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How Does Successful Catch-Up Occur in Complex Products and Systems from the Innovation Ecosystem Perspective? A Case of China's High-Speed Railway

Zhongji Yang [1,*], Liangqun Qi [1], Xin Li [1] and Tianxi Wang [2,*]

[1] School of Economics and Management, Harbin University of Science and Technology, Harbin 150080, China; qiliangqun@163.com (L.Q.); slxxah@163.com (X.L.)
[2] Business School, University of Edinburgh, 29 Buccleuch Place, Edinburgh EH8 9JS, UK
* Correspondence: yangzhongji0047@hrbust.edu.cn (Z.Y.); s1819714@ed.ac.uk (T.W.)

Abstract: Successful catch-up is an important channel to achieve sustainable development for emerging economies; however, it is a great challenge to catch up in complex products and systems (CoPS). Studies show limited evidence on how successful catch-up occurred in CoPS for emerging economies. This study holds the view that CoPS catch-up means a narrower gap in the innovation ecosystem between latecomers and leaders. This study disentangles the CoPS innovation ecosystem and uses China's high-speed railway (HSR) as a longitudinal case with abundant data to explore how successful catch-up in CoPS is achieved. The results show that the CoPS innovation ecosystem presents a dynamic evolution in the technology innovation subsystem, the value creation subsystem, and the habitat. Four types of forces from the innovation ecosystem mix together to drive CoPS catch-up. Finally, this study proposes a CoPS catch-up process model following the basic logic of start point, activities, and performance, and CoPS industrial standards are used to measure CoPS catch-up performance. The study on CoPS catch-up from an innovation ecosystem perspective provides new insights and useful implications for governments and entities in CoPS of emerging economies.

Keywords: complex products and systems; catch-up; innovation ecosystem; high-speed railway; China; emerging economies

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1. Introduction

CoPS are defined as high-cost, engineering-intensive products, systems, and networks [1], and they play a critical role in modern industrial systems [2]. Studies focusing on CoPS catch-up hold controversial opinions [3]. On the one hand, the characteristics of CoPS make it a great challenge for emerging economies to master key technologies and develop systems integration capabilities [4]; much of CoPS literature is skeptical about catch-up in the CoPS industries of emerging economies [5,6]. On the other hand, an increasing number of successful catch-up cases prove that it is possible to realize CoPS catch-up in emerging economies, such as China's HSR, Brazil's aircraft, and Iran's land gas turbine industries [4,7,8]. Thus, this study focuses on the successful catch-up case in CoPS to eliminate the debate.

Extant literature focuses on an evolutionary perspective and pays attention to the key role of the catch-up context and environment [9,10]. The notion of national innovation systems is used to explain Japan's catch-up process from the 1960s to the 1980s [11,12]. Subsequently, the sectoral innovation system is proposed to explore the determinants for industrial leadership changes [13]. However, since the 1990s, the rise of Silicon Valley has attracted increasing attention to the innovation ecosystem and sustainable development [14]. Innovation ecosystem has become an attractive concept used by governments and scholars to explain economic competition and catch-up, especially in strategic management literature [15–17]. Few studies focus on the CoPS innovation ecosystem [18], and extant literature on CoPS catch-up follows the sectoral system of innovation. There are three main differences between the innovation ecosystem and the innovation system at the industrial level. First, the sectoral innovation system focuses on various knowledge bases, networks, and institutions at the industrial level [13], while the innovation ecosystem emphasizes the role of market. Second, the innovation ecosystem at industrial level focuses on a common value proposition to materialize [19], while the sectoral innovation system focuses on upstream and downstream of production. Third, the innovation ecosystem pays much attention to diversity, balance, and symbiosis of different actors, while the sectoral innovation system emphasizes on competition among actors [20]. The highly complex characteristics of CoPS mean that no innovation succeeds in isolation. Heterogeneous actors in the CoPS cooperate with each other much more closely and they are involved in a dynamic and complicated innovation environment [21]. However, how technology innovation and value creation coordinate to promote catch-up in CoPS is ignored. This study addresses this gap; we examine CoPS catch-up under the innovation ecosystem perspective using a longitudinal case of China's HSR and investigate the process mechanism of CoPS catch-up to elaborate how different subsystems interact to achieve successful catch-up in the CoPS of emerging economies.

The contributions of this study are as follows. First, we combine the innovation ecosystem perspective with the evolutionary approach to examine CoPS catch-up and disentangle the CoPS innovation ecosystem and analyze the evolution of the CoPS innovation ecosystem. In particular, we define catch-up as a decrease in the gap in innovation ecosystems between latecomers and leaders, enriching the definitions and scenarios of catch-up [22,23]. Second, we explore four types of driving forces from the innovation ecosystem, namely, institutionalization force, indigenous innovation force, basic research force, and relevant supporting force. Meanwhile, their mixed functions in the catch-up process are investigated. Our study explores a wider range of driving forces to explain the determinant of a successful catch-up in CoPS, and it extends literature on crucial factors of successful CoPS catch-up [3]. Finally, we focus on the general catch-up logic of start point, activities, and performance to construct a catch-up process model of CoPS. Then, we elaborately depict the evolution of the CoPS innovation ecosystem in the catch-up process.

The study is organized as follows: Section 2 reviews literature on CoPS catch-up and the innovation ecosystem, while Section 3 describes the research design of this study. Section 4 presents the catch-up process of China's HSR. Then, in Section 5, the main findings of this study are presented. Section 6 concludes the study.

2. Literature Review

2.1. CoPS Catch-Up in Emerging Economies

2.1.1. Characteristic of CoPS

Extant literature distinguishes distinct characteristics between CoPS industries and mass production industries [1,3].

First, many scholars claim that CoPS are technology intensive, project-based and user embedded, representing national competitiveness [21]. Hobday [1] noted that CoPS activities are more skill and craft intensive. Additionally, some scholars have explored the level of competencies and competitiveness of CoPS [2]. Some evidence shows that developed countries rely on CoPS industries to ensure continuous economic advantage in a global economic downturn [6].

Second, CoPS industries have strong industrial upstream and downstream relationships. Hobday [1] provides more than eighty examples of CoPS, including high-speed trains, airplanes, nuclear power plants, telecommunications exchanges, etc. Firms in CoPS industries should develop world-class products and assets and build open relationships with partners at home and abroad [24]. For example, Boeing, one of the largest aircraft manufacturers, has approximately 3000 suppliers and complementors all over the world, driving the development of steel, rubber, equipment manufacturing, and other industries [25].

Third, value in CoPS industries follows a pyramidal hierarchy process. CoPS markets are often oligopolistic and bureaucratic [1]. The government plays an important role in value creation [4]. Specifically, a CoPS is coordinated by a system integrator. A production unit or a temporary project-based organization involving many firms, and it comprises many customized components [26]. Compared with mass production industries, value is delivered from system integrators to others, and the process goes beyond the production chain and extends to co-production and value-in-use [27].

2.1.2. CoPS Catch-Up Models in Emerging Economies

Latecomers from emerging economies are often seen as in lack of resources and capabilities [28]. To understand how the catch-up process works, there are four streams of literature on CoPS catch-up models from different perspectives.

The first stream involves the learning process model by Hobday [29], which concludes that learning occurs not only at the technology level but also at the market level. Hobday [29] also argued that some latecomers in electronics in East Asia started with simple activities such as assembly and then gradually progressed to more technologically complex tasks. Meanwhile, some latecomers accumulate various capabilities, such as systems integration, design, and production engineering through learning by doing [16,30].

The second stream involves Kim's [31] three-stage model, called acquisition, assimilation, improvement, which suits both CoPS industries and mass production industries [3]. Specifically, latecomers acquire advanced technologies through international technology transfer. Then, they assimilate advanced technology through indigenous R&D, and finally, latecomers improve their existing knowledge to create a new or advanced product. However, latecomers in emerging economies have the risk of falling into a vicious cycle of "import-lag behind-import again" [32].

The third stream involves [33] three types of catch-up strategies, including path-following, path-skipping, and path-creating. Shan and Jolly [34] found that China's telecommunication firms adopted a path-following strategy in the early stage and moved to path-skipping strategy in the later stage. Lim et al. [35] proposed that the shipbuilding industry in Japan and Korea used a path-creating strategy to be a global industry leader. Nevertheless, Majidpour [8] displayed the view that path-following is the dominant model of technology catch-up in the CoPS industries of emerging economies.

In addition, the secondary innovation model by Wu et al. [32] focuses on latecomers in the Chinese context and emphasizes the combination of acquired technologies and existing technology systems. This model is used to explain technology catch-up in emerging industries and firms in China [36,37].

All the above studies focus on the catch-up process of industries or firms in emerging economies and have developed different models from various perspectives. However, on the one hand, these models do not depict the details of the catch-up process, such as the starting point and specific activities; thus, we still know little about the process mechanism in the catch-up process. On the other hand, catch-up models are used to reveal the determinants of successful catch-up in a specific context, and there is no universal model to explain various catch-up phenomena, especially in the CoPS context. Therefore, diverse catch-up models are urgently needed [38].

2.2. The CoPS Innovation Ecosystem and Catch-Up

2.2.1. Structure and Habitat of CoPS Innovation Ecosystems

Innovation ecosystems, as the main innovation paradigm in global highly intensive competitive environments, has attracted substantial interest in academia during the past two decades [17,39]. Adner [16] defined an ecosystem as encompassing "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize". Granstrand et al. [40] concluded that an innovation ecosystem corresponds to "the evolving set of actors, activities, and artefacts, and the institutions and relations".

Based on the structure approach, innovation ecosystems can be divided into several subsystems [41,42]. For instance, Xu et al. [43] proposed three subsystems of innovation ecosystems: science, technology, and market; each subsystem has an integrated network to form a hierarchical structure. Wu et al. [44] constructed a structure model of innovation ecosystem at the industrial level, focusing on the technology innovation layer and the value creation layer, but the habitat layer was ignored. Chen and Liu [18] set up an innovation ecosystem framework including technology dimension, value dimension and capability dimension.

A habitat is the environment in which species live. Species not only are affected by their habitats but also modify their habitats [45]. However, scholars in innovation ecosystems focus on actors, activities, artefacts, relationships, and institutions [17,40]. Oh et al. [46] criticized the fact that scholars pay little attention to the "eco". In fact, an increasing number of scholars are urging the academia to look beyond the technology elements in innovation ecosystems to see the habitat in the co-evolution of technological and socio-technical regimes [47,48].

2.2.2. Technology Innovation Subsystem in the CoPS Innovation Ecosystem

Technology plays a determining role in catch-up. Because of technological interdependence, the competitive advantage of incumbents' innovation ecosystems depends on their components from suppliers and complements from complementors. In addition, actors and relationships form the generic scheme of the technology innovation subsystem [49,50].

Compared with mass production industries, technology innovation subsystems in CoPS industries present distinctive characteristics.

In the product dimension, CoPS comprise hundreds or even thousands of customized components. Key components and complementary components need distinct technology knowledge. Thus, the number of components, the degree of customization, the range of the knowledge base, and the capabilities of suppliers can influence the complexity of CoPS [1,51]. Within the product architecture of CoPS, alternative designs for particular components may exhibit disruptive performance at the system level [26]. The complex products characteristics of CoPS make catch-up difficult for latecomers.

In the innovation process dimension, as a result of product properties, innovation activities, and diffusion may overlap and collapse in CoPS [1]. In contrast to the life cycle of mass products [52], the life cycle of CoPS remain in the fluid stage for a long time [3]. The difficulty and complexity of technology innovation in CoPS significantly increase from one generation to another [53].

Moreover, complementary assets are an important enabling factors in CoPS catch-up [4], such as complementary technology, manufacturing and services [24]. System integrators in CoPS industries need to coordinate large numbers of suppliers and complementors; in cases such as the A380 super-jumbo passenger aircraft, the breakthrough of core technology alone is not equivalent to the success of the whole industry [49]. Therefore, the level of complementary assets perform a fundamental role in the catch-up of CoPS industries [4].

2.2.3. Value Creation Subsystem in the CoPS Innovation Ecosystem

The value creation subsystem consists of entities including supplies, complementors, focal firms, and other partners [41]. Value proposition, value transfer, and value distribution are basic value creation activities [54]. The market structure of CoPS industries determines different characteristics of value creation compared with mass production industries.

On the one hand, the market regime in CoPS industries is oligopolistic and it is often bureaucratically administered without a free market transaction environment [1,8]. User demand is blurred in the early stage of CoPS industries [5]; thus, project-based organizations, especially those focal firms, often propose vague value propositions in line with their own interests [55]. On the other hand, the government is the key source of value propositions in CoPS industries due to its international power of speech, military, national security, and other unique status [56]. Users, generally referring to public sectors, jointly design, maintain, and upgrade CoPS with partners [57]. Overall, focal firms, governments, users, suppliers, and complementors create value together and distribute value layer by layer.

2.2.4. Habitat in the CoPS Innovation Ecosystem

Similar to the natural ecosystem, the habitat of entities in the innovation ecosystem depends on competition and cooperation relationships [58]. The bureaucratic market of CoPS industries indicates that the government plays a critical role in shaping the habitat, especially in emerging economies [18,30]. Therefore, the habitat in CoPS industries is different from that in mass production industries.

In terms of a competitive environment, protective industrial policies are the main choice for governments to develop CoPS industries [59,60]. For example, the Korean government planned promotion policies for the shipbuilding industry in 1976 and promulgated policies such as financial incentives, complementary investments, and trade incentives to protect the domestic market [35]. Similarly, the governments of India and China used abundant protective policies to develop the wind turbine industry [61].

In terms of the cooperative environment, the successful catch-up of Iran's gas turbine industry, Korea's e-government and China's medical device industry show that the university–industry linkage (UIL), such as joint or contract-based research, is a key factor for catch-up [3,8].

2.2.5. Elements of CoPS Innovation Ecosystem and Catch-Up

From the above literature, CoPS innovation ecosystems consist of three elements: technology innovation subsystem, value creation ecosystem, and habitat. Each element plays a unique role in CoPS catch-up. First, the lagging of technology level is the direct cause of the latecomer to catch up, so that it is critical to develop technology innovation subsystem to speed up catch-up. Second, leaders always create much more value than latecomers in CoPS, but complex value creation activities in CoPS is ignored by extant literature; this study considers value creation subsystem as one of important elements for successful catch-up. Finally, habitat is a fundamental environmental factor in CoPS catch-up. Indeed, competition and cooperation coexist in the innovation ecosystem, a vibrant innovation ecosystem is often constructed intentionally by all participants. Regardless of what kind of ecosystem is constructed, the shared value proposition is consistent, and the ultimate goal is to achieve sustainable development similar to a natural ecosystem [62,63] so that the evolution of innovation ecosystems always accompanies successful catch-up.

In summary, we disentangled the CoPS innovation ecosystem and propose a framework to analyze the evolution process of CoPS innovation ecosystem in catch-up as seen in Figure 1.

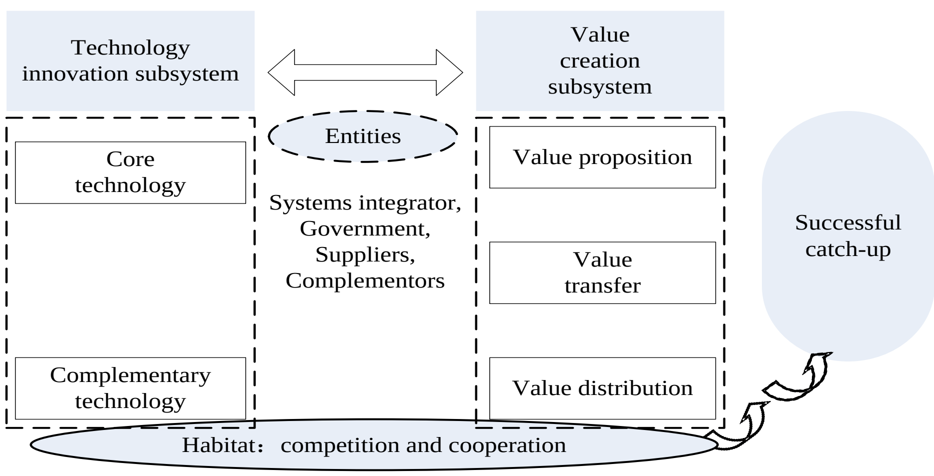

Figure 1. An analysis framework.

3. Research Design

3.1. Longitudinal Case Selection

This study focuses on how successful catch-up happens in the CoPS industries of emerging economies using the innovation ecosystem perspective. A longitudinal case has strong applicability to answer "how" and "why" questions by exploring the internal development rule of things through historical description [64]. We selected China's HSR as a longitudinal case for three reasons.

First, HSR is a typical CoPS industry, and China is the world's largest emerging economy with rapid transformation innovation [4]. Through rapid development, China leapfrogged to become a technology leader in HSR and has made remarkable achievements in the global market share [65]. In brief, this case suits well the general principles of case selection.

Second, China's HSR has undergone an entire innovation ecosystem construction process accompanied by a catch-up process [4,66]. The technology innovation subsystem of HSR includes the high-speed rolling stock system, communication and signal system, bridge and tunnel engineering system, traction power supply system, dispatching system, and passenger service system [67]. The value creation subsystem of China's HSR involves users, governments, rolling stock manufacturers, universities, suppliers, and complementors. These entities play different and dynamic roles in the construction process of the innovation ecosystem.

Third, China's HSR has accumulated abundant data. As an important part of China's basic transportation network, HSR has received great attention from the central government and local governments for a long time. Government and public institutions have also collected rich data on China's HSR industry, forming a collection of policies, books, documents, reports, videos, and other materials.

3.2. Data Collection and Analysis

Following the view of Yin [68], original data were collected from various sources to form the evidence chain; the first-hand data and second-hand data, as shown in Tables 1 and 2. The data were transcribed, classified, and sorted from October 2019 to October 2021.

Table 1. First-hand data.

Data Sources	Data Content	Data Size
Vice present of Qiqihar Rolling Stock Co., Ltd. of the CRRC	Information of CRRC's management system and supply chains of CRRC	Two times, 1 h at a time
Chief engineer of CRRC Qingdao Sifang	Introduction of CR400AF and story of china HSR	1 h
Two officials from the Harbin Railway Bureau	Construction process of HSR railway and reform of railway management system	Four times, 1 h at a time

Table 2. Second-hand data.

Data Type	Data Sources	Data Content	Data Size
Policy documents	Website of the State Council, website of the MOT	Policies by the central government on supporting HSR from 2005 to 2020	Nearly 50,000 words
Interview videos	China Central Television	Interviews with the chief designer and stakeholders of HSR by official media	Nearly 10 h
Literature and books	Web of Science, China National Knowledge Infrastructure	Forty Chinese and English academic papers and five books on China's HSR	Nearly 700,000 words
Industrial reports	Industry association, independent third party	China's HSR development report by the World Bank, reports by the Prospective Industry Research Institute of China	Nearly 60,000 words

We screened and cleaned the data through the following steps: First, we comprehensively compared the data from different sources, eliminated biographies and unrelated data, and finally summarized text data amounting to nearly 300,000 words. Second, we carried out triangle validation to ensure the reliability and validity of our research, nearly 250,000 words remained. Third, we compared the key time nodes and events in China's HSR and iterated the critical constructs, theoretical dimensions, and logical relationships many times. Finally, we reached theoretical saturation based on existing data.

4. Catch-Up Process of China's HSR

To clarify the catch-up process of China's HSR, Figure 2 shows the management structure of China's HSR at present. We divided the catch-up process of China's HSR based on the catch-up cycle [3]. The time point was decided based on the key events and Mei and Zhang [4].

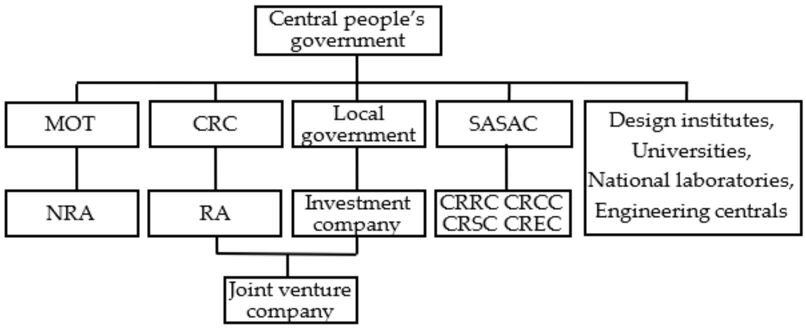

Figure 2. Management structure of China's HSR. Source: Reprinted with permission from ref. [69]. Lawrence, et al., 2019. Abbreviations: Ministry of Railways, MOR. China Railway Corporation, CRC: In March 2013, MOR was dissolved, and its duties were assumed by an expanded Ministry of Transport ((MOT) for safety and regulation), National Railways Administration ((NRA) for inspection), and the CRC (for construction, service operation and management). China National Railway Group Limited, CR: On 18 June 2019, the CRC was restructured to form CR. China South Locomotive and Rolling Stock Co., Ltd., (Beijing, China), CSR. China North Locomotive and Rolling Stock Co., Ltd., (Beijing, China), CNR. China Railway Rolling Stock Co., Ltd., (Beijing, China), CRRC: On 1 June 2015, the CNR and CSR merged into the CRRC. China Railway Highspeed, CRH. Ministry of Science and Technology, MOST. State-Owned Assets Supervision and Administration Commission, SASAC. China Academy of Railway Sciences Co., Ltd., (Beijing, China), CARS. China Railway Signal and Communication Co., Ltd., (Beijing, China), CRSC. China Railway Materials Co., Ltd., (Beijing, China), CRM. China Railway Construction Co., Ltd., (Beijing, China), CRCC. China Civil Engineering Construction Co., Ltd., (Beijing, China), CCECC: In September 2003, the CCECC merged into the CRCC. China Railway Group Ltd., (Beijing, China), CREC. China Railway International Group, (Beijing, China), CRIG: On 30 October 2013, the CREC established a subsidiary, the CRIG, which is responsible for overseas business.

4.1. Entry Stage (before 2004)

China has more than 50 years of independent product development experience in the railway equipment industry. In 1956, the government proposed that railway traction power should be shifted from steam locomotives to electric locomotives and diesel locomotives. Local rolling stock manufacturers started indigenous research based on an electric locomotives prototype purchased from the Soviet Union (collapsed in 1991), France, and Japan. After 1978, the era of HSR officially began. The State Council promulgated the outline of the 8th and 9th Five-Year Development Plans, which defined the overall target of capacity expansion and acceleration of the rail transit industry. Meanwhile, the MOR delegated train procurement power to local railway bureaus to stimulate the vitality of independent operation. Thus, many local railway bureaus cooperated with rolling stock manufacturers, universities, and scientific research institutes affiliated with the MOR to develop new rolling stock and to test new railway lines. Figure 3 shows the key entities in China's HSR innovation ecosystem at this stage.

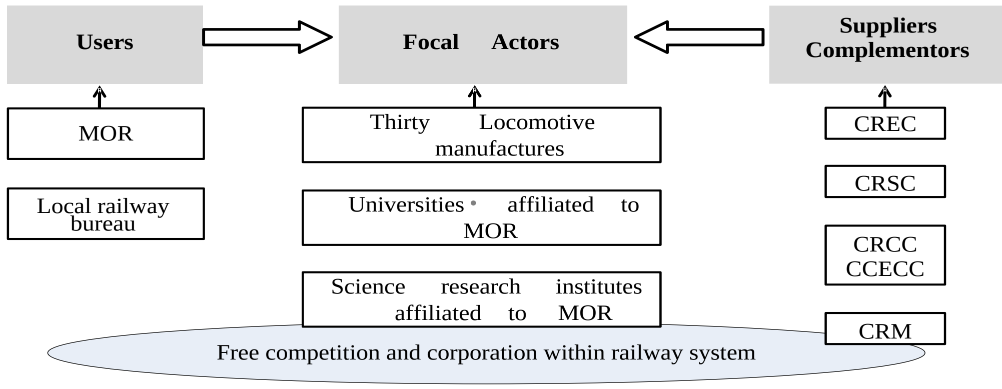

Figure 3. Key entities in China's HSR innovation ecosystem at the entry stage.

In terms of the rolling stock system, local rolling stock manufacturers widely tried various technical paths, such as diesel locomotives, tilting locomotives, and electric locomotives. A total of thirteen types of quasi-high-speed rolling stock prototypes were developed at the end of the 1990s. For example, the first Chinese quasi-high-speed locomotive, "DF9", with the highest speed reaching 160 km/h, was developed by the Qishuyan Co., Ltd. of the CRRC in 1990. The first quasi-high-speed diesel multiple units (DMUs) to be put into the market, the "NZJ1" DMU, was developed by the Qishuyan Co., Ltd. of the CRRC combined with the Nanjing Puzhen Co., Ltd. of the CRRC in 1999. Unfortunately, there was only one train operation in use.

Regarding electric multiple units (EMUs), China developed distributed traction EMUs and centralized traction EMUs at this stage. "KDZ1", the earliest self-designed EMU in China, was completed by the Changchun Railway Vehicles Co., Ltd. of the CRRC combined with the Zhuzhou Institute Co., Ltd. of the CRRC and the CARS in 10 years from 1978 to 1988. The test speed was 143 km/h, but it was limited by operating conditions and could not be put into use formally. Later, new models such as "Chuncheng", "Pioneer" and "Changbai Mountain" were successfully developed [4].

Nevertheless, China also made great breakthroughs in centralized traction EMUs at this stage. For example, in 1999, "White Shark", jointly developed by the Zhuzhou Institute Co., Ltd., (Zhuzhou, China), Changchun Railway Vehicles Co., Ltd., (Changchun, China), Qingdao Sifang Co., Ltd., (Qingdao, China), Tangshan Co., Ltd., (Tangshan, China) and Nanjing Puzhen Co., Ltd., (Nanjing, China) of the CRRC as well as universities and scientific research institutes affiliated with the MOR, was tested on the Guang-Shen Railway at 223.2 km/h and travelled from Shenzhen to Guangzhou at a maximum speed of 180 km/h. Then, "Blue Arrow", "China Star" and other centralized traction EMUs emerged. "China Star" ran at 321.5 km/h in the experimental stage, formally operated in Shenyang–Shanhaiguan from August 2005 to August 2006, and completed a total distance test of 536,000 kilometers on the Qin-Shen dedicated passenger line in December 2004.

In terms of complementary systems, first, the plan of HSR lines was jointly completed by the MOR and multiple ministries of China. For example, in 1999, the Qin-Shen dedicated passenger line was the first dedicated passenger line independently developed, designed, and constructed in China. The feasibility of the Beijing–Shanghai HSR line started to be discussed in 1990 and the line was constructed 18 years later. Second, through the system reform of the MOR, modern enterprise regulations related to the design, construction, and operation of HSRs were formulated. For example, after the restructuring of the MOR in 2000, several large state-owned enterprises (SOEs), such as the CRSC, CRCC, CREC, CCECC, and CRM, were established to be fully responsible for the railway communication signal system, railway engineering construction system and material supply system. Finally, China began to transform and build large-scale stations suitable for HSR. For example, on 6 November 2001, the Beijing West Railway Station, with the largest investment and the most advanced technology in China's railway construction, was officially put in use.

4.2. Path-Following Stage (2004–2007)

In March 2003, the MOR proposed a "leapfrog development" target for China's railways within five years. The fastest choice to achieve this target in a short period was to acquire advanced, mature, economic, applicable, and reliable high-speed rolling stock technology abroad. Therefore, China's HSR entered the path-following stage. Figure 4 shows the key entities in China's HSR innovation ecosystem at this stage.

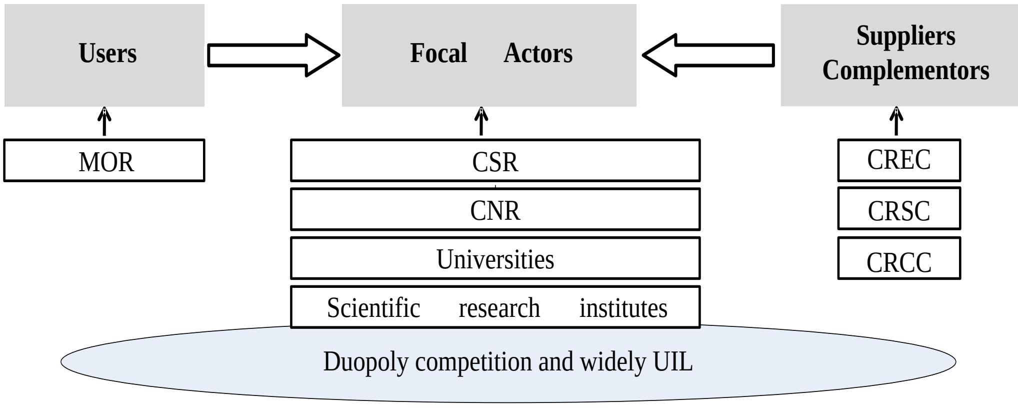

Figure 4. Key entities in China's HSR innovation ecosystem at the path-following stage.

In terms of the rolling stock system, China acquired four mature distributed traction EMU platforms from four firms in different countries. Specifically, the scattered rolling stock manufacturers were restructured into CSR and CNR to maintain a reasonable market concentration and integration. On 28 July 2004, the MOR introduced EMUs capable of 200 km/h, including one package with 20 sets of "Regina C2008" from Bombardier to the CSR's CRH1, three packages with 60 sets of "E2-1000" from Kawasaki to the CSR's CRH2, and three packages with 60 sets of "Pendolino 600/610" from Alston to the CNR's CRH5 [4]. Then, on 20 November 2005, the MOR introduced three packages with 60 sets of "Velaro E" capable of reaching 300 km/h from Siemens to the CNR's CRH3. It is noteworthy that indigenous R&D funds for local rolling stock manufacturers were suspended with this technology acquisition, and a large number of basic research funds began to be implemented for the localization of HSR technology [66,70]. However, some locomotive manufacturers insisted on indigenous innovation and improved their technology capabilities through learning by doing. For example, Qingdao Sifang Co., Ltd., (Qingdao, China) of the CRRC jointly designed CRH2A with six foreign firms, while CRH2C was developed independently by redesigning system parameters, raising the speed level from 200 km/h to 350 km/h.

In terms of complementary systems, first, the medium- and long-term railway network plan of China was issued in 2004, proposing the "four vertical and four horizontal" network and the target of building a 12,000 km dedicated passenger line. Second, China's railway engineering construction capacity and HSR operation experience were greatly improved. For example, ground settlement treatment technology, tunnel construction technology, and advanced geological prediction technology were developed. Meanwhile, several SOEs were restructured again and completed the stock system reform. They were then listed in the stock market in 2007. Finally, new breakthroughs were made in the construction of HSR stations.

4.3. Gradual Catch-Up Stage (2008–2015)

Since the acquisition of high-speed rolling stocks, China's HSR has not stopped the pace of technology innovation. In February 2008, the MOR and MOST issued an agreement on a joint action plan for the indigenous innovation of China's high-speed rolling stocks, which aimed to establish China's HSR technology system with independent intellectual property, a speed of over 350 km/h and strong international competitiveness as soon as possible. Since then, China's HSR entered a gradual catch-up stage. Figure 5 shows the key entities in China's HSR innovation ecosystem at this stage.

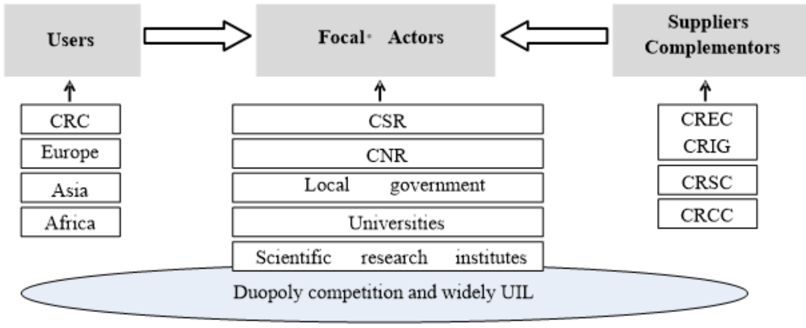

Figure 5. Key entities in China's HSR innovation ecosystem at the gradual catch-up stage.

In terms of the rolling stock system, the CSR and CNR built their own ecosystems around the industrial chain. With the support of the MOR and MOST, the CSR and CNR developed CRH380A and CRH380B separately on the basis of technology acquisition and absorption, and they were named as "Harmony EMU". In 2010, CRH380A reached a maximum speed of 486.1 km/h during a test on the Beijing–Shanghai railway. In 2011, 380 series EMUs began commercial operation on the Beijing–Shanghai railway. Some core technology models, such as traction transmission and network control, were developed by Chinese firms. Therefore, 380 series EMUs became the representative product of the integration innovation of China's HSR.

China's 380 series EMUs performed well domestically and were exported to other countries, such as Thailand, Malaysia, and Mexico. For example, in December 2010, China signed a cooperation agreement with Thailand and Laos at the 7th World HSR Congress in Beijing, aiming to build an HSR line linking China, Laos, Thailand, and other Asian countries. In 2014, the Zhuzhou Institute Co., Ltd., (Zhuzhou, China) of the CRRC established the "Southeast Asian Railway Center" in Malaysia to provide local products.

In terms of complementary systems, first, the mileage and investment scale of railway lines were continuously grown. By December 2015, the actual operation mileage of China's HSR reached 19,800 kilometers, ranking first in the world. Investment in railway projects soared from RMB 337.6 billion in 2008 to RMB 600.4 billion in 2009, and the investment peaked at RMB 842.7 billion in 2010. Second, the indigenous innovation ability of HSR civil engineering and construction significantly improved. For example, the Nanjing Dashengguan Yangtze River Bridge constructed by the CREC received the George Richardson Award from the International Bridge Association in 2012. Finally, several local governments began to participate in the construction of HSR. For example, Guangdong and Shandong Provinces made a promise to build HSR stations and raised funds to participate in HSR line construction.

4.4. Forging-Ahead Stage (2016–)

Through acquisition and integration innovation, 380 series EMUs meet people's travelling demand in a short time. However, these products were developed based on different product platforms, and so the technology standards are not interconnected. The lack of interchangeability increases the operation and maintenance costs. Therefore, in 2012, China started to design EMU with Chinese standard. In July 2016, China's standard EMU finished the world's first 420 km/h rendezvous and reconnection tests. On 25 June 2017, China's standard EMU was officially named "Fuxing" and operated on the Beijing–Shanghai railway the next day. China's EMU entered the forging-ahead stage. Figure 6 shows the key entities in China's HSR innovation ecosystem at this stage.

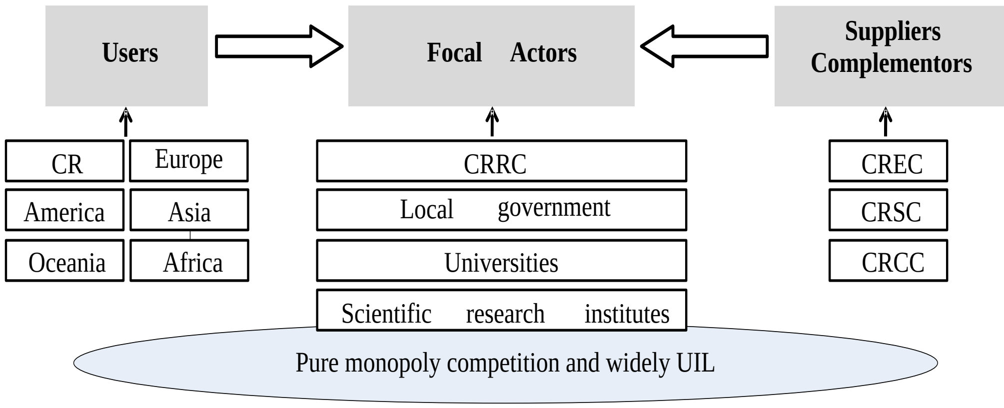

Figure 6. Key entities in China's HSR innovation ecosystem at the forging-ahead stage.

In terms of the rolling stock system, the Fuxing EMU formed two product platforms, CR300AF and CR400AF, with speeds of 250 km/h and 350 km/h, respectively. Compared with existing EMUs in China, the Fuxing EMU is more technically advanced, safer, more comfortable and more cost-efficient. For example, the designed lifecycle of the Fuxing EMU is 30 years, while that of the Harmony EMU is 20 years. With a brand new low-resistance streamlined head and body smoothing design, the running resistance is reduced by 7.5–12.3% compared with the Harmony EMU. When running at 350 km/h, the per capita, energy consumption per hundred kilometers is reduced by approximately 17%. The Fuxing EMU adopted 260 standards, including 84% Chinese standards and some international standards [71].

In terms of complementary systems, first, the mileage and operation of HSR lines continued to increase. For example, from 2016 to 2019, China's railway fixed asset investment was more than RMB 800 billion per year, and more than 5000 km of HSR lines were built every year. By December 2020, the national railway operating mileage reached 146,300 km, including 38,000 km of HSR lines, which account for more than 66% of the world's HSR operating mileage. Second, the practical experience of China's HSR survey and design, engineering construction, and communication signals was standardized, forming a number of international standards. Finally, China's HSR stations cover 95% of Chinese cities with a population of 1 million or more.

5. Findings

5.1. The Evolution of the CoPS Innovation Ecosystem in Catch-Up

Following the catch-up process of China's HSR, we used the analysis framework (see Figure 1) to examine how CoPS innovation ecosystem evolves in successful catch-up.

5.1.1. Technology Innovation Subsystem in Catch-Up

The successful technology catch-up of CoPS industries in emerging economies should involve a process from core technologies to complementary technologies. Technology acquisition, which is seen as the first stage in Kim's three-stage model [31] may not be the starting point of technology catch-up in CoPS industries, on the contrary, independent technology exploration is more important, regardless of whether it succeeds or fails.

For the core technologies of HSR in China, high-speed rolling stock technology starts with long-term independent research of various technologies, and most prototypes may fail. In fact, technology acquisition from four foreign companies significantly shortens the time it takes to catch up. In other words, because Chinese rolling stock manufacturers accumulated technology capability before technology acquisition, the design, manufacture, and integration technologies of HSR technologies could be finished in a short time.

For the complementary technologies, such as railway planning technologies, civil engineering and construction technologies, communication and signal technologies and other related technologies, improve along with technology acquisition and learning by doing. Compared with other countries, China's diverse demands and scenarios of the HSR industry play a unique and critical role in technology innovation. These characteristics are not found in the catch-up of South Korea and Iran [5,16]. In particular, China's HSR engineering technologies have reached the world's leading level. Table A1 in Appendix A shows the typical cases of China's HSR technology innovation subsystem.

5.1.2. Value Creation Subsystem in Catch-Up

The CoPS value creation subsystem in emerging economies should undergo a process from a closed value system to an open value co-creation system, while the CoPS market scale should expand from the domestic market to the global market, as opposed to export-oriented countries, such as Korea and Japan. On the one hand, SOEs play an important role in the CoPS industries of many emerging economies, and a bureaucratic market regime easily forms a closed value system. However, the value creation subsystem should be changed via market-oriented reform. On the other hand, some emerging economies own large-scale domestic markets, which provides an important chance to test and improve the CoPS.

First, the value proposition of China's central government changed from modernizing railway equipment to constructing a strong railway country. Thus, the MOR accelerated the pace of market-oriented reform after 2000, which also made China's HSR form a multiple value source system jointly supported by SOEs, the central and provincial governments and social capital. This value structure is very efficient in decision making and information transfer, it becomes the most important feature of China's HSR compared with other emerging economies, such as Korea, India, and Iran. Second, the value transfer mechanism evolved from leadership by the MOR to following market principles after the MOR's reform of separating government functions from enterprise management functions. The systematic reforms are rare in the CoPS industries of other emerging economies [55,72]. Third, the value distribution network extended from the internal value network of the MOR to the outside one. For example, China's rolling stock manufacturers are increasing their position and power in the global HSR manufacturing network. Table A2 in Appendix A shows the typical cases of China's HSR value creation subsystem.

5.1.3. Habitat in Catch-Up

The habitat in the CoPS innovation ecosystem is affected by dynamic competition and cooperation among entities. Overall, competition and cooperation dynamically interact to adapt to CoPS catch-up context.

The competition environment within China's HSR innovation ecosystem gradually changed. For instance, the rolling stock industrial structure has undergone free competition, duopoly, and pure monopoly, while the industrial structure of suppliers and complementors is from oligopoly to free competition, which is different from Iran's land-based gas turbine industry and China's semiconductor industry [8,73]. We argue that a concentrated industrial structure helps with CoPS catch-up, supplementing the study by Lee et al. [22] which stated that market segments speed up indigenous firms to catch up. More specifically, first, China's rolling stock technology originated from free competition among thirty locomotive manufacturers at the entry stage. The MOR issued a series of measures to encourage research competition among rolling stock manufacturers. Although most prototypes did not ultimately realize commercial operation, the design and manufacture capacity of rolling stock manufacturers improved, and a large amount of domestic technical talents were trained. Second, the CRRC was divided into the CSR and CNR in 2000, but it was merged into the CRRC again in 2014. During this period, as a coordinator, the MOR coordinated the competition between CSR and CNR to maintain the industrial concentration within a reasonable range. Third, CRRC, CREC, CRSC, and CRCC monopolize the domestic locomotive market, railway civil engineering market, and signal and communication market. The high monopoly and self-reliance of the whole industry chain is conducive to the overall export of China's HSR.

The cooperation between universities and enterprises in the HSR industry started at the entry stage; the cooperation scale evolved from a sealed railway system to an open and diversified cooperation system. However, cooperation in the CoPS industries of other countries emerged after technology acquisition, aiming at technology localization [74,75]. Specifically, first, the early China railway system was a highly independent, completely closed, and bureaucratic system, including all kinds of entities. Cooperation was limited within this system and often controlled by regulators. Second, after the MOR reform, more universities, scientific research institutes and component enterprises had opportunities to participate in railway research projects and to help to localize HSR technology. Table A3 in Appendix A shows the typical cases of China's HSR habitat.

5.2. Driving Forces of CoPS Innovation Ecosystem in Catch-Up

Following the evolution of the CoPS innovation ecosystem in catch-up, we further investigated the driving forces to answer why the CoPS innovation ecosystem shows the evolution characteristics. Changes in innovation ecosystems are caused by entities and their interaction. We explored four types of driving forces from different entities.

5.2.1. Institutionalization Force from the Government

Institutionalization is defined as the establishment of formal organizational features and is always directed by the government in innovation management [76]. Government support, mostly referring to various policies, is one of the most common factors in CoPS industries [9,12]. However, the powerful institutionalization capabilities of the government in CoPS industries are often ignored. We argue that the firm resolution and institutionalization capabilities of the government play a key role in building and maintaining the CoPS innovation ecosystem. The institutionalization force refers to a series of actions, including innovation plan, innovation guidance, innovation motivation, and so on.

For instance, China's central government was an important promoter of MOR reform in 2000, speeding up the openness of the Chinese railway system. Meanwhile, China's central government was the decisionmaker in technology acquisition in 2004, accelerating the innovation of China's HSR. Moreover, China's central government promulgated railway line planning and proposed the target of constructing an indigenous innovation-driven country. Lastly, the central government implemented a massive investment plan in 2008, accelerating the development of complementary assets, such as HSR lines, bridges, and stations.

5.2.2. Indigenous Innovation Force from the System Integrator

System integrators, as critical entities in CoPS innovation ecosystem, need to coordinate the amount of supplies and complementors, and the technology capability of system integrators is the decisive factor of CoPS catch-up performance [1]. Jin et al. [77] also showed that for latecomers in emerging economies, the only way to enhance technology capability and market competitiveness is to insist on indigenous innovation. This view is instructive for CoPS catch-up in emerging economics.

For example, on the one hand, CRRC as the main system integrator of China's HSR innovation ecosystem input over RMB 10 billion per year in research and development from 2017 to 2019. On the other hand, rolling stock manufacturers accumulated technology capability and talent through unsuccessful independent research so that they had the ability to assimilate advanced knowledge and could avoid the re-acquisition trap [32].

5.2.3. Basic Research Force from Universities

Universities are good at basic research in the CoPS innovation ecosystem [66]. Similar to Lee and Kang [74] and Majidpour [8], UILs are a trend in the East Asian context; however, we argue that UILs emerged before technology acquisition and are more dynamic at different catch-up stages. Indeed, the basic research capability of universities in emerging economies is poor at the beginning, and it is increased by combining with learning by doing and tentative exploration.

For example, at the entry stage, researchers at universities proposed new ways of thinking about HSR, and Southwest Jiaotong University constructed a rolling vibration test rig for railway vehicles in 1995. At the path-following stage, universities were deeply involved in every sector of the HSR industry to help solve common technical principle problems, such as wheel-rail interactions, pantograph–catenary relations, fluid–structure interactions, engineering materials, and structures.

5.2.4. Relevant Supporting Force from Suppliers and Complementors

Suppliers and complementors play a fundamental supporting role in the CoPS innovation ecosystem. Because of the interdependence among the system integrator, suppliers and complementors, the technology capability of these entities should be improved synchronously. Otherwise, the CoPS innovation ecosystem is defective.

For example, HSR integrates various technology systems, such as the ballastless track, the traction power supply system, and bridge construction. Suppliers and complementors in China's HSR industry make remarkable achievements along with rolling stock manufacturers. At the early stage, the line standard was not strict, and some key parts and components were bought from abroad. Suppliers and complementors accumulated skills and experience through railway construction projects, such as the Guang-Shen Railway, accelerating projects for existing railways, such as the Qin-Shen dedicated passenger line. Second, at the technology acquisition stage, domestic suppliers, and complementors achieved the localization of parts and components through assimilation and learning. Meanwhile, many original innovative technologies were provided by a large number of local engineering practices. Third, suppliers and complementors formed Chinese standards in the HRS industry technology system through indigenous innovation. The development process of suppliers and complementors in the HSR innovation ecosystem verifies the agreement that a successful catch-up means a narrower gap in the CoPS innovation ecosystem between latecomers and leaders.

5.2.5. Mixed Effects of Various Forces

Dynamic and diverse forces promote the evolution of the CoPS innovation ecosystem in emerging economies to decrease the gaps with leaders. Indeed, none of the forces exert an effect alone, and different forces have mixed effects on CoPS catch-up at every stage. Figure 7 shows the strength and relationship of various driving forces.

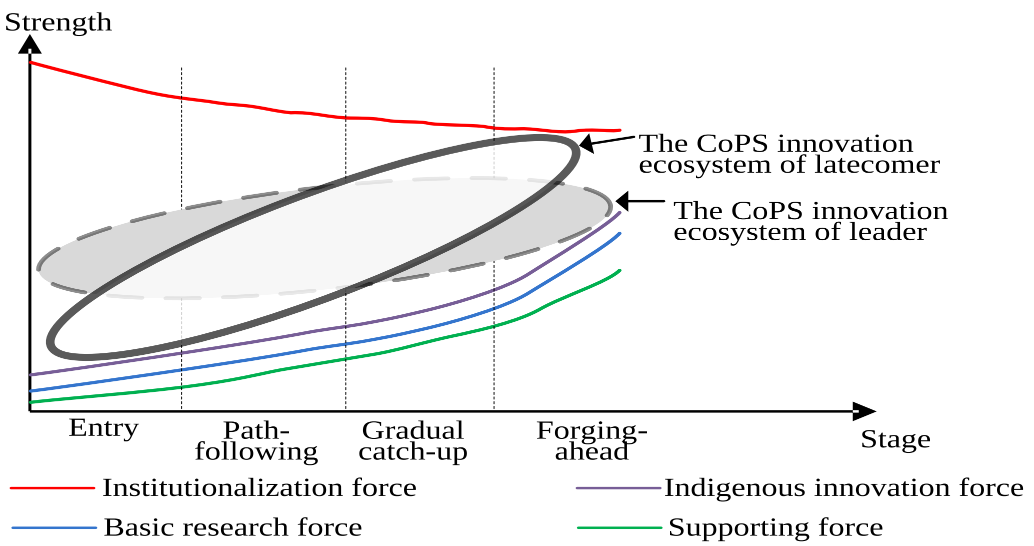

Figure 7. The strength and relationship of various driving forces.

In general, the government is the direct driver of the CoPS innovation ecosystem to promote catch-up, and the institutionalization force plays the most significant role in nurturing the CoPS innovation ecosystem at the entry stage. Then, the effect decreases with the maturity of the CoPS innovation ecosystem. However, the institutionalization force from the government is always the main leading force of CoPS catch-up in emerging economies. This is different with main forces of catch-up in mass production industries. The system integrator is the core of the CoPS innovation ecosystem; however, in emerging economies, their indigenous innovation force is relatively weak but not totally negligible at entry stage, as shown in Figure 7. Otherwise, the system integrator would not be able to absorb advanced knowledge after acquisition. In addition, the basic research force and relevant supporting force increase over time; this tendency to increase is not automatic, but through continuous learning and engineering practice.

5.3. Catch-Up Process Model of CoPS

The CoPS catch-up process is accompanied by the evolution of the CoPS innovation ecosystem. We summarized the CoPS catch-up model following the catch-up logic of start point, activates, and performance, seeing Figure 8.

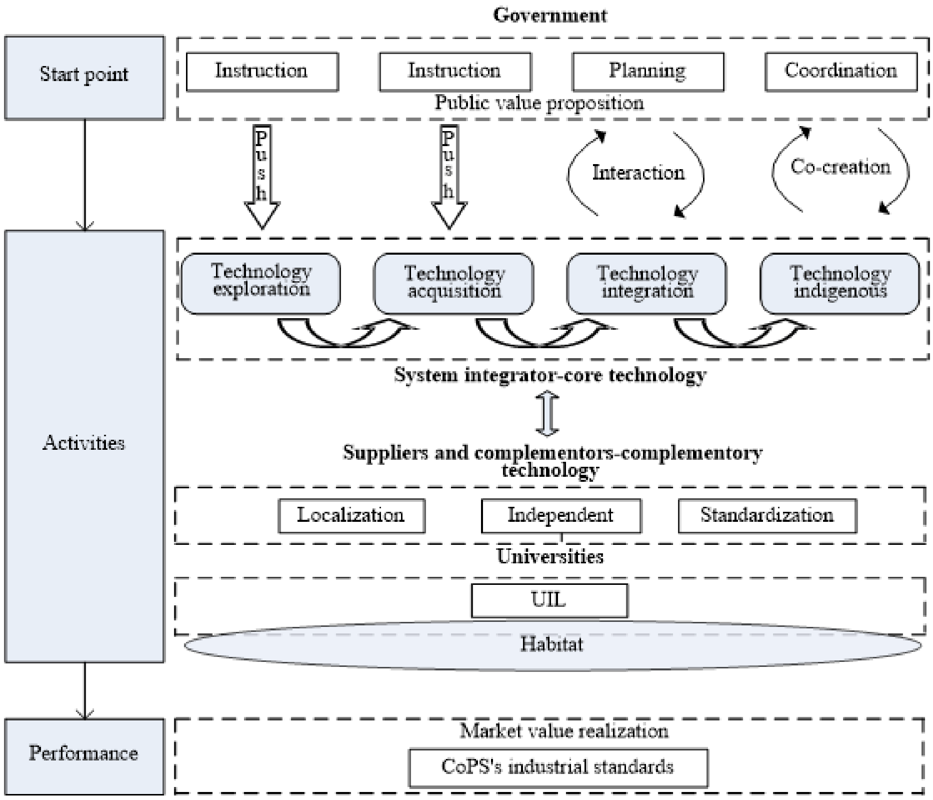

Figure 8. Catch-up process model of CoPS.

First, the starting point of CoPS catch-up is the public value proposition of the government, which refers to being "consumed" collectively by citizens rather than individually by clients [78]. On the one hand, as an important part of the industrial system in emerging economies, CoPS industries attract sustainable attention from the government. This is in contrast to the catch-up of mass production industries starting with the market demand of individuals [79]. On the other hand, the role of the government and the content of public value propositions significantly change with the catch-up process.

Second, the activities of CoPS catch-up refer to the process of various actors building and maintaining an innovation ecosystem. On the one hand, the relationship between the public value proposition and market value realization changes from passive reaction to co-creation by partners. On the other hand, the system integrator realizes market value with support from universities, suppliers, and complementors.

Third, the catch-up performance of CoPS industries is the competitiveness of representative products rather than the market shares of mass production industries used by Lee and Malerba [22]. Because of the bureaucratic CoPS market, market shares in CoPS industries do not truly reflect the result of competition. Nevertheless, a higher competitiveness of CoPS industries indicates greater potentials in the global market. For example, the Jakarta–Bandung HSR, constructed in June 2018, is the first overseas line with a speed of 350 km/h using China HSR industrial standards, including China's standard EMUs, HSR construction, and operating standards. The large volume of exports has greatly improved the global competitiveness of China's HSR.

6. Conclusions

6.1. Theoretical Contributions

Successful catch-up in the CoPS industries of emerging economies has occurred frequently in recent decades. We extended literature on CoPS catch-up from the innovation ecosystem perspective using the longitudinal case of China's HSR. The results show that evolution of the CoPS innovation ecosystem is accompanied with CoPS catch-up. CoPS catch-up is influenced by various forces from different entities in the innovation ecosystem, such as the institutionalization force from the government, indigenous innovation force from the system integrator, basic research force from universities, and relevant supporting force from suppliers and complementors. Several theoretical contributions are concluded as follows:

First, this study sheds light on CoPS catch-up in emerging economies. We combined the insight from innovation ecosystems theory [16,44] and CoPS catch-up literature [3,4,9], defined successful CoPS catch-up as the narrower gaps in the innovation ecosystem between latecomers and leaders, disentangled the CoPS innovation ecosystem and summarized the characteristics of the CoPS innovation ecosystem in the catch-up process. Previous literature from the sectoral innovation system perspective defined catch-up as the process of closing the gap in global industry market shares between leaders and latecomers, especially in mass production industries [3,5,79]. However, CoPS industries are driven by politicized markets [16,21], and it is difficult to reflect catch-up performance in CoPS industries using global market shares. Instead, the catch-up of China's HSR prove that building and maintaining an innovation ecosystem is the key to CoPS catch-up in emerging economies. This result provides new insight to understand catch-up and enriches CoPS literature.

Second, prior literature has focused on finding the successful driving factors of catch-up, such as government support, technology capability construction, and strategy [3,33,80]. We explored four types of driving forces and the effect of their mixed in the catch-up process. Our findings extend literature on factor exploration and investigate the driving forces coming from different entities in the CoPS innovation ecosystem. Similar to previous literature [4,9], we argue that the government play a critical role in nurturing the CoPS innovation ecosystem in latecomer economies and the institutionalization force has the most significant but declining strength in CoPS catch-up, other three types of driving forces increase over time because of continued learning. This finding provides comprehensive driving factors in catch-up.

Lastly, prior studies on the CoPS catch-up model focused on the learning process, the technology capability construction process, and a comprehensive view [30,38]. We investigated the catch-up process model of CoPS based on catch-up logic including catch-up start point, activities, and performance. Then, we explored the evolution of the CoPS innovation ecosystem in the catch-up process. In contrast to Miller et al. [5], Ren and Yeo [6], and Majidpour [8], we provide evidence to prove that it is possible to realize path-creation catch-up via innovation ecosystems in the CoPS of emerging economies [35], and our findings respond to the opinion that successful catch-up does not equal to cloning [22]. In addition, we emphasize the evolution of CoPS innovation ecosystem in catch-up, supplementing Malerba and Lee's [9] view about an evolutionary perspective in economic catch-up.

6.2. Practical Implications

This study provides several practical implications for the government and entities in the CoPS of emerging economies.

For the government, first, the CoPS in emerging economies always face restrictions. The government should hold a firm resolve and make proactive decisions to build a sustainable innovation ecosystem. If latecomers receive advanced technology through international technology transfer, the government should develop the indigenous capability of entities in the CoPS innovation ecosystem. Second, the government in emerging economies should improve its institutionalization capability, including its planning capability, implementation capability, coordination capability, and so on. Third, for the sake of public welfare, the government should carefully deal with the relationship between public value and market value in CoPS.

For entities in the CoPS innovation ecosystem, most system integrators and suppliers and complementors are SOEs. They play an indispensable role in the CoPS innovation ecosystem. First, SOEs should aim to improve their technology capability, especially their product forward design capability, and construct the learning organization. Second, SOEs in emerging economies should build and continuously improve modern enterprise regulations to compete with international CoPS giants. Third, SOEs should maintain close UILs to overcome difficulties in basic theories and generic technologies. In addition, universities in emerging economies lack high-quality talents and resources and should focus on basic research and open education systems. Moreover, coordinating the interests of various entities in the CoPS innovation ecosystem is the greatest challenge for system integrators in practice.

6.3. Limitations

As a longitudinal case, HSR is only one of the typical successful catch-up phenomena in China. In fact, various unexpected factors have influenced the catch-up process of China's HSR. We focused on the innovation ecosystem perspective and tried to isolate the construction process of China's HSR innovation ecosystem in the catch-up process. Although our findings may be limited to a single CoPS industry, they still have useful implications for other CoPS industries in emerging economies. Despite these limitations, we argue that using the innovation ecosystem perspective is an important supplement for CoPS catch-up.

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Appendix A

Table A1. Typical cases of China's HSR technology innovation subsystem.

	Entry Stage	Path-Following Stage	Gradual Catch-Up Stage	Forging-Ahead Stage
High-speed rolling stock	Thirteen types of quasi-high-speed rolling stock prototypes were developed, such as "White Shark", "Pioneer", "Blue Arrow", and "China Star".	In October 2006, CRH1A, CRH2A, CRH3C, and CRH5A, China's first-generation EMUs after learning and adapting advanced technology, were called "Harmony". On 1 August 2008, CRH2C, the most modified product, was operated on the Beijing–Tianjin intercity railway.	The CRH380 series, China's second-generation EMUs with autonomous technology, was the representative product of China's integration innovation on the technology acquisition platform.	On 21 September 2017, the Fuxing EMUs, which were third-generation EMUs, operated at a speed of 350 km/h on the Beijing–Shanghai HSR. The Fuxing EMUs were the fastest wheeled train for commercial use in the world.
High-speed lines (HSLs)	On 16 June 2002, the Qin-Shen dedicated passenger line, which was the first line with a design speed of 250 km/h, was completed independently by Chinese firms.	In January 2004, the central government approved the medium- and long-term railway network planning, which was the first railway line plan in China.	On 1 August 2008, the Beijing–Tianjin intercity railway, which was the first line with a design speed of 350 km/h in China, was operated.	China's HSLs exceed 20,000 km in 2016. China's HSL travelled through almost every type of climate and environment in China.
Signal and communication	The CRSC completed the first program-controlled switching communication project in China. The CRSC was separated from the MOR in 2000.	The CRSC participated in six railway speed hikes and was responsible for railway communication signal engineering independently.	On 7 August 2015, the CRSC was listed on the Hong Kong stock exchange.	The CRSC independently developed the train control system (CTCS3) to manage HSR. In June 2018, the CRSC successfully tested the world's first 350 km/h self-driving system.
Bridges and tunnels	In 2000, the CREC, CRCC, and CCECC were separated from the MOR. In 2003, the CCECC was merged into the CRCC.	On 3 and 7 December 2007, the CREC was listed on the Shanghai and Hong Kong stock exchange, respectively.	On 10 and 13 March 2008, the CRCC was listed on the Shanghai and Hong Kong stock exchange, respectively.	The world record in railway bridge construction was broken by some Chinese projects, such as the Shanghai-Suzhou-Nantong Yangtze River bridge, Wufengshan bridge and Pingtan Straits rail/road bridge.
Stations	On 6 November 2001, the Beijing west railway station, which had the largest investment and advanced technologies of China's railway stations, formally opened.	Since 2006, more than 200 HSR stations were built on new railway lines, and the total construction area was more than 200,000 square meters.	By the end of 2015, China had completed 340 HSR stations.	HSR stations already covered 95% of Chinese cities with a population of 1 million and above.

Source: Extract from research data.

Table A2. Typical cases of China's HSR value creation subsystem.

	Entry Stage	Path-Following Stage	Gradual Catch-Up Stage	Forging-Ahead Stage
Value proposition	The central government proposed to meet the high-speed requirement of customers. In 2003, the MOR planned the target of realizing the leapfrog development of China's railway.	In 2004, the MOR advocated the modernization of HSR equipment. In 2004, the central government set up the general principle of technology acquisition called "acquiring advanced technology, jointly designing and producing, building the Chinese brand".	In 2006, the central government proposed the indigenous innovation strategy of China. In 2008, the MOR and MOST issued the agreement on the joint action plan for the indigenous innovation of China's HSR rolling stock.	In 2016, the central government revised the medium- and long-term railway network plan, the planning period was 2016–2025, and the long-term outlook was 2030. In 2019, the central government proposed the target of building China into a country with a strong transportation network.
Value transfer	Different local railway bureaus selected their own partners and formed an independent cooperation network.	The MOR paid a technology transfer fee of approximately RMB 600 million for CRH2, approximately RMB 800 million for CRH3 and RMB 900 million for CRH5. The CSR and CNR obtained mature rolling stock technology platforms from foreign firms.	Users, focal actors and complementors shared value through various cooperation channels, such as cooperation contracts, joint projects, and personnel exchanges. China implemented "high-speed railway diplomacy" in 2011.	The value created by various partners in China's HSR innovation ecosystem was transferred in a free and fair manner. The value transfer channels, scales, and categories are much richer. China's HSR was exported to more than fifteen countries.

Source: Extract from research data.

Table A3. Typical cases of China's HSR habitat.

	Entry Stage	Path-Following Stage	Gradual Catch-Up Stage	Forging-Ahead Stage
Competition	After 2000, the MOR created a two-layer competitive mechanism. Domestic rolling stock manufacturers competed freely for orders from local railway bureaus, and the MOR balanced the strength of the CSR and CNR by directing orders.	In 2004, the MOR coordinated the competition between the CSR and CNR by restricting bid qualifications. In 2004, the MOR held the decisive rights in technology acquisition negotiations.	Before 2015, the CSR and CNR formed duopoly competition in the domestic HSR market.	Since 2016, the CRRC has formed pure monopoly competition in the domestic HSR market and has gained a competitive advantage in foreign HSR markets.
Cooperation	Before 2000, 30 locomotive manufacturers, 5 institutes, and 11 universities in the railway system closely cooperated. In 2000, the reform of the MOR began to be implemented, and the CSR and CNR formed relatively fixed partners separately.	After 2004, China's HSR enterprises cooperated with universities and research institutes to solve localized R&D and engineering problems. In 2006, the MOR conducted a systematic technical bid for the Beijing–Tianjin intercity railway, including ballastless tracks, rail switches, and the power supply system.	From 2008 to 2015, there were 25 universities, 11 research institutes, and 51 national key laboratories and engineering centers in China participating in R&D projects run by the MOR and MOST.	China's HSR established a large network with the CRRC as its core and close cooperation between universities and research institutes.

Source: Extract from research data.

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