Technological Uncertainty and Catch-Up Patterns: Insights of Four Chinese Manufacturing Sectors

Lu Xu, Jie Xiong, Jie Yan, Richard Soparnot, and Zhe Yuan

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.**

Index Terms—**Catch-up cycle, explanatory, hybrid, predictive, process patterns, technological uncertainty.**

I. Introduction

STRATEGIC management scholars have demonstrated a long-term interest in sustaining their organizations' superior performance over competitors [1], [2]. 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 [3].

The convergence between the laggards and the frontier, or catch-up, is a gap-closing process [4]. Some studies emphasize leadership turnover during continual catch-up attempts [5], 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" [6, p. 339], in order to eliminate latecomer disadvantages while raising and creating latecomer advantages to forge ahead [7], [8], [9], [10], [11].

Hobday [12, p. 19] distinguishes original equipment manufacturing (OEM), original design manufacturing (ODM), and original brand manufacturing (OBM). According to Kim [13], 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 [9] or path-following, path-skipping, and path-creating [10]. 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 [6], [14].

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" [6, p. 338] during the early prologue, interim development, or final complement. Therefore, latecomers maneuver their capabilities by building and learning mechanisms with diverse permutations [15]. 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 [16]. Government initiatives introducing institutional WOPs may reshape technological paradigms and breed technological WOPs [17], thereby encouraging latecomers to pursue a novel approach to catch up with path-breaking innovation [18]. When demand uncertainty is high, market information is rapidly revealed. Thus, enterprises may eventually enter the market simultaneously. Stackelberg's leader-follower behavior may be more appropriate [19]. When the followers observe their industry leaders to determine the profitable amount, production decisions are made [19]. Thus, even in one predesigned catch-up process, phases fluctuate as WOPs evolve and the actors' responses vary. In this study, we

Manuscript received 7 March 2022; revised 26 August 2022 and 15 November 2022; accepted 23 November 2022. This work was supported by the National Natural Science Foundation of China under Grant #71772142. Review of this manuscript was arranged by Department Editor F. Tietze. *(Corresponding author: Jie Xiong.)*

Lu Xu and Richard Soparnot are with the Department of Innovation and Development, ESC Clermont Business School, CleRMa, 63000 Clermont-Ferrand, France (e-mail: lu.xu@esc-clermont.fr; richard.soparnot@esc-clermont.fr).

Jie Xiong is with the Department of Strategy, Entrepreneurship and International Business, ESSCA School of Management, 49003 Angers, France (e-mail: jie.xiong@essca.fr).

Jie Yan is with the Department of Management and Technology, Grenoble Ecole de Management, 38000 Grenoble, France (e-mail: jie.yan@grenoble-em.com).

Zhe Yuan is with the Research Center, Léonard de Vinci Pôle Universitaire, 92916 Paris La Défense, France (e-mail: zhe.yuan@devinci.fr).

Color versions of one or more figures in this article are available at https://doi.org/10.1109/TEM.2022.3228114.

Digital Object Identifier 10.1109/TEM.2022.3228114

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*." [20, 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 [21]. 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 [12]. 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 [5]. 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 [5]. Latecomers' capabilities to consolidate, imitate, or outsource operations were upgraded to creative development, innovation, and original brand establishment [12], [21].

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 and Nelson [11] established catch-up process research mainly focuses on high-tech industries, such as the Korean electronic industry [5], [10], [21]. Low-tech industries such as retailing and wine production have received less attention [22], [23], with even less given to cross-industry comparisons (except for Malerba and Nelson [11]). However, technological uncertainty varies between sectors, and catch-up processes are heterogeneous [24].

Over the last few decades, China has embraced globalization's division of labor 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 [25], 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 [26]. 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.

II. Literature Review and the Oretical Development

A. Stage of Catch-Up Cycle

Strategy Process and Strategy-as-Practice share some common propositions and theoretical resources but differ in practice [27]. The catch-up process is described by several models, such as leapfrogging [9] or path-following, path-skipping, and path-creating [10]. 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 [28] examines organizational processes and summarizes three widely accepted definitions: first, explaining the logical relationship between variables; second, a concept or variable segment involving individuals or organizational behavior; and third, a series of phenomena describing how things change over time. The process is defined as "*a sequence of events, activities, and interactions over time*" [27, 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 [28] 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 in explanation. Cloutier and Langley [29] 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 [6]. 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 [6]. 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).

B. Predictive Catch-Up Process

Catch-up strategy research focuses on the forging ahead phases of the technological trajectory. Kim [21] 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 [9]. 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 [9, 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 [10]. 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 [12]. According to Dosi [7], 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.

C. *Explanatory Catch-Up Process*

The dialectic and evolution process theories are examples of explanatory processes that attentively observe how change and development transpire [28]. 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 and Ramani [30] 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 [31]. 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 [23].

D. *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 [32]. Shenhar and Dvir [33] 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 [10]. 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 [12]. This is relevant except where WOPs such as institutional interventions, policy tilts, or the emergence of new market preferences are present [34].

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 [10]. 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 [5]. 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 and von Zedtwitz's [35] 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 [21] three-phase evolution. In the high-tech industry, Almudi et al. [36] 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 [37]. 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 [38].

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 endeavors, 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 nonconforming solutions, and retaining appropriate solutions are analogous to the logic of evolution as an explanatory pattern [28]. 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 [39]. Under such circumstances, organizations endeavor to compete and collaborate to standardize in order to mitigate the risk associated with extraordinarily high technological unpredictability [32]. 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 [26]. Mowery and Nelson [40] 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 [41]. 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 and Dvir's [33] typology, technological uncertainty is divided into two groups: low and high.

III. Methodology

The High-tech Industry (Manufacturing) Classification of China[1] (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[2] (hereafter GB/T 4754-2017) and reclassifies activities connected to the high-tech manufacturing industries' features. We do not 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 [33].

Case selection follows two key principles: the sample should be representative with theoretically diverse dimensions [43]. The selection of the four representative industry sectors is based on the following criteria: first, the catch-up cycle phase(s) are visible in its development trackway; second, two are in the high-tech segment and two are in the low-tech segment; and third, in each segment, one is in the early catch-up phase and the other is in the late phase. Table I 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 [42]. The breakdown of interview information is shown in Appendix B.

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

[1][Online]. Available: www.stats.gov.cn/tjsj/tjbz/201812/t20181218_1640081.html

[2][Online]. Available: www.stats.gov.cn/tjsj/tjbz/hyflbz/201710/t20171012_1541679.html

TABLE I
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	1,510
Electronic device (UAV)	03 (0383)	3963	7.9
Pharmaceutical	01	27	2,454.44

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).

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 min, with the longest lasting 128 min, and the shortest only 15 min. 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; 64 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 [42].

Explanation building is carried out in a succession of revisions and is based on the interpretation of primary and secondary data [42]. 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.

Please refer to Fig. 1 for the research steps.

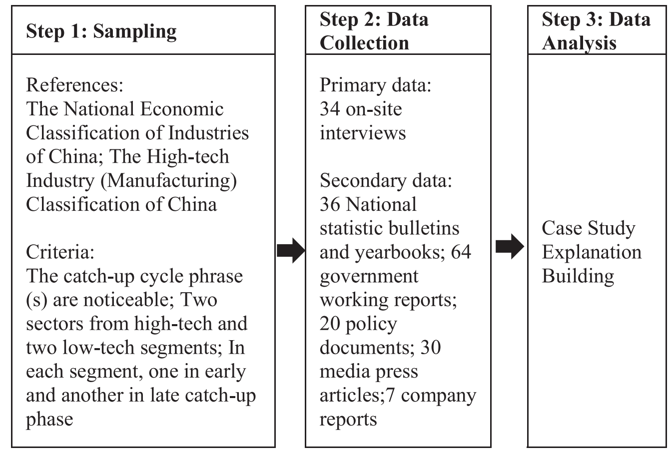


Fig. 1. Research method flow chart.

IV. 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 differ 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.

A. Patterns in the Early Stage

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) 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 subindustries. 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 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*."

B. Hybrid Patterns in Late Stage

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) 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.

V. Discussion and Conclusion

A. Discussions

1) Typology of Catch-Up Patterns: Fig. 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 [28] 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 [10]. 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 Fig. 2, this situation is labeled as a divergent hybrid pattern and the transition logic is indicated by the lower arrow.

However, when technological uncertainty is high, along with the catch-up cycle stages, latecomer industries transform from an

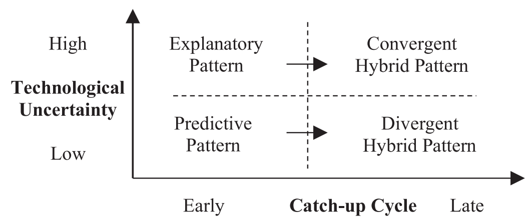


Fig. 2. Process patterns in catch-up cycle under technological uncertainty.

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 [10] 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 Fig. 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.

2) 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, sociocultural elements, and the ecological environment [6]. For example, labor 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 [31]. 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 [12]. 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 [10]. 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 [10], [13].

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's [30]. 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 [39]. China has favorable 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 [44]. These are all core competencies that Chinese biopharmaceutical categories can build by leveraging their resources and orchestrating capabilities.

3) 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 require efficient and timely responses to WOPs. Latecomers who are more adaptable to radical innovations and disruptive technologies may capitalize from technological discontinuity [5]. Notably, latecomers are leading radical industrial innovation initiatives [45]. Novel and innovative market preferences generate new consumer demands, requiring the development of market-favorable businesses by new entrants. Incumbents must pivot or modify current structures to readjust to the marketplace [23]. The importance of institutional WOPs is reinforced and confirmed by empirical studies of catch-up in diverse industries and economies [11]. 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 [46]. Home appliance manufacturing has followed a conventional catch-up process [21]. 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 [23]. 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 preemptive 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 [35], which enables an innovative architectural approach to drone manufacturing. Another determinant is that the three primary WOPs [6] 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 [44]. 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 [35]. 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 [5].

B. Conclusion

Based upon the Chinese manufacturing industry and through the lens of Process Theory, this study endeavors 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.

C. 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 [27], [29]. 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 [10], [21]. 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 [6], [31], [44]. 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 maneuvers 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 [24]. It contributes to the ongoing discussion on how technological uncertainty affects strategic management [32], [38]. 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 [39]. 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 [32].

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 [28].

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.

D. 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 [22], telecommunication [47], electric vehicles [48], 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.

E. 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 regards 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.

Appendix A
Semistructured Interview Questions

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 B
INFORMATION OF INTERVIEWS

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
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

REFERENCES

[1] C. Campbell-Hunt, "What have we learned about generic competitive strategy? A meta-analysis," *Strategic Manage. J.*, vol. 21, no. 2, pp. 127–154, 2000, doi: 10.1002/(SICI)1097-0266(200002)21:2<127::AID-SMJ75>3.0.CO;2-1.

[2] A. W. King and C. P. Zeithaml, "Competencies and firm performance: Examining the causal ambiguity paradox," *Strategic Manage. J.*, vol. 22, no. 1, pp. 75–99, 2001, doi: 10.1002/1097-0266(200101)22:1<75::AID-SMJ145>3.0.CO;2-I.

[3] L. Xu, S.-Y. Kim, J. Xiong, J. Yan, and H. Huang, "Playing catch-up: How less developed nations can jump-start technology innovation," *J. Bus. Strategy*, vol. 41, no. 2, Dec. 2018, Art. no. JBS-09-2018-0160, doi: 10.1108/JBS-09-2018-0160.

[4] S. Yang, S. Lancheros, and C. Milner, "Technological catch-up to the national and regional frontier: Firm-level evidence for India," *J. Develop. Stud.*, vol. 57, pp. 1303–1320, Feb. 2021, doi: 10.1080/00220388.2021.1881492.

[5] H. Kang and J. Song, "Innovation and recurring shifts in industrial leadership: Three phases of change and persistence in the camera industry," *Res. Policy*, vol. 46, no. 2, pp. 376–387, Mar. 2017, doi: 10.1016/j.respol.2016.09.004.

[6] K. Lee and F. Malerba, "Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems," *Res. Policy*, vol. 46, no. 2, pp. 338–351, 2017, doi: 10.1016/j.respol.2016.09.006.

[7] G. Dosi, "Technological paradigms and technological trajectories," *Res. Policy*, vol. 11, no. 3, pp. 147–162, Jun. 1982, doi: 10.1016/0048-7333(82)90016-6.

[8] C. Perez and L. Soete, "Catching up in technology: Entry barriers and windows of opportunity," in *Technical Change and Economic Theory*. London: Pinter Publishers, 1988.

[9] D.-S. Cho, D.-J. Kim, and D. K. Rhee, "Latecomer strategies: Evidence from the semiconductor industry in Japan and Korea," *Org. Sci.*, vol. 9, no. 4, pp. 489–505, 1998, doi: 10.1287/orsc.9.4.489.

[10] K. Lee and C. Lim, "Technological regimes, catching-up and leapfrogging: Findings from the Korean industries," *Res. Policy*, vol. 30, no. 3, pp. 459–483, 2001, doi: 10.1016/S0048-7333(00)00088-3.

[11] F. Malerba and R. Nelson, "Learning and catching up in different sectoral systems: Evidence from six industries," *Ind. Corporate Change*, vol. 20, no. 6, pp. 1645–1675, Dec. 2011, doi: 10.1093/icc/dtr062.

[12] M. Hobday, "East Asian latecomer firms: Learning the technology of electronics," *World Develop.*, vol. 23, no. 7, pp. 1171–1193, Jul. 1995, doi: 10.1016/0305-750X(95)00035-B.

[13] L. Kim, *Imitation to Innovation: The Dynamics of Korea's Technological Learning*. Boston, MA, USA: Harvard Business School Press, 1997.

[14] F. Landini, K. Lee, and F. Malerba, "A history-friendly model of the successive changes in industrial leadership and the catch-up by latecomers," *Res. Policy*, vol. 46, no. 2, pp. 431–446, Mar. 2017, doi: 10.1016/j.respol.2016.09.005.

[15] P. N. Figueiredo and M. Cohen, "Explaining early entry into path-creation technological catch-up in the forestry and pulp industry: Evidence from Brazil," *Res. Policy*, vol. 48, no. 7, pp. 1694–1713, Sep. 2019, doi: 10.1016/j.respol.2019.03.017.

[16] M. D. Amore, "Innovation disclosure in times of uncertainty," *J. Econ. Manage. Strategy*, vol. 29, no. 4, pp. 792–815, Oct. 2020, doi: 10.1111/jems.12390.

[17] G. Xu, Y. Zhou, and H. Ji, "How can government promote technology diffusion in manufacturing paradigm shift? Evidence from China," *IEEE Trans. Eng. Manage.*, pp. 1–13, 2020, doi: 10.1109/TEM.2020.2981147.

[18] P. Gao, X. Gao, and G. Liu, "Government-controlled enterprises in standardization in the catching-up context: Case of TD-SCDMA in China," *IEEE Trans. Eng. Manage.*, vol. 68, no. 1, pp. 45–58, Feb. 2021, doi: 10.1109/TEM.2020.3005274.

[19] M. Hirokawa and D. Sasaki, "Endogenously asynchronous entries into an uncertain industry," *J. Econ. Manage. Strategy*, vol. 10, no. 3, pp. 435–461, Sep. 2001, doi: 10.1111/j.1430-9134.2001.00435.x.

[20] J. R. Galbraith, *Organization Design*. Reading, MA, USA: Addison-Wesley, 1977.

[21] L. Kim, "Stages of development of industrial technology in a developing country: A model," *Res. Policy*, vol. 9, no. 3, pp. 254–277, Jul. 1980, doi: 10.1016/0048-7333(80)90003-7.

[22] J. Xiong and P. Monin, "Antecedents to catching up in low-tech industries: Group-level dynamics in the Chinese hypermarket industry 1992–2011," *Manage. Int.*, vol. 19, pp. 148–168, 2015.

[23] A. Morrison and R. Rabellotti, "Gradual catch up and enduring leadership in the global wine industry," *Res. Policy*, vol. 46, no. 2, pp. 417–430, Mar. 2017, doi: 10.1016/j.respol.2016.09.007.

[24] Y. Miao, J. Song, K. Lee, and C. Jin, "Technological catch-up by East Asian firms: Trends, issues, and future research agenda," *Asia Pacific J. Manage.*, vol. 35, no. 3, pp. 639–669, Sep. 2018, doi: 10.1007/s10490-018-9566-z.

[25] L. Guo, M. Y. Zhang, M. Dodgson, D. Gann, and H. Cai, "Seizing windows of opportunity by using technology-building and market-seeking strategies in tandem: Huawei's sustained catch-up in the global market," *Asia Pacific J. Manage.*, vol. 36, no. 3, pp. 849–879, Sep. 2019, doi: 10.1007/s10490-018-9580-1.

[26] K.-H. Park and K. Lee, "Linking the technological regime to the technological catch-up: Analyzing Korea and Taiwan using the US patent data," *Ind. Corporate Change*, vol. 15, no. 4, pp. 715–753, Aug. 2006, doi: 10.1093/icc/dtl016.

[27] S. Kouamé and A. Langley, "Relating microprocesses to macro-outcomes in qualitative strategy process and practice research," *Strategics Manage. J.*, vol. 39, no. 3, pp. 559–581, Mar. 2018, doi: 10.1002/smj.2726.

[28] A. H. van de Ven, "Suggestions for studying strategy process: A research note," *Strateg. Manag. J.*, vol. 13, pp. 169–191, 1992. [Online]. Available: https://www.jstor.org/stable/2486359

[29] C. Cloutier and A. Langley, "What makes a process theoretical contribution?," *Org. Theory*, vol. 1, no. 1, Jan. 2020, Art. no. 263178772090247, doi: 10.1177/2631787720902473.

[30] S. Guennif and S. V. Ramani, "Explaining divergence in catching-up in pharma between India and Brazil using the NSI framework," *Res. Policy*, vol. 41, no. 2, pp. 430–441, Mar. 2012, doi: 10.1016/j.respol.2011.09.005.

[31] K. Lee and J. Ki, "Rise of latecomers and catch-up cycles in the world steel industry," *Res. Policy*, vol. 46, no. 2, pp. 365–375, Mar. 2017, doi: 10.1016/j.respol.2016.09.010.

[32] C. A. F. Riillo, R. Allamano-Kessler, N. Asnafi, V. V. Fomin, and G. van de Kaa, "Technological uncertainty and standardization strategies: A coopetition framework," *IEEE Trans. Eng. Manage.*, pp. 1–14, 2022, doi: 10.1109/TEM.2022.3145240.

[33] A. J. Shenhar and D. Dvir, "Toward a typological theory of project management," *Res. Policy*, vol. 25, no. 4, pp. 607–632, Jun. 1996, doi: 10.1016/0048-7333(95)00877-2.

[34] C. Giachetti and G. Marchi, "Successive changes in leadership in the worldwide mobile phone industry: The role of windows of opportunity and firms' competitive action," *Res. Policy*, vol. 46, no. 2, pp. 352–364, Mar. 2017, doi: 10.1016/j.respol.2016.09.003.

[35] J. Jin and M. von Zedtwitz, "Technological capability development in China's mobile phone industry," *Technovation*, vol. 28, no. 6, pp. 327–334, Jun. 2008, doi: 10.1016/j.technovation.2007.06.003.

[36] I. Almudi, F. Fatas-Villafranca, and L. R. Izquierdo, "Innovation, catch-up, and leadership in science-based industries," *Ind. Corporate Change*, vol. 21, no. 2, pp. 345–375, Apr. 2012, doi: 10.1093/icc/dtr041.

[37] Y. Guo and G. Zheng, "Recombinant capabilities, R&D collaboration, and innovation performance of emerging market firms in high-technology industry," *IEEE Trans. Eng. Manage.*, pp. 1–16, 2021, doi: 10.1109/TEM.2021.3095551.

[38] S. K. Fixson, D. Khachatryan, and W. Lee, "Technological uncertainty and firm boundaries: The moderating effect of knowledge modularity," *IEEE Trans. Eng. Manage.*, vol. 64, no. 1, pp. 16–28, Feb. 2017, doi: 10.1109/TEM.2016.2638847.

[39] D. McMahon and H. Thorsteinsdóttir, "Pursuing endogenous high-tech innovation in developing countries: A look at regenerative medicine innovation in Brazil, China, and India," *Res. Policy*, vol. 42, no. 4, pp. 965–974, May 2013, doi: 10.1016/j.respol.2012.12.003.

[40] D. C. Mowery and R. R. Nelson, Eds., *Sources of Industrial Leadership: Studies of Seven Industries*, 1st ed. Cambridge, U.K.: Cambridge Univ. Press, 1999, doi: 10.1017/CBO9781139175128.

[41] D. S. Hain, R. Jurowetzki, P. Konda, and L. Oehler, "From catching up to industrial leadership: Towards an integrated market-technology perspective. An application of semantic patent-to-patent similarity in the wind and EV sector," *Ind. Corporate Change*, vol. 29, no. 5, pp. 1233–1255, 2020, doi: 10.1093/icc/dtaa021.

[42] R. K. Yin, *Case Study Research: Design and Methods*, 3rd ed. Thousand Oaks, CA, USA: Sage, 2003.

[43] J. Seawright and J. Gerring, "Case selection techniques in case study research: A menu of qualitative and quantitative options," *Political Res. Quart.*, vol. 61, no. 2, pp. 294–308, Jun. 2008, doi: 10.1177/1065912907313077.

[44] C. Binz, J. Gosens, X.-S. Yap, and Z. Yu, "Catch-up dynamics in early industry lifecycle stages—A typology and comparative case studies in four clean-tech industries," *Ind. Corporate Change*, vol. 29, no. 5, pp. 1257–1275, Sep. 2020, doi: 10.1093/icc/dtaa020.

[45] L. M. B. Cabral, "R&D competition when firms choose variance," *J. Econ. Manage. Strategy*, vol. 12, no. 1, pp. 139–150, 2003, doi: https://doi.org/10.1111/j.1430-9134.2003.00139.x.

[46] J. Nahm and E. S. Steinfeld, "Scale-up nation: China's specialization in innovative manufacturing," *World Develop.*, vol. 54, pp. 288–300, Feb. 2014, doi: 10.1016/j.worlddev.2013.09.003.

[47] P. Fan, "Catching up through developing innovation capability: Evidence from China's telecom-equipment industry," *Technovation*, vol. 26, no. 3, pp. 359–368, Mar. 2006, doi: 10.1016/j.technovation.2004.10.004.

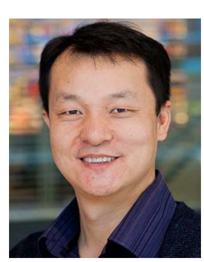
[48] J. Xiong, S. Zhao, Y. Meng, L. Xu, and S.-Y. Kim, "How latecomers catch up to build an energy-saving industry: The case of the Chinese electric vehicle industry 1995–2018," *Energy Policy*, vol. 161, Feb. 2022, Art. no. 112725, doi: 10.1016/j.enpol.2021.112725.

Lu Xu received the Ph.D. degree in management from Rennes School of Business, Rennes, France, in 2021.

She is an Assistant Professor with ESC Clermont Business School and a Member of Clermont Recherche Management (CleRMa) Laboratory, Clermont-Ferrand, France. Her research has been published in journals, such as *Energy Policy, Technology Analysis & Strategic Management*, *Journal of Business Strategy*, *Strategic Change*, etc. Her research interests include emerging markets, catching up strategy, sustainable development and innovation, and nonprofit organizations.

Jie Xiong received the Ph.D. degree in management from EMLYON Business School, Écully, France, in 2013.

He is an Associate Professor with ESSCA School of Management, Angers, France. His research has been published in journals, such as *Journal of Environmental Management*, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, *Energy Policy*, *Technological Forecasting and Social Change*, *Journal of Agricultural Economics*, *Journal of Product Innovation Management*, *Journal of Business Research*, *International Journal of Production Economics*, among others. His research interests include catching up of latecomer industries and firms, sustainable development and innovation, with emerging markets focus.



Jie Yan received the Ph.D. degree in management from Hull University, Hull, U.K., in 2004.

He is a Professor in Entrepreneurship and Innovation Management with Grenoble Ecole de Management (GEM), Grenoble, France. He has authored or coauthored articles in *R&D Management, Information and Management, International Journal of Technology Management, International Journal of Information Management, Technology Analysis and Strategic Management, Management International*, etc. His research focuses on business models and user behaviors on social media and other online platforms.

Richard Soparnot received the Ph.D. degree in management science from Université Val d'Essonne, Évry-Courcouronnes, France, in 2004, and the Habilitation à Diriger des Recherches (HDR) from IAE de Rennes, Rennes, France, in 2008.

He is a Professor of Corporate Strategy and Management with ESC Clermont Business School and a Member of Clermont Recherche Management (CleRMa) Laboratory, Clermont-Ferrand, France. He also serves as the Dean of ESC Clermont Business School since September 2022. He has authored or coauthored several papers in *Journal of Organizational Change Management, Journal of Change Management, Management International*, etc. His main areas of research are innovation, learning and strategic, organizational change, and the usefulness of management research.

Zhe Yuan received the Ph.D. degree in industrial sciences and technologies from Centrale Supélec, Université Paris-Saclay, Gif-sur-Yvette, France, in 2019.

She is an Assistant Professor with EMLV Business School, Courbevoie, France. Her research has been published in journals, such as IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, *Computers & Industrial Engineering*, *Journal of the Operational Research Society*, *Journal of Cleaner Production, Energy Economics*, *International Journal of Production Research*, among others. Her research interests include operations management, interface research between artificial intelligence and management science.