TOWARDS INDUSTRY UPGRADING: A STUDY OF CATCHING UP STRATEGIES OF CHINESE SECTORS

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ABSTRACT

Although interest in the Catching up strategy of developing countries has increased during recent years, this line of research is focused on national analysis from the beginning, developed nations as benchmark for fruitful lagging-behind countries, which need to be reviewed. Accordingly, we utilize a literature analysis method to distinguish the difference among developing and developed countries of catching up process. Based on our analysis, we state that the lagging-behind countries have the late-coming advantages. In the short term, the developing countries are able to achieve technical imitation by catching up with the technology. However, in the long run, imitation innovation is always based on the main concepts of developed countries, and does not really integrate the actual situation, social resources, and economic situation of developing countries. Consequently, it is essential for developing countries to find an innovating way to precede transformation.

Keywords: Industry upgrading, Catching up processes, Industry evolution, Capability building

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INTRODUCTION

In the early 1990s, computer integrated manufacturing gained considerable momentum. Since then, digitalizing the production chain has become a trend. With more and more factors involved in manufacturing, such as globalization, climate change, technology innovation, etc., the complexities of manufacturing systems and external environmental challenges are increasing (Spath et al., 2013). Under this background, Industry 4.0 is set to be Germany's strategy as a novel approach to develop manufacturing. Bauer and Horvath (2015) describe Industry 4.0 as "the intelligent real-time, horizontal and vertical integration of humans and machines with objects and information and communication technology systems to enable a flexible and dynamic management of complex systems". A more specific definition of Industry 4.0 is given by Kagermann and Wahlster (2013) as an

"integration of cyber-physical-systems in production and logistics as well as the application of the Internet of Things in industrial processes. This includes the consequences for the value chain, business models, services and work environment."

The viciousness of the competition between economies can be reflected from their strategies in manufacturing industries. Besides the Industry 4.0 strategy engaged by Germany, the President's Council of Advisors on Science and Technology (2011) suggested the US government take action to implement an advanced manufacturing strategy. Also, European Commission (2013) approved Horizon 2020 strategy which forms a roadmap for intelligent manufacturing machine factories in the future. Meanwhile, focusing on intelligent manufacturing product and process innovations, green manufacturing, and advanced materials, China adapted the Made in China 2025 strategy for industrial upgrading. What's more, since 2013, advanced manufacturing enjoys prioritization in Russia (Dezhina et al., 2015). Generally, catching up in manufacturing industry can no longer be carried out without the participation of advanced manufacturing strategies for the growth of economy.

Researchers in the field of economics have been committed to emphasizing the benefits of catching up for a long time, for instance, reducing poverty, providing help to countries' development track, improving national productivity, raising per capita GDP, and enhancing the competitiveness of the industry (Abramovitz, 1986; Malerba and Nelson, 2011; Kumaraswamy, Mudambi, Saranga and Tripathy, 2012). The key point of catching up is that, the more primary the country's science and technology and its ability to store the resource are, the stronger the retrograde will be, as well as the potential for improving its productivity.

The scholars in management field have carried out three levels of research on the theory of catching up. Macro national level, meso industrial level and micro firm level. Most of these studies have focused on the analysis of the inducement of successful catching up but less are about the process. In these rare studies about the catching up process, the objects of majority research are technology industries and technology-driven industries, such as South Korea and Taiwan's semiconductor research (Cho et al., 1998), China Telecom equipment suppliers (Fan, 2006), and integrated circuits in Taiwan and China (Rasiah et al., 2010). These studies basically follow a basic assumption of catching up theory: the technical orbit is predictable. In other words, the current research on catching up is that the catching up process is continuous and linear.

However, for low technology based industries such as retail, or disruptive developed high-tech industries such as high-speed rail, their technical orbital predictability is relatively low compared to the general technology-driven industries. In those cases, the processes do not necessarily follow the technological catching up on continuity and linear assumptions. Therefore, in a more generalized assumption, catching up may not have to be continuous or linear. Catching up theory needs further research, especially the theory itself and its process.

China is in the stage of economic transformation and industrial upgrading. But in most industries, especially the basic manufacturing and service industries, for foreign advanced industries or enterprises, the catching up is still in the exploratory stage. Based on the findings and results of different nations and/or industries published in the established literature, this paper has carried out a series of innovative research on the processes of catching up which have occurred in history. Doing so can help latecomer countries or industries to benefit the direction of the technological catching up.

THEORETICAL BACKGROUND

The processes of technological Catching up

Many studies focus on the meso-level (industrial level) of catching up process. Some scholars have developed a catching up process model, mainly through the study of emerging industrialized countries' (such as South Korea) high-tech industry technological catching up, and then analysis of emerging countries' high-tech industries. Kim (1980) studied the electronics industry in Korea and found three stages of catching up. The author pointed out that local companies in local industry which initially implemented foreign technology had accumulated experience in product design and production operations, and gained imported technology for limited numbers of domestic companies. Finally, the local and international market competitions are intensified, and the

improvement of local staff capacity and the assimilation of foreign technology, lead to the gradual improvement of foreign technology. Sung and Hong (1999) also illustrate the process that domestic companies improve their foreign technology by reviewing South Korea's nuclear power program. The authors found that the process of catching up foreign technology in any industry in developing countries was achieved through the preparation, implementation, acquisition and improvement of foreign technology. Jin and von Zedtwitz (2008) extended the model of Kim (1980) by studying China's mobile phone industry. The author added the complementary phase to tacit technology and believed that developing country firms acquire and absorb mature, growth and emerging technologies at the same time. Guennif and Ramani (2012) examined the pharmaceutical industries in India and Brazil and confirmed Kim's (1980) catching up process model. The authors found that the catching up process began with the creation of "production capacity" in some markets, and then continued to develop "redesign capabilities", followed by gaining "new drug discovery" in the upstream market for innovation in specific drug markets. Lee and Lim (2001) conducted cross-sectional studies through several industries in Korea, including dynamic random access memory (D-RAM), automotive, mobile, electronic consuming, personal computer and machine tools. The authors summarize three different types of technology catching up process: path following, path skipping and path creation. All in all, these studies show how local firms can gradually use foreign technology to narrow the gap with foreign technology.

Technological catching up and capability building

Some other scholars have also studied the process of catching up of technology-based industries in latecomer countries. These studies do not explicitly focus on the process of technological catching up, but emphasize the catching up process from a competency perspective (i.e. Malerba and Nelson, 2011; Kumaraswamy, et al., 2012). Mathews (2002) studied the semiconductor industry in Taiwan and discussed the various stages of the process from the original equipment manufacturing (OEM) to the original design and manufacturing (ODM), and ultimately to the original brand manufacturing (OBM). Amsden and Chu (2003) studied the electronics industry in Taiwan and believed that the catching up process began with foreign direct investment studies, approving certification and then conducting local research and development. Sheng (2009) has carried on theoretical research of technological catching up in Japan and Korea, and found that the technological catching up of the developing country is closely related to its technical capability, and the process of technological catching up is also the process of continuous improvement of technical capability. Cheng et al (2011) took China's high-speed rail industry as the object of case analysis. These authors have found that the unique needs of China's industrial development process have a positive contribution to basic research. Exploring the basic theory behind mature foreign technology is still an indispensable stage for the development of core technology in China. Malerba and Nelson (2011) studied six industries in several developing countries and pointed out the other three stages of catching up: from export and entry, to production and specialization upgrades, and finally to internationalization. Kumaraswamy et al. (2012) studied India's auto parts industry and summed up the three stages of catching up: transition, integration and global integration. The authors also point out that successful catching up has laid a strategic foundation for creating knowledge in the integration of domestic industries and global value chains. Zhao et al. (2015) conducted theoretical research connecting market demand, technical capacity and product development by the technical road map to technological catching up. These scholars use the visual method to sum up the four technological processes for the catching up model: the technical line catching up, product on behalf of catching up, technical ability catching up, and market expansion catching up. Huang and Wei (2014) constructed the profit function model analysis of technological catching up based on capital, talent, technology and emerging industry time evolution. They found that: catching up with the strength of the country after the strong advantage of the emerging industries can affect the evolution of the unstable phase of emerging industries, and through the cultivation of open and innovative capacity, the accumulation of technology to catch up with the ability to achieve in the transition phase catch up. Additionally, the

ability to catch up with the weak enterprises should grasp the emerging industry, the transition phase of the opportunity window, to strengthen the learning and absorption of technology, focus on resources to break through the key technologies to achieve a stable stage catch up.

Liu and Wang (2015) selected high-end equipment manufacturing, communications equipment manufacturing in the representation of the catching up enterprises to carry out cross-case studies. These scholars found that in the emerging market countries, high-tech manufacturing enterprises' catching up process path is based on the upgrading of enterprise technology capabilities. Technological catching up strategy and catching up path take technical capacity as the basis, as there is no unified optimal model with a variety of options.

Although the above studies still analyse the technology industries of followers, they extend the technology catch-up process from a competency perspective to a more general based capability process. In short, these studies are still rooted in a model that follows the process of catching up (for example, Kim, 1980), with only slightly different focuses.

In summary, the literature on the interdisciplinary process focuses on two main categories: the three stages of industrial technological catching up in the new industrialized countries and emerging countries. However, in addition to a few cases, such as Jin and von Zedtwitz (2008), who found the complementary part of the Kim (1980) model, most of the literature still follows Kim's (1980) technique to catch up with the model. The implicit assumption of these studies is that catching up is a linear and continuous process.

Jin and von Zedtwitz (2008) found that the development of Chinese technology and capacity was different from the three-stage model of Kim (1980): the stage could proceed at the same time. However, this finding is based on the provision of different generations of mobile technology for developing Chinese companies in the host country market. In other words, the existing technology-based industry catching up process research is based on the technical trajectory in predictable condition (Figueiredo, 2010). In this case, due to the predictable technical trajectory, the process of catching up and development can be clearly identified. However, we do not know much about the catching up process for any industry that is less predictable in the technology trajectory, such as the catching up process for low-tech industries or disruptive developed industries.

For example, we do not know how Kim's (1980) technological catching up process, acquisition, assimilation and improvement of the classic model occurred among different nations. At the same time, we do not know how Lee and Lim's (2001) technological catching up, path-following, path skipping and path creation models appear. In addition, the models of Kim (1980) and Lee and Lim (2001) are summarized from the analysis of the high-tech industry that is more predictable of the technical trajectory. We rarely know which mechanisms and triggers lead to every step of the existing study. Therefore, there ia a need to carefully study the processes of catching up, based on the industry history analysis of how it happened.

Methodology

Chinese technological catching up mechanism and process direction research results are sparse, and most of them focus on theoretical research, at the national level (Sheng, 2009), industry level (Cheng et al., 2011; Lin et al., 2013; Zhao, 2015), and the enterprise level (Huang and Wei, 2014; Liu and Wang, 2015). However, research on comparisons of the technological catching up processes and different stages of the processes are limited. We aim to analyse the published technological catching up processes from the academic literature and compare them to provide guidelines to latecomer countries, such as emerging markets.

Therefore, we examine the published articles related to industrial evolution and technological catching up processes. We paid attention to the studies of catching up, excluding those focusing on the antecedents and factors which facilitate the catching up outcome. By the end, we obtained 14 articles with clear patterns of catching up processes in different countries and industries. As two articles are review articles of the theories, we took the other 12 industries/countries as the empirical settings to examine the catching up processes.

The empirical settings, thus include the catching up processes from country, industry and firm level. Among these countries, Asian countries such as Korea, Taiwan, Singapore and Japan are widely covered. We then decouple the

catching up processes based on the level of analysis, including country level, industry level and firm level. Then we examine the catching up processes, focusing on how the phenomenon happened from the very beginning to the end. Then we further analyse how these catching up processes at different levels can align to the established literature of the three different patterns, namely path following, path skipping and path creation. Doing so allows us to understand the characteristics of selected catching up processes, especially the strategies of the catching up in different stages/periods. Then we compare the catching up strategy/patterns across levels of analysis and compare the divergent strategies of catching up at the same level of analysis. To this end, it is expected to understand more on how technological catching up processes emerged at divergent levels of analysis and how different catching up strategies could be implemented at the same level of analysis.

FINDINGS

Among the selected catching up processes, we identified two summary studies on the catching up processes, 2 catching up processes at firm level, 7 studies of catching up processes at industry level, and 1 study of the processes at country level. Then we briefly introduce these catching up processes here.

Zhao et al. (2015) tried to visualize the different ways of catching up from company's technological development perspective. The authors summarized the technological catching up processes as progressive and evolutionary, starting from technology jump gap, to leading competition, to production generation gap, to market share competition and finally to break the existing technology and reach the technological leapfrogging. This study also highlights the importance of technology discontinuity. It means that companies catch up from one technology to the next, by closing the technological gaps at different levels.

Lee and Lim (2001) examine the technological regime and identified three divergent patterns of catching up, namely path-following, path-skipping and path-creating. The path-following catching-up means that the same path created by forerunners is followed by the latecomers while the latecomers go through it using less time. Path skipping catching up indicates that the latecomers follow the path to a certain extent but some stages are skipped to save time. Finally, the last type, path-creating catching up occurs when latecomers explore their own paths of technological development which are different from the ones created by the forerunners. This mode can take place after the latecomers having followed the forerunners' path.

However, the existing studies rarely address the catching up processes, including the technological catching up processes, by examining the divergent catching up strategies along with the catching up periods/stages or across the level of analysis. Therefore, we illustrated the results along with the catching up periods and across different levels.

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See Appendix Table 1.

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Catching up processes at national level

Cavallaro & Mulino (2007) conducted a numerical simulation and found that the technological disadvantage of a country can be considered as a positive determination of a catching up process, which means that catching up process can be driven by the technological lagging. Only when the country is open to the rest of the world, their lack of resources can be obvious from different aspects, such as goods and service trade, foreign direct investment, migration and business contacts, etc. At the same time, it is able to enjoy the benefits brought from international knowledge spill-overs, by gaining skills in applying to the goods it manufactures the know-how embodied in products of the advanced country, and thanks to the variety of the goods trade, companies have the opportunity to apply a given know-how to a different type of good. These methods carry on both innovation and imitation in the latecomer's R&D sector which will drive the catching up process.

Catching up processes at industry level

Chen et al. (2011) identified that with the help of industrial basic research, cracking the shackles of the core technology of the industry, is one of the main sources of knowledge accumulation in the process of technological catching up. Over the past few years, China's high-speed rail has achieved a leap-forward development, which makes it the country owning world's longest term high-speed

railway operating mileage. 2004 China's introduction of high-speed rail technology from abroad, the first problem is how to make foreign technology to adapt to China's geographical condition. Thus, foreign mature high-speed rail technology in China doesn't meet perfection so that this technology must see further innovation to adjust the national conditions. The introduction of high-speed rail from abroad is the model attempting to digest and absorb the introduction of technology containing the tacit knowledge, using the first imitation, optimization, and then re-innovation way. The Ministry of Railways localization of the requirements force China's high-speed rail manufacturing enterprises and various scientific research institutions to extract the relevant issues related to the project and the theoretical knowledge. Engaging in basic research helps companies to better absorb external knowledge, but also easy to find expert advice in time when the technical problems come up. After grasping the 250 km/h high-speed rail technology, the China Ministry of Railways demand enterprises to further create the faster trains whose speed can reach 320 km/h. Speed is a typical indicator of measuring high-speed rail equipment technical performance. A substantial increase in speed will lead to qualitative changes take place in the railway industry and its related system. Frontier research on virtual train at the speed of 500 km/h needs further investigation.

Huang et al. (2012) discovered that after determining the catching up timing of the strategic emerging industry, by analysis of the catching up capability and opportunity, the appropriate catching up path can be settled. Path catching up strategy can be divided into path following strategy, path jump strategy, path creation strategy. The path following strategy is that the latecomers develop along the same path as the forerunner, but the latecomers develop faster. The followers of this strategy will start at a mature and standardized product technology point, and gradually approach to the process of recycling, product design, product development and other high-end links, such as "OEM-ODM-OBM" path.

The origin of the path jump strategy is the re-innovation of the digestion and absorption of the introduced technology, which is a series of product performance improvement and production process improvement along the established technical trajectory. Path creation strategy implies that the latecomers are not entirely in accordance with the mainstream technology trajectory forward created by leaders, but create a new path when their technical capacity reaches a certain stage, in accordance with the local elements of the conditions and demand conditions, the development of new technologies, products and markets.

Xing (2017) summarized that with the protection of the comparative firm advantage, BYD reduced the traditional automobile business step by step and increased the new energy automotive business gradually. This gradual switch contributes to cultivate absolute superiority for BYD's catching up strategy. Plunge catching up is also known as the way of "no switch, path creating" whose typical example is Tesla. Tesla invested nothing in the traditional car producing so that it does not have to bear the sunk costs. Thanks to its technological innovation in new energy vehicles, Tesla jumped to the leader from a new entrant in the pure electric vehicle industry coupled with the comparative firm advantage and competitive advantage. Toyota's gas and electricity hybrid technology is losing the interests from Europe, the US and China, although its hybrid car owned the world's largest cumulative sales. What's worse, Tesla's catching up makes Toyota into a poor situation in pure electric technology. Therefore, Toyota anticipates developing hydrogen fuel cell vehicles, which is considered as a path creating resistance to transcendence from Tesla and dealing with the uncertainty of future technology trends. This mode is defined as hybrid catching up.

Hobday (1995) analysed four different technological industries and examined that catching up processes, including the chip industry, consumer electronics manufacturing, PC manufacturing and telecommunication.

The technological learning within Anam Industrial contributed to its catching up process which can be divided into 4 main phases. The first is a long slow period because of absorbing and being proficient in the related basic manual techniques, then trying to move on to semi-automated assembly gradually. When it is involved in learning the engineering process skills because of facing complex manufacturing processes, it enters in the second phase. The booming of the US's chip industry brought the increasing and diverse demand which pushed

Anam to invest in engineering facilities. The engineering R&D improved and maintained the core manufacturing processes. However, in the phase 3, a remarkable switch took place from customer-pull to supplier-push technological development which is considered as an important step from catching up learning to innovation. The reason why Anam took the initiative by offering specifications is the increasing demand complexity. This move is similar to the transition from OEM to ODM in which the latecomer internalized design skills. The upgrading of product innovation capability brings Anam into the phase 4 with a series of process skills deepening.

For consumer electronics manufacturing, it is common in many East Asian companies to begin manufacturing basic products or parts under OEM. During this stage, they learn and absorb the techniques of how to manufacture various different products. Because they have assistance of simple know-how by receiving quality control engineers from their stakeholder, also outlets, market and technical information are provide by local and foreign traders. Gradually, RJP designed and launched its own product by learning under OEM which means it proceeded into ODM. OEM and then ODM forced RJP to improve the quality of its products. The ultimate of the catching up stage is OBM which happens at the stage when the company launches products under its own brand name, capturing more post-production added value. With OBM, it began the transition from latecomer to follower, competing with improved design, and by adding new proprietary features.

The case of Weaners clarified the dependent nature of latecomer technological catching up process. Firstly, it built up a high reputation in PCs thanks to its high quality, fast delivery OEM supplier and so on. And under OEM, the firm learned the rigors of high-quality, fast turnaround production. Gradually, the firm developed its own in-house designers and brand name, progressing beyond OEM. It continued OEM alongside OBM as a part of its business strategy for expansion. As Weaners progressed from subcontract assembly of connectors, to OEM, ODM and OBM in computers, capabilities were learned with respect to technology, organisation management and marketing. As a latecomer, OEM remained an important option for the company, despite its product design abilities and OBM aspirations.

MTI accumulated manufacturing skills under OEM and then began to introduce its own product innovations, some for ODM, other OBM. Regarding OBM strategy, the company's size pre-empted direct competition with major suppliers. It also pre-empted large-scale R&D spending on major innovations.

Cho et al. (1998) examined MTI latecomer's strategies based on the evidence from the semiconductor industry in Japan and Korea. The authors discovered that catching up processes of the semiconductor industry consist of 3 steps, completed one after the other, which are taken by Japanese semiconductor firms for building their competency. Developing an internal demand for semiconductor is the first step be taken aiming at achieving a take-off in the new industry. The firms' internal demand brought market information which is considered as most valuable source so that further improvement in the quality and marketability is oriented. By accumulating experience, Japanese manufactures of semiconductors took the second step for building their competency. In order to get benefits from economies of scale and learning curve effects, they invested a large amount in process technologies and manufacturing facilities. Once they gained manufacturing competence, those companies finally sought for technological leadership in the last step. As changing from latecomers into leadership, they notably launched massive investment in R&D for their technological capabilities upgrading.

The mode of catching up process created by Japanese semiconductor industry provides a referenceable experience for Korean dynamic random access memory (DRAM) companies. Firstly, the success factors shared by Korean companies are paralleling Japanese strategies. Secondly, unique entrepreneurial leadership was applied when entering the new industry by the top managers, such as odd timing, time compression and human embodied technology transfer. Those elements are significantly increasing their catching up strategies.

Sung and Hong (1999) studied the process of nuclear power industry in Korea. During the preparation stage, the government first made the related law to build up the infrastructures since it has been interested in atomic energy. National research institutes and education programs were launched for support. When they had prepared basic support, they moved on

to the stage of implementation of foreign technology. Technical emphasis was largely placed on the acquisition of operation techniques to make self-operation of turnkey reactors. Peripheral technology is acquired in the stage three. Through learning-by-doing process, they had mastered their skills, and their knowledge was transferred to the organization level. After absorbing the peripheral technology, the core technology was desired so that in the stage four, a master plan for technological localization was generated, mentioning that domestic firms should be prime contractors in the succeeding projects. After, they exerted various efforts for internalizing the core design technology steadily, in the final stage, the design model was developed based on the Korean geological situations and foreign new technologies to improve. The design technologies have been improved in the sense of safety, efficiency, and convenience in operation and maintenance.

Jin and von Zedtwitz (2008) studied the China's mobile phone industry in order to understand more on the technological capability development of the technological sectors in China. Technological capability is the essential factor for technological catching up whose development follows three steps according to the empirical research. Domestic firms transfer nature technology from multinational companies. Next, they absorb the transferred technology and diffuse the technology within the firm and in the industry, even in the whole economy. Eventually, these firms innovate and develop their own, new technologies. Here, a recessive stage is defined as the stage of technology obsolescence in advanced countries. So, Kim's (1980) 3 stages of TC development is extended into four stages adding a complementary stage of recessive technology.

Lee and Ki (2017) found that after the 2nd world war, new technologies emerged in the world steel industry. While US companies were stranded in an incumbent trap during the post-war period because of continuing the existing approaches, Japanese companies caught this window of opportunity as their swift adoption these new technologies and created their own development methods. In this case, the path created by the Japanese companies engaged the way of absorption and carry on innovation. Thereafter, the global steel industry plummeted, which brought windows of opportunity for a Korean steel company, namely POSCO. Its catching up process started from the low-end segment, blossomed by path-following (mature knowhow importing from forerunner, namely Japan), and advanced by switching into path-skipping strategy (downturns capitalization and technology innovation).

The research conducted by Kang and Song (2017) shows in the early days of the camera industry, Japan and Germany both produced rangefinder cameras while Japan as a latecomer was not able to compete with German competitive leaders. The situation took a favourable turn for the Japanese camera industry in the late 1950s since the SLR camera was developed as a distinct technology which contributed to improving their performance considerably. The SLR camera took over the market criterion thanks to its handy operation and high performance-price ratio, replacing the German-dominated rangefinder camera. Soon, in the early 1960s, Japan succeeded in leapfrogging over Germany in camera industry for its production and export. However, a threat to the leadership of Japan in camera industry emerged from the late 2000s when the new window of opportunity technology, mirrorless cameras, gained the attention from some secondary-line Japanese companies and Korean companies. The leadership change of this phase not only took place between Japan and Korea but also among the individual Japanese companies.

Morrisona and Rabellotti (2017) proved that less technology is involved in the catching up process in the worldwide wine industry. The steady decrease in traditional consuming countries' consumption provided the window of opportunity as a critical point in the first catching up cycle. The new inexperienced British and American consumers' entry and the increasing large-scale distribution play important roles in this stage. While old world producers like France and Italy were stranded by the existing technologies and institutions, the new world producers took swift actions to adapt to the new market climate. Unlike with the technology oriented industries, latecomers' initial competitive advantage in the wine industry gained mainly from production innovation and institutional set-up other than basing on low costs. Consumers' requirement of diversity developed into a qualitative consumer taste change which reformed the world wine industry from 2000s. This opened a window of opportunity for newer latecomers.

Shin (2017) held the point of view that the competition between forerunners and latecomers in the semiconductor industry, for research and development, never stops because they both need to update their technologies, processes, and facilities for adjusting with new product generation. Therefore, a dynamic catching up strategy brought out by Japanese latecomers, however is more suitably considered as a portion leapfrogging process than stage-skipping catching up. It is defined as a dynamic strategy not only because it puts eyes on changeable targets and focuses on two generations' development, but also thanks to the R&D efforts which are exerted more on innovation process than product technologies. In addition, the Japanese firms did not skip the 16K DRAMs stage or put it into less important position. In the memory industry, that same generational product developing path is followed by both the forerunners and latecomers. Korea's triumph of gaining leadership is generated by a similar strategy as Japan took, and its persistence of the leadership counts the windows of opportunity and capability expansion.

An introduction of a criterion catching up process begin with the entry of a latecomer into an industry and surmounting its shortcomings, introduced by Lee and Malerba (2017). It is followed by the "gradual" catching up stage, in which it starts gaining market shares thanks to its cost advantages, technology absorbing and capability accumulation. Catching the windows of opportunity and positive response drive it to forge ahead into a more mature stage where the latecomer takes over the leadership with the decline of incumbent. Gradually, with the emergence of newer threating entrants, the present leading latecomer could not avoid falling behind as the forerunners did.

Within an interval 14 years, the leadership in the mobile phone industry changed twice, where technological change was the trigger of window of opportunity for latecomers. Digital technology emergence led Nokia's triumph over Motorola, while later the window of opportunity led the transition from Nokia to Samsung, namely, Android OS takeover of the leadership of Symbian.

Within an interval of 11 years, the memory chip industry witnessed two leadership changes and one leadership persistence. In order to face the swift changes taking place in this industry each 3 or 4 years, latecomers have to pay attention to moving targets and dynamically develop two generations' technologies coupled with prediction of the possible changes ahead.

Three main technological shifts happened in the camera industry where the first and third shifts had leadership change involved and in the second shift the leadership of incumbents was retained. For the first and third changes, increasing demand offered the window of opportunity.

Japan dominated the leadership of steel industry from the US by adopting Bag of Features (BOF) method early and at low cost thanks to coordination between government and industry at late 1970s. Korean company POSCO, with limited producing capability at that time, thus missed the Continuous Casting opportunity. However, POSCO learnt mature technology from Japan and moved into a path following catching up method.

Changes in demand served as the window of opportunity in both two leadership changes in regional jets industry which but also reinforced regulatory changes in the US.

The regional jets industry witnessed two leadership changes. In 1995, British Aerospace (BAe) and Fokker dominance in the market were replaced by Canada's Bombardier, because the latter created a niche for the 50-seat market while the former focused on 70 to 120-seat range. The second leadership change took place in 2005 by the Brazilian Embraer. The window of opportunity was the changes in demand in both instances.

Technology did not play a role in opening windows of opportunity in the global wine industry but policy and regulation did.

The four-stage catching up cycle was verified by Landini, Lee and Malerba (2017), namely, the aborted cycle, persistent leadership, return of the old leadership, and coexistence in leadership between latecomers and incumbents. Two successive changes in mobile phone industry leadership were led by technological discontinuities, from the US to Finland and from Finland to Korea and partially the US. Similar story happens in the memory chips industry. The window of opportunity was opened by the frequent technological generation changes that forced latecomers' predicting and aggressive investment in two generation technologies for obtaining the leadership from the incumbents.

Ghazinoory, Dastranj, Saghafi, Kulshreshtha and Hasanzadeh (2017) suggested that the technological path is predictable in Iranian social banking industry, but the technological capabilities average level is rather low as well as the R&D motivations: thus experts recommend the path following strategy for short term development. When the capabilities are learned and accumulated, path skipping strategy can be. Furthermore, the bank will be able to create its path once it gains social bank capabilities, so that it could deliver required financial and non-financial services.

Shi and Shi (2015) examined Chinese mobile phone industry as a latecomer: its catching up process is identified in 4 stages. In the first stage, the accumulation of resources and infrastructures is the main mission. The resources accumulated in the first phase are utilized to acquire manufacturing capabilities in the second stage. Once the capabilities have been built, in the third stage, capturing market become the main object. Dominance in the market reflects the success catching up which is the symbol of the final phase, namely diversifying portfolios where companies seek for swift expansion and diversity of products.

Catching up processes at firm level

The automobile industry is highly influenced by government institutions (Yeo and Pearson, 2008), whose development path can reflect the traits of transitional economy. Geely's catching up process took place in a transitional economy background. In the initial stage, it ran in a non-institutional environment, chose a defensive-oriented competitive strategy, took the way from hiring, through reverse engineering to imitate the target model, outsourcing core components, thus entering the low-end market. In this environment, it added a forward-looking component in the competitive strategy. In addition to learning from the hiring, it also gained acknowledgment from research and technology introducing. In these efforts, Geely has achieved a breakthrough in the core components of the ability, and its structural capacity has also undergone a qualitative change. Although its products are still located in the low-end market, its market share has entered the domestic top ten and it began to export to overseas markets. In the transition phase, Geely was able to create a supportive institutional environment due to the expansion of the political strategy and the success of the ability to catch up.

Lin et al. (2013) found that the technical trajectory is the path of technological evolution, determined by the rules that are implicit in the direction of technological change. Technology, economy, environment and enterprises are the key factors influencing the formation of technical trajectory. The technological trajectory is composed of technology selection methods, the core technology line, product-oriented design patterns, product and process technology standards, technology integration inertia and mainstream manufacturing processes and other organic composition. Many factors related to the economy, such as market demand, size, relative price, especially the composition, change and growth rate of demand, will have a great effect on the rate of technological trajectory evolution and the selection mechanism of potential technology paradigm. Innovative activities are the result of co-evolution (selection-learning) of technology, institutions, markets, and so on. The formation and selection of technological trajectory can often be determined by the national conditions, such as system, culture, technology gap, innovation system. Entrepreneurs are the decision makers of technology selection, enterprise group selection is the formation of technological trajectory, the driving force of development.

Farab, the hydro electricity company in Iran, didn't process its technological capability building in a linear path (Kiamehr 2017). Instead of started from the early stage of PLC, it began from the second stage, studying advanced technologies from the industry leaders and learning how to apply them into supporting their projects. By doing so, Farab gained engineering core equipment which formed a foundation for moving on to the third stage where technological problems need to be resolved during the operation of those complex equipment. Interestingly and finally, it went back to the first stage. At this stage, Farab achieved the design of its own system with the supply from leading firms, although it is backward in skill compared with the leaders because of the lower amount of participation in the R&D.

In the complex product system industry, catching up can be an arduous and challenging process. Thus the general approach of technological catching up method is on the basis

on path-following, while path-skipping is less possible in minor technologies and path-creating is almost unfeasible (Majidpour, 2016). MAPNA, the Iranian company in land-based gas turbine industry is a CoPS latecomer firm in a developing country which has fully localized and expanded into overseas markets too. MAPNA's catching up pattern shows the typical path-following strategy. From the beginning, it only owned assimilation of repairing and assembling knowledges. Gradually, it gained manufacturing capability in tandem with training while it skipped a few minor manufacturing processes. Thanks to co-manufacturing, reverse engineering and licensing, it has real product engineering. Nowadays, it grows design capabilities by licensing and R&D contracts. Its path-following path shows the track from OEM to ODM.

MAPNA is the dominant local supplier of large thermal power generation plants in Iran, which has complete 3 stages for its catching up development and is currently facing major challenges for its possible transition to leadership in its industry (Kiamehr, Hobday and Hamedi, 2015). Barriers emerged at its infant period after its entry. Its shortcoming was reflected in lacking of project and industry experience or technical and management capabilities. On the aspect of production chain, it lacked upstream local suppliers and was disconnected from international ones and downstream supportive local clients. What's worse, access to lower cost resources was not achievable. Seeking local collaborations was the main object by offering low-cost project management and engineering service, using linkage with local clients to secure initial projects, and using packages of local projects to build business relationships with international companies learning non-core systems. Gradually, gaining technology experience and capital drove MAPNA into the second stage where new barriers arose. Orders were not enough to exercise and enhance its capabilities, coupling the threats from local low-cost competitors. Thus, facing the growing domestic market, capability exploiting measures were taken and enhancing the linkage with local clients was higher valued. Manufacturing was not limited to the non-core system but engaged in more complex engineering activities, which solidified its position in the domestic market. In the expansion and export stage, competitive threats in the domestic market increased. Iranian electricity generation is privatized, and problem emerged of the access to foreign knowledge sources. In order to enter other local project markets, overseas electricity project markets and operation and maintenance of local plants, MAPNA used its accumulated credits and experience, investing in design and engineering capabilities. Reorganization allowed the firm's engineers to undertake trial and error learning which contributed to growth.

Patterns of Catching up processes at different settings

Next, we examine the selected catching up processes and compare their strategies. We implemented Lee and Lim (2001)'s three different patterns of catching up, namely path-following, path-skipping and path-creating, to investigate the stages and periods of catching up processes chosen. The results can be shown in Table 2:

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See Appendix Table 2.

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Path-following. For most technological industries, such as automotive, flat panel display, some new energy automotive, electronic technology, semiconductor, nuclear, automobile, telecommunication, PC, machine tools and mobile phone industries, starting the catching up processes by implementing path-following strategy is common and reasonable. The logic behind this is learning, which help the followers to build competence and accumulate the knowledge for further development (to be internationalizing or to compete). By implementing the path-following strategy, the industries are normally at the early stage of the development.

Path-skipping. This kind of catching up strategy can be found in the flat panel display industry in Japan, semiconductor industry in Korea, D-RAM and automobile industries in Korea. But in other industries where path-following strategy is more applicable, the path-skipping strategy is not very common to see. These industries, however, either have strong motivation to create, or have the risk seeking attitudes, or have low frequency of innovation, which can be identified through the path-skipping strategies implemented.

Path-creating. This strategy could be identified in the Chinese high speed rail sector,

CDMA technology of telecommunication in Korea and new energy automotive such as Tesla. These industries are normally technology driven or face strong competition of existing technology. Industries or companies implementing path-creating strategy require strong capability of innovation and knowledge to lead the market. However, some industries or companies such as Toyota implement the combination of path following and path creating strategy. It might be because the business model and scope of Toyota is different from its competitor Tesla.

DISCUSSION AND CONCLUSION

The choices of catching up approaches differ in sectors and firms. By revisiting the catching up process of different Asian firms in different industries, some commonalities are achieved.

The industries in their early phase of development tend to implement the path-following strategy. By doing this, latecomers can take advantage of technology learning and imitation to accumulate catching up capability and acquire predominance because of taking less risk of technology innovation.

The industries having strong creation motivation, or having the risk seeking attitudes, or having low frequency of innovation, can be identified by the path-skipping strategies implemented. They need to have a certain degree of technological innovation, be able to accurately determine the technical trends in the field according to the technical trajectory, and make reasonable choices of technological catching up targets.

Path creation strategy requires that the industrial development has strong technology innovation involved. The breakthrough of the original technological path means the leaders created by the original technology and market, facing new technology and market knowledge, need different technical assets to support.

The research meanings conducted by this study can be defined into four aspects. First, deepening the process of comprehensive catching up theory. This project begins with a broader theoretical assumption, and from the new perspective of comprehensive catching up, to research the industries and enterprises of the latecomer countries, frees them from the traditional technological catching up analysis framework and re-examines the more generalized situation of catching up. It opens the black box of how managers make decisions during the catching up process. This has led to an extendedness of comprehensive catching up study, different from the technological catching up, from the development of technology trajectories for how to develop a comprehensive catching up strategy, which is closer to the reality. This will not only be a strategic choice from a new perspective on the development of the industry and enterprises, but also provide feasible implementation strategic recommendations to promote the study of catching up theory.

Second, helping to launch a new level of analysis and multi-level analysis of the theory of catching up. This project considers the differences in the initial conditions when the catching up strategies are taken in different industries in Asia. In the comprehensive catching up study, we take the multi analysis level from nation level, to industry level and firm level. That is to say, carrying out an in-depth study about the comprehensive catching up in industrial level in a host country, based on host country's groups and foreign groups. At the same time, this project combines the meso and micro levels, that is, the group and the enterprise level, to conduct a comprehensive discussion about comprehensive catching up process. This is based on a new analytical level, the multi-level analysis of catching up theory, especially the catching up mechanism and process. It is expected to provide a very micro-theoretical basis (micro foundations) for the macro-state catching up, thus expanding the scope of catching up theory.

Thirdly, contributing to the development of multi-theoretical research in combination with other theories. Based on the theory of catching up and combining with organizational learning theory and organization capability, this study examines the undevelopment of the leading industries in different markets. Based on the different economic characteristics, different industrial structure and the different industrial cycles of latecomer industries, from the perspective of organizational learning and organization capability, conduct multi-theoretical analysis on catching up theory. It will help from a deeper point of view for understanding better the catching up theory, but also to expand a wider range of research for these auxiliary theories.

Fourth, being conducive to catching up strategy taken in countries and industries to complete the industrial upgrading. For the latecomer industry that wants to take the catching up strategy to complete the industrial upgrading, this project will help some of those latecomer industries to select the correct catching up strategy, to implement comprehensive catching up successfully, so as to complete the purpose of industrial upgrading. Because it starts from the induction, mechanism, process and boundary conditions of the comprehensive catching up theory, and combines the horizontal and vertical analysis of the cross-catching stage with multiple industries in different backgrounds, it provides the appropriate analysis and discussion for different economic characteristics of the industry.

Industry 4.0 heralds fourth industrial revolution influence no matter technological or non-technological processes. Learning from the pioneers can contribute to the latecomers' catching up strategies. Intelligent production (Smart Factory and Smart Products) as the core concept of Industry 4.0 is necessary to be implemented if the manufacturer wants to maintain or/and gain more market share in the global market sustainably. Companies, organizations, and governments all exert their efforts on advanced manufacturing and digitalization in order to achieve efficiency, productiveness and flexibility.

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Appendix

Table 1. List of examined catching up processes

Author	Firm	Industry	Nation	Processes
Jiang, Gong, and Wei (2011)	Geely	Automotive	China	Learning from hiring – outsourcing – enter the low-end market – catching up
Cheng, Liu, Chen, and He (2011)		High Speed Rail	China	Foreign technology introduction – technology digestion – technical innovation
Zhao, Huang, and Guo (2015)		Flat Panel Display	Japan, Korea, Taiwan	Japan- path jump; Korea- path creating; Taiwan- path following (OEM, ODM, OBM)
Xing (2017)	BYD, Tesla, Toyota	New energy automotive	China, Korea, America	BYD- Phased catching up; Tesla- Plunge catching up; Toyota- Hybrid catching up
Hobday (1995)	Anam Indusrty, RJP, Weames Hollingsworth Group, MTI	Chip manufacturing, Electronic manufacturing, PC, Telecommunication	Korea, Hong Kong, Taiwan, Singapore,	Assembly-OEM-ODM-OBM
Cavallaro and Mulino (2007)			Latecomer countries	driven by international knowledge spillovers
Cho, Kim and Rhee (1998)	NEC, Toshiba, and Sharp, Hyundai and LG	Semiconductor	Japan, Korea	Technological leapfrog
Sung and Hong (1999)		nuclear power	Korea	Prepare, implement, acquire and improve
Lee and Lim (2001)		D-RAM, automobile, mobile phone, consumer electronics, personal computer and machine tool	Korea	
Mathews (2002)	Taiwan semiconductor Manufacturing Corporation	semiconductor Manufacturing	Taiwan	OEM-ODM-OBM
Fan (2006)		Telecom-equipment	China	Capability building, in-house R&D developing, external alliance
Jin and von Zedtwitz (2008)		Mobile phone	China	Technological capability building, organizational learning, OEM-ODM-OBM

Table 1. List of examined catching up processes (continue

Author	Firm	Industry	Nation	Processes
Steel industry (Lee and Ki, 2017)	POSCO	Steel industry	Japan, Korea	New technology emerge as a window of opportunity, path-creation, path-skipping
Kanga, Songb (2017)		Camera industry	Japan, Korea	Leapfrogging. Leadership shift from Germany to Japan, Japan sustained leadership, leadership shift from some Japanese company to others and Korean companies.
Morrisona and Rabellotti (2017)		Wine	USA, Australia, Chile, South Africa, Argentina, New Zealand	Changes in the market triggered the success of new world wine
Shin (2017)		Memory	Japan, Korea	Focused on two generations' development and leapfrogged the process innovation
Lee and Malerba (2017)		Mobile, memory chips, camera, steel, regional jet, wine		Entry and initial growth, gradual catching up, forging ahead and change in leadership
Ghazinoory, Dastranj, Saghafi, Kulshreshtha, Hasanzadeh (2016)		Social banking	Iran	Low technological capabilities level chooses the path-following for the short term
Kiamehr (2016)	Farab	Hydro electricity generation systems	Iran	Non-linear path
Majidpour (2016)	Mapna	Turbine	Iran	Path-following, OEM-ODM
Kiamehr, Hobday, Hamedi (2015)	Mapna	Turbine	Iran	3 stages. Entered with disadvantages, low cost and seeking linkages, dominant local market
Shi and Shi (2015)	Shanzhai, Xiaomi	Mobile phone	China	4 stages. Accumulating resources, building capabilities, capturing market, diversifying portfolios

Table 2. Comparisons of different catching up paths

Industry	Path-following	Path-skipping	Path-creation
Automotive (Jiang et al., 2011)	Completed by organizational learning- out sourcing- low end market entering		
High Speed Rail (Cheng et al., 2011)			Completed by technology introduction – digestion – innovation, following, following then create path
Flat Panel Display (Zhao et al., 2015)	Korea PC, OEM-ODM, limitation of this mode	Japan, technology intake, absorb and innovation	Korea, created CDMA to face competition with TDMA and GSM
New energy automotive (Xing, 2017)	BYD- Phased catching up Toyota- Hybrid catching up		Tesla- Plunge catching up (Only path creation) Toyota- Hybrid catching up (both path following and creation)
Electronic technology (Hobday, 1995)	Completed by OEM-ODM-OBM		
Latecomer countries (Cavallaro and Mulino, 2007)	Completed by organizational learning		
Semiconductor (Cho, Kim and Rhee, 1998)	Japan completed by competency building, internal and external demand	Korea, lack of experience, risk-taking leapfrogging	
Nuclear power (Sung and Hong, 1999)	Organizational learning		
D-RAM, automobile, Telecommunication, consumer electronics, personal computer and machine tool (Lee and Lim, 2001)	Consumer electronics, personal computers and machine tools, OEM-ODM-OBM	D-RAM and automobile, Low innovation frequency,	Telecommunication, Emerging CDMA technology
Semiconductor Manufacturing (Mathews, 2002)	Completed by OEM-ODM-OBM		
Telecom-equipment (Fan, 2006)	Completed by capability building		
Mobile phone (Jin and von Zedtwitz, 2008)	Completed by capability building, OEM-ODM-OBM		
Steel industry (Lee and Ki, 2017)		Korea, completed by path-following the Japan case then developed by path skipping	Japan, completed by creating its own path catching the window of opportunity

Table 2. Comparisons of different catching up paths (continue)

Industry	Path-following	Path-skipping	Path-creation
Camera (Kanga and Songb, 2017)	Korea, Path following, window of opportunity	Japan, completed by leapfrogging.	
Wine (Morrisona and Rabellotti, 2017)	New world of wine producers' institutional set up, windows of opportunity from the market needs		
Memory (Shin, 2017)		Japan and Korea, leapfrogging by the windows of opportunity	
Mobile, memory chips, camera, steel, regional jet, wine (Lee and Malerba, 2017)	Wine, mobile	Memory chips, camera, steel	Regional jet,
Mobile, memory chips (2017)	Mobile and memory chips have similar catching up cycles		
Social baking (2016)	Short term strategy	Once capability is accumulated	Further development
Hydro electricity generation systems (2016)			Began from the second stage of catching up cycle and end at the first stage
Turbine (Majidpour, 2016)	OEM-ODM		
Turbine (Kiamehr, Hobday, Hamedi, 2015)	Capability building		
Mobile phone (Shi and Shi, 2015)	OEM-ODM-OBM		