriate.

General Conclusion

This thesis set out to explore the complex dynamics of technological catching up, focusing on the role of various WOPs in shaping the development trajectories of latecomer firms and industries. By examining case studies within the Chinese context, the research offers valuable insights into how emerging economies can navigate technological uncertainty, leverage government policies, and adapt to exogenous shocks to foster innovation and sustainable growth. This conclusion synthesizes the findings across the three empirical studies, integrates theoretical contributions, and discusses practical implications for both practitioners and policymakers.

Chapter 2 studies the sector-specific dynamics of technological catching up by comparing different Chinese manufacturing sectors, such as general equipment, pharmaceuticals, home appliances, and electronic devices. The study highlighted how varying levels of technological uncertainty influence catching-up patterns. It was found that sectors with lower technological uncertainty tend to follow more predictable and linear catching-up paths, whereas sectors with higher uncertainty exhibit non-linear and cyclical patterns. This chapter underscored the importance of context-specific strategies, emphasizing that a one-size-fits-all approach is inadequate for addressing the diverse challenges faced by different industries. The theoretical contribution of this chapter lies in its application of process theory to understand the cyclical nature of catching up. By categorizing the different stages of the catching-up cycle, this study provides a nuanced understanding of how firms transition from initial imitation to innovation and leadership. This taxonomy of catching-up patterns enriches the existing literature by highlighting the iterative nature of technological advancement and the continuous need for adaptation.

Chapter 3 focuses on the role of government policy evolution in creating and sustaining WOPs, using the Chinese electric vehicle (EV) industry as a case study. This chapter demonstrated

how proactive and adaptive government policies can effectively create technological and market WOPs, facilitating the catching-up process for latecomer firms. The study traced the evolution of policies from initial support for R&D and market entry to more advanced stages of standardisation and global competitiveness. One of the key theoretical contributions of this chapter is the detailed examination of how government interventions can systematically generate opportunities for industrial catching up. By exploring the interactions between policy evolution, technological advancement, and market demand, this study provides a framework for understanding the dynamic interplay of different types of WOPs. It shows that the success of catching-up strategies is often contingent upon the alignment of these factors, which can be orchestrated through well-designed policy measures.

Chapter 4 examines the impact of exogenous shocks, such as the COVID-19 pandemic, on creating and utilising WOPs. This chapter introduced the concept of relative WOPs, emphasising the uneven distribution of opportunities among firms and regions during crises. The study found that crises could act as accelerators of digital transformation, providing latecomer firms with unique chances to leapfrog traditional development stages. The theoretical contribution of this chapter lies in its integration of crisis-induced WOPs into the broader framework of technological catching up. By analysing how firms leveraged the pandemic-induced opportunities for rapid digitalization, this study highlighted the importance of agility and adaptability in times of uncertainty. The concept of relative WOPs adds depth to the understanding of how crises can create both opportunities and disparities, depending on firms' ability to recognize and seize these chances.

Collectively, these chapters contribute significantly to the literature on technological catching up by developing a comprehensive framework that integrates different types of WOPs.

This thesis advances the understanding of how technological, institutional, and market WOPs interact dynamically to influence the catching up trajectories of latecomer firms. The differentiation of catching up patterns across sectors, the role of adaptive policymaking, and the impact of exogenous shocks all contribute to a more holistic understanding of the complex nature of technological development in emerging economies. The introduction of new concepts such as the taxonomy of catching-up patterns, the dynamics of WOPs interplays, and relative WOPs provide valuable tools for future research. These contributions emphasize the need for a nuanced approach that considers the specificities of sectors, the evolution of policy frameworks, and the unpredictable nature of crises.

For practitioners, this research emphasizes the importance of cultivating organizational agility, investing strategically in research and development, and being prepared to leverage crisis-induced opportunities. These strategies are crucial for maintaining competitiveness in rapidly changing technological and market environments. Firms should adopt flexible management practices, enhance their digital capabilities, and continuously monitor the policy landscape to align their strategies with emerging WOPs. For policymakers, the findings underscore the need for proactive and adaptive policy development. Governments should design regulatory frameworks that can respond dynamically to technological changes and market demands. Ensuring equitable access to WOPs is also critical for promoting inclusive growth. Policies should support not only large firms but also SMEs and diverse regions, ensuring that the benefits of innovation and growth are widely distributed.

This thesis has laid a solid foundation for understanding the role of WOPs in technological catching up, with a particular focus on sector-specific dynamics, policy evolution, and the impact of crises. Building on these insights, some following research projects are planned and conducted

for gaining deeper understandings on several interconnected themes. One study examines how different learning orientations, paradigms, and integration strategies impact the catching up process. This research aims to unbox the role of multidimensional learning in catching up, highlighting how these mechanisms evolve from early-stage to late-stage technological advancements. Understanding these learning processes will provide a more granular view of how firms can effectively navigate the complex landscape to achieve technological catching up. Building on the role of government intervention highlighted in the thesis, another research will focus on how entrepreneurial states create and utilize WOPs to build sectoral innovation systems. Using the Chinese high-speed rail industry as a case study, this research will investigate how state-led initiatives coordinate technological and market opportunities to achieve catching up. Expanding the scope of WOPs beyond technological catching up, a following study will explore the concept of “Public Windows of Opportunity” and their impact on social development. By examining the role of policy-induced WOPs in enhancing social welfare, this study will provide valuable insights into how strategic public interventions can address regional inequalities and improve the quality of life, thus linking economic growth with social development.

Future research could explore how different countries, particularly other emerging economies, utilize WOPs to achieve technological catching up. By comparing cases from various geopolitical contexts (e.g., Brazil, India, and South Africa) with China, researchers can identify common strategies and unique approaches influenced by specific socio-economic and political conditions. This comparative analysis could highlight best practices and provide a more global perspective on technological catching up. Further exploration into how cultural and organizational factors influence a firm's ability to recognize, adapt to, and capitalize on WOPs could provide valuable insights. Studies could examine how organizational culture, leadership styles, and internal

communication affect the agility and innovation capabilities of firms. This research would be particularly useful for understanding why some firms are more successful than others in leveraging WOPs, even within the same sector. These additional research directions would expand on the findings of the thesis and the following studies already planned, providing a broader and deeper understanding of technological catching up.

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Appendices

Appendix 1. Semi-structured Interview Questions in Chapter 2

Q1: What is your current position in the company?

Q2: What are your company's current main business and operations?

Q3: In your opinion, how is the relationship between your company's development and industry development?

Q4: Would you please describe the development process and phases of your industry? If you are not sure, please describe your company's development process and current phase.

Q5: What are the significant milestones in your industry developments, if you see the technological gaps of your industry and international leaders reduced? If not, what could be a possible explanation according to your understanding?

Q6: Please summarize how your industry changes from the technological perspective if there are any changes. Please give us a detailed example to illustrate each change.

Q7: Regarding the technological development of your industry, is there anything particularly important but did not cover in our conversations? Please tell us, with detailed examples.

Appendix 2. Information of Semi-structured Interviews in Chapter 2

Date	Position of Interviewee	Company Code	Company Type	Location
20170721	Sales Director	FH	Business partners	Wuhan
20170726	Sales Director	ZY	Business partners	Wuhan
20170726	R&D Engineer	HW	Electronic device	Wuhan
20170727	Sales Director	ZY	Business partners	Wuhan
20170727	Head of Production Department	ZY	Business partners	Wuhan
20170727	Head of Technology Department	ZY	Business partners	Wuhan
20170730	Outreach Department	SL	Business partners	Wuhan
20170802	Vice General Manager	ZSH	Business partners	Wuhan
20170802	Head of Marketing Department	ZSH	Business partners	Wuhan
20170802	Research Institute	ZSH	Business partners	Wuhan
20170804	Vice President of Business Unit	FH	Business partners	Wuhan
20170804	Vice President of Business Unit	FH	Business partners	Wuhan
20170804	Head of Marketing Department	FH	Business partners	Wuhan
20170804	Manager of Information Department	FH	Business partners	Wuhan
20170807	Senior Researcher	CS	Electronic device	Wuxi
20170808	Vice Chairman	ZF	Business partners	Wuxi
20170808	Director, Vice President	ZF	Business partners	Wuxi
20170808	General Manager of Subsidiary Company	ZF	Business partners	Wuxi

Date	Position of Interviewee	Company Code	Company Type	Location
20170809	General Manager	PC	Electronic device	Shanghai
20170809	Vice General Manager	SFL	Business partners	Shanghai
20170810	Senior Manager, Plant Planning and Logistics Department	SFL	Business partners	Nanjing
20170810	Vice General Manager	PK	Electronic device	Wuxi
20170810	Head of Production Department	HC	General equipment	Wuxi
20170810	Deputy General Manager	HC	General equipment	Wuxi
20170811	Deputy General Manager	XJN	Industry experts	Wuxi
20170811	Chairman of the Board	SX	Industry experts	Jiaxing
20170812	Senior Engineer of R&D Department	ZX	Industry experts	Wuxi
20170813	Business Manager of Information Department	JS	Business partners	Shanghai
20170813	Senior Manager of Product Development	PL	Home appliance	Shanghai
20170813	Former Project Manager	TY	Business partners	Shanghai
20170814	Assistant Director of Government Affairs and Policy Research	YMKD	Pharmaceutics	Wuxi
20170814	General Manager, Senior Engineer	BST	General equipment	Wuxi
20170815	General Manager's Office	AMW	General equipment	Wuxi
20170815	Project Manager	DE	Electronic device	Wuxi

Appendix 3. Semi-structured Interview Questions in Chapter 3

Q1: What is your current position in the company?

Q2: What are the significant differences between traditional cars and emerging new energy vehicles? Please elaborate on various aspects such as technical characteristics and market perception (consumer attitudes).

Q3: In the field of traditional automobile manufacturing, China has always played the role of a follower, competing with foreign brands in the domestic and international markets. What do you think is the current level of development in this field in China?

Q4: In the field of new energy vehicles, how does the industry's inception and development in China compare to that of foreign industry leaders, and what are the characteristics and trends?

Q5: What do you think are the key prerequisites and development opportunities for the rise of the new energy vehicle industry in China?

Q6: From an institutional perspective, as you understand it, what role have Chinese policy measures played in this process?

Q7: What are the technological milestones independently achieved in the development of new energy vehicles in China?

Q8: How is the relationship between market demand and the supply of new energy vehicles in China?

Q9: Besides the automotive industry, please discuss the application of new energy technologies in other fields and the current development status and potential of China in these areas.

Appendix 4. Semi-structured Interviews list in Chapter 3

Date	Position of Interviewee	Company Code	Company Type	Location
20180410	Sales consultant	G	Automotive manufacturer	Shenzhen
20180413	Senior engineer	G	Automotive manufacturer	Shenzhen
20180419	Deputy Director of Vehicle Testing Centre	G	Automotive manufacturer	Shenzhen
20180427	Sales consultant	B1	Automotive manufacturer	Shenzhen
20180427	Sales consultant	B1	Automotive manufacturer	Shenzhen
20180508	Retail manager	B2	Automotive manufacturer	Shenzhen
20180508	Sales consultant	B2	Automotive manufacturer	Shenzhen
20180427	Supply chain manager	B3	Automotive manufacturer	Shenzhen
20180427	Marketing and sales manager	B3	Automotive manufacturer	Phone call
20180509	Supply chain manager	V	Automotive manufacturer	Shenzhen
20180509	Sales consultant	V	Automotive manufacturer	Shenzhen
20180509	Sales manager	T1	Automotive manufacturer	Shenzhen
20180511	Sales consultant	T2	Automotive manufacturer	Shenzhen
20180511	Sales consultant	T2	Automotive manufacturer	Shenzhen
20180517	Supply chain manager	C1	Automotive manufacturer	Shenzhen
20180605	Sales consultant	B1	Automotive manufacturer	Shenzhen
20180605	Sales consultant	B1	Automotive manufacturer	Shenzhen
20180607	Sales consultant	B2	Automotive manufacturer	Phone call
20180607	Store manager	B2	Automotive manufacturer	Phone call
20180608	Store manager	B3	Automotive manufacturer	Shenzhen
20180608	Sales consultant	B3	Automotive manufacturer	Shenzhen
20180608	Market manager	B3	Automotive manufacturer	Shenzhen
20180613	Sales consultant	V	Automotive manufacturer	Shenzhen
20180613	Sales consultant	V	Automotive manufacturer	Shenzhen
20180621	Sales consultant	G	Automotive manufacturer	Shenzhen
20180621	Sales consultant	G	EV manufacturer	Shenzhen
20180621	Sales consultant	G	Automotive manufacturer	Shenzhen
20180625	Sales consultant	T2	Automotive manufacturer	Shenzhen

Date	Position of Interviewee	Company Code	Company Type	Location
20180625	Sales consultant	T2	Automotive manufacturer	Shenzhen
20180704	Sales manager	C1	Automotive manufacturer	Shenzhen
20210627	Senior engineer	G	Automotive manufacturer	Phone call
20210629	Vice general manager	C2	Battery supplier	Phone call
20210629	Sale manager	Q	Accessory supplier	Phone call
20210629	Senior engineer	S	Automotive manufacturer	Phone call
20210630	Sale manager	S	Automotive manufacturer	Phone call
20210701	R&D Manager	N	Automotive manufacturer	Phone call
20210703	Founder/general manager	L	Accessory supplier	Phone call
20210703	Sale manager	C3	Automotive manufacturer	Phone call
20210704	R&D manager	M	Accessory supplier	Phone call
20210704	Senior engineer	N	Accessory supplier	Phone call
20210705	Senior engineer	Z	Technique consultant	Phone call
20210705	Senior engineer	Z	Technique consultant	Phone call
20210713	Senior engineer	W	Technique consultant	Phone call
20210725	R&D manager	H	Software supplier	Phone call
20210804	R&D manager	V	Automotive manufacturer	Phone call

Appendix 5. Policy Reports analysed in Chapter 4

Published on (2021)	Policy title
Jan-24	Notice on the proper handling of labour relations during the prevention and control of pneumonia outbreaks caused by new coronavirus
Jan-25	Notice on the relevant funding guarantee policy for the prevention and control of new coronavirus infection pneumonia
Jan-26	Notice on Facilitating Procurement Prevention and Control Procurement
Jan-28	Notice on strengthening the leadership of the party and providing a strong political guarantee for winning the epidemic prevention and control
Jan-30	Notice on optimizing tax payment services and cooperating with the prevention and control of new coronavirus infection pneumonia
Jan-30	Notification of the handling of social insurance during the prevention and control of a pneumonia epidemic
Jan-30	Urgent notice on organizing key materials for epidemic prevention and control, production enterprises resuming production and scheduling arrangements
Jan-31	Notice on further improving the funding for the prevention and control of new coronavirus infection pneumonia
Jan-31	Notice on Further Strengthening Financial Support to Prevent and Control New Coronavirus Infection of Pneumonia
Feb-01	Announcement on the tax exemption policy for imported materials for the prevention and control of new coronavirus infection in pneumonia
Feb-01	Announcement on Supporting Financial Enhancement Services and Doing a Good Job in the Prevention and Control of New Coronavirus Infection Pneumonia; Announcement on the tax exemption policy for imported materials for the prevention and control of new coronavirus infection in pneumonia
Feb-05	Notice on doing well in employment during the epidemic prevention and control period; Notice on responding to the epidemic situation of new coronavirus infection pneumonia, supporting the encouragement of workers to participate in online vocational skills training
Feb-06	Notice on student financial assistance during the prevention and control of new coronavirus infection pneumonia
Feb-06	Notice on matters related to government procurement activities during epidemic prevention and control
Feb-06	Announcement on the exemption of some administrative fees and government funds during the prevention and control of pneumonia outbreaks caused by new coronavirus

Published on (2021)	Policy title
Feb-06	Announcement on Donation Tax Policy Supporting the Prevention and Control of New Coronavirus Infection Pneumonia
Feb-06	Announcement on Supporting the Prevention and Control of New Coronavirus Infected Pneumonia Epidemic Relevant Personal Income Tax Policy
Feb-06	Notice on further improving the service guarantee for the return of migrant workers to the city after the Spring Festival
Feb-06	Announcement on Tax Policies Related to Supporting the Prevention and Control of the Pneumonia Epidemic Infected by a New Type of Coronavirus
Feb-06	Announcement on the Individual Income Tax Policies Related to Supporting the Prevention and Control of the Pneumonia Epidemic Infected by the New Coronavirus
Feb-07	Notice on earnestly guaranteeing funds for school epidemic prevention and control
Feb-07	Urgent notice from the Development and Reform Commission, the Ministry of Industry and Information Technology, the People's Bank of China, and the National Audit Office on winning epidemic prevention and control, strengthening the epidemic prevention and control, and ensuring the financial support of enterprises
Feb-07	Notice on matters related to lottery ticket sales and sales during epidemic prevention and control
Feb-07	Urgent notice on winning the epidemic prevention and control battle
Feb-09	Announcement on Donation Tax Policy Supporting the Prevention and Control of New Coronavirus Infection Pneumonia
Feb-10	Announcement on supporting tax collection and management matters related to the prevention and control of pneumonia outbreaks of new coronavirus infection
Feb-10	Notice on measures to give full play to the role of taxation functions to help win the epidemic prevention and control
Feb-10	Notice on Playing the Role of Government Reserves to Support the Increase of Production and Supply of Scarce Materials in Response to the Epidemic Situation
Feb-11	Notice on wages and treatment issues of personnel in institutions during the prevention and control of new coronavirus pneumonia
Feb-13	Notice on state-owned financial enterprises actively making donations related to epidemic prevention and control
Feb-14	Notice on doing a good job in safeguarding assets for the prevention and control of the new coronary pneumonia epidemic

Published on (2021)	Policy title
Feb-14	Notice on effectively supporting the stable production and supply of agricultural products during the prevention and control of the new coronary pneumonia epidemic
Feb-14	Notice on effectively supporting the stable production and supply of agricultural products during the prevention and control of the new coronary pneumonia epidemic
Feb-17	Notice on strengthening the implementation of fiscal and taxation policies for the prevention and control of the new coronary pneumonia epidemic and the supervision of financial funds
Feb-17	Notice on actively responding to the impact of the new coronary pneumonia epidemic, strengthening the project management of special financial poverty alleviation funds, and ensuring that the goal of poverty alleviation is completed
Feb-17	Notice on matters related to further extension of the tax filing deadline of February 2020
Feb-18	Notice from the General Office on the work of human resources services during the prevention and control of the new coronary pneumonia epidemic
Feb-19	Notice on doing a good job of "point-to-point" service guarantee for returning migrant workers to work
Feb-20	Notice on strengthening the management of pollution prevention funds and supporting the fight against the epidemic prevention and control
Feb-20	Notice on the work related to export tax rebate (exemption) during the prevention and control of pneumonia outbreaks caused by new coronavirus
Feb-20	Notice on periodic reduction and exemption of corporate social insurance premiums
Feb-21	State Medical Insurance Bureau, Ministry of Finance, General Administration of Taxation
Feb-21	State Council Poverty Alleviation Office's Notice on Responding to the New Coronary Pneumonia Outbreak
Feb-23	Notice of the Central Leading Group on New Coronavirus Infection and Pneumonia Outbreak in Full Implementation of Several Measures to Further Protect and Care for Medical Staff
Feb-25	State Administration of Taxation Notice on Implementing the Policy of Periodic Reduction and Exemption of Corporate Social Insurance Premiums
Feb-28	The State Council responded to the new coronavirus infection pneumonia outbreak joint prevention and control mechanism on further improving civil service agencies
Feb-29	Guidance on Increasing Support for Individual Businesses in Response to the Impact of the Epidemic
Mar-03	Notice from the Central Leading Group on New Coronavirus Infection and Pneumonia Outbreak on Issuing the Current Guidelines for Spring Plow Production

Published on (2021)	Policy title
Mar-04	Notice on the policy of financial support during the prevention and control of the new coronary pneumonia epidemic in civil aviation transportation enterprises
Mar-04	Notice on effectively responding to the impact of the new coronary pneumonia epidemic and effectively strengthening the “three guarantees” of local finance
Mar-04	Notice of the Central Leading Group on the Response of New Coronavirus Infection Pneumonia to the Full Implementation of the Prevention and Control of the Frontline Urban and Rural Community Workers' Care Measures
Mar-07	Notice from the Central Leading Group on New Coronavirus Infection and Pneumonia Outbreaks to Further Do a Good Job in Safeguarding the People in Difficulties during the Prevention and Control of the Outbreak
Mar-11	Notice of the General Office of the Organization Department of the Central Committee of the Communist Party of China on Responding to the Impact of the New Coronary Pneumonia Outbreak
Mar-20	Guidance on supporting preferential tax and fee policies for epidemic prevention and control and economic and social development
Mar-30	Notice on matters related to the extension of the tax return deadline in April 2020
Apr-01	Announcement on giving full play to the role of government financing guarantees to increase credit for small and micro enterprises and "three rural" entities
Apr-03	The State Council responded to the new coronary pneumonia epidemic situation joint prevention and control mechanism scientific research team on the "Notice on regulating medical institutions to carry out new coronavirus pneumonia drug treatment clinical research;
Apr-14	Announcement on Expanding the Pilot Policy on Selective Tariff Collection for Domestic Sales
Apr-16	Notice from the Torch Center of the Ministry of Science and Technology on launching the interactive technology services of the epidemic prevention and control enterprises and the information exchange of scientific and technological personnel
Apr-16	Announcement on Policies Regarding Exemption of Vehicle Purchase Tax for New Energy Vehicles
Apr-20	Announcement on the continued implementation of preferential tax policies for inclusive finance
Apr-23	Announcement on Continuing the Income Tax Policy for Western Development Enterprises
Apr-23	Notice on the implementation of the phased measures of "employment first, then examination" for some occupational qualifications in response to the impact of the new coronary disease
Apr-24	Notice on further implementing preferential policies for detailed taxation and fees and resolutely preventing violations of taxation charges

Published on (2021)	Policy title
Apr-27	Notice on clarifying matters related to the deadline for tax declaration in May 2020
Apr-28	Notice on measures to stabilize and expand automobile consumption
Apr-30	Announcement on Extending the Implementation Period of the VAT Reduction and Exemption Policy for Small-Scale Taxpayers
May-02	Announcement on Doing a Good Job of Public Procurement of Government Procurement
May-11	Regarding the response to the new coronary pneumonia epidemic, we will further help small and micro enterprises in the service industry and individual businesses
May-13	Announcement on matters related to pre-tax deductions for charitable donations
May-14	The Ministry of Finance and the National Film Administration issued an announcement to temporarily exempt the national film industry development special funds