

Catch-up in Complex Products and Systems: A Fuzzy-Set Qualitative Comparative Analysis of China's Equipment Manufacturing Industry

Han Huang, Jie Xiong, Lu Xu, Zhe Yuan, Chun Liu

Abstract— The rapid advancement of Chinese Complex Products and Systems (CoPS) enterprises marks their transition into a post-catch-up phase, challenging conventional theories of catch-up. This study employs a configurational approach to explore the intricate relationships between catch-up environments and strategies, specifically focusing on the distinct paths of State-Owned Enterprises (SOEs) and non-State-Owned Enterprises (non-SOEs) within the CoPS sector. Utilizing Fuzzy-Set Qualitative Comparative Analysis (fsQCA) with data sourced from the EU Industrial R&D Investment Scoreboard (2017-2020) and corresponding Chinese-listed companies, our research identifies diverse catch-up configurations for SOEs, characterized by “complexity adoption” and “complexity decipher” models. In contrast, non-SOEs encounter challenges in strategically adapting to environmental shifts, which affects their catch-up strategies. Our findings emphasize the critical role of strategic alignment with external conditions, technological learning, and resource utilization in achieving successful catch-up in CoPS. These configurations enable SOEs to effectively align internal resources with external opportunities, resulting in superior catch-up performance. In contrast, non-SOEs encounter significant obstacles in adapting to environmental changes and optimizing resource utilization, which hinders their ability to attain similar successes. Moreover, our study sheds light on specific challenges faced by non-SOEs in responding to environmental shifts. This enriched understanding provides valuable theoretical insights into the catch-up of latecomer CoPS enterprises and has practical implications for both policymakers and business practitioners.

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Index Terms— Catch-up Performance, Complex Products and Systems, Data Envelopment Analysis, Enterprise Ownership, Fuzzy-set Qualitative Comparative Analysis.

I. INTRODUCTION

CATCH-UP in Complex Products and Systems (CoPS) are generally defined as involving high-cost, engineering-intensive products, systems, networks, or constructs [1]. The existing literature on catch-up highlights two key features: the processes and boundary conditions of catch-up. The initial stream of literature on catch-up within CoPS posits that this process is complex and diverse, often leading to distinct innovation paths divergent from those of mass-produced goods [2]. Therefore, the catch-up in CoPS typically follows “path-following” rather than “path-skipping” or “path-creating” [3]. The second thematic area focuses on boundary conditions, suggesting that catch-up in CoPS depends on two key factors: a conducive external environment and the embedded capabilities and resources of latecomer firms. A supportive external environment may include governmental intervention or backing for industries [4], a moderately concentrated market structure [5], and the emergence of technological windows of opportunity [6]. Internally, the capabilities and resources of latecomers must align with these external conditions, encompassing strategies responsive to emerging opportunities [7], adequate technological capabilities [8], and proficiency in leveraging organisational resources [9].

Assessing catch-up performance within the CoPS context necessitates a thorough analysis of specific factors unique to this sector [4]. These factors range from government support and technology transfer mechanisms to in-house R&D capabilities, the strength of industry ecosystems or clusters, and external alliances—all crucial for shaping catch-up performance within CoPS [10]. Unlike traditional manufacturing sectors, CoPS involve high-cost, engineering-intensive products and systems that require a robust support structure to foster innovation and efficiency. Externally, government support can provide the necessary regulatory frameworks and funding for large-scale projects [10], while technology transfer mechanisms ensure the effective sharing and implementation of cutting-edge technologies [6]. Strong industry ecosystems or clusters facilitate collaboration and resource sharing among enterprises [11]. And external alliances further enhance this collaborative

environment, enabling firms to leverage external expertise and market opportunities [12]. Internally, in-house R&D capabilities are crucial for developing unique solutions tailored to specific challenges in CoPS [11].

Existing studies on catch-up in CoPS have mainly focused on the linear relationship between catch-up factors and catch-up performance (universalistic perspective) (i.e., [13], [14]) or examined how other conditions influence this linear relationship (contingency perspective) (i.e., [7]). However, these approaches do not adequately address the complex causal dynamics inherent in the catch-up processes, as they tend to overlook the holistic interactions among influencing factors. Scholars advocate for a more comprehensive understanding of catch-up as a complex interaction involving multiple levels, subjects, and stages, which cannot be fully captured by traditional regression analysis [15]. Furthermore, there is a knowledge gap in aligning the internal and external conditions for effective catch-up in CoPS, particularly within the context of China's transitional economy where the technological and market regimes present a more complex pattern in the catch-up process [16]. Delery and Doty [17] have identified three dominant modes of theorizing in management research: universalistic, contingency, and configurational. Despite this classification, established catch-up studies often neglect the configurational perspective, which is crucial for understanding the intricate patterns of catch-up in CoPS. Therefore, a shift towards a configurational perspective that accounts for the holistic interaction among catch-up factors is essential to advance our understanding of effective catch-up strategies in CoPS, particularly in complex and multifaceted contexts like China.

In addition, ownership's role is pivotal in shaping the catch-up strategies of latecomer CoPS firms in China [18]. SOEs often benefit from direct government support, regulatory frameworks, and preferential access to financial and technological resources, facilitating their adoption of complex technological innovations and implementation of large-scale market strategies [19]. These advantages are supported by initiatives like "Made in China 2025," enabling SOEs to lead in capital-intensive sectors where market concentration and regulatory compliance are crucial [20]. Internally, the greater organizational slack in SOEs allows for flexibility in undertaking long-term projects, absorbing risks, and dedicating resources to technology importation and R&D during early catch-up stages [21]. In contrast, non-SOEs, which lack similar levels of governmental support, operate in more fragmented and competitive markets, driven by market competition and efficiency [22]. Their catch-up strategies often start with technology assimilation or reverse engineering [19], [23], and their internal resource allocation focuses on maximizing efficiency and responsiveness to technological opportunities and market changes [24].

Due to the influence of ownership, these divergent strategies of latecomer SOEs and non-SOEs result in varied performance outcomes. SOEs, with their abundant resources and government support, excel in environments where large-scale, resource-intensive projects are crucial, managing complex

technologies and leveraging state support to sustain performance in concentrated markets [24] [25]. Non-SOEs, on the other hand, often thrive in competitive, dynamic markets where agility and innovation are essential [24]. By efficiently utilizing their resources and focusing on niche markets, non-SOEs can achieve catch-up, albeit at a potentially slower pace due to limited access to capital and technological resources. These divergent paths illustrate how different configurations of external and internal factors lead to varied catch-up trajectories and performance outcomes.

To bridge the aforementioned research gaps, this study adopts a configuration lens to explore the mechanisms leading to divergent catch-up outcomes among latecomers in the CoPS field. We employ Fuzzy-Set Qualitative Comparative Analysis (fsQCA) to investigate China's equipment manufacturing industry. Specifically, this research examines how CoPS latecomer firms in China's equipment manufacturing sector respond to their external environment (technological opportunities and market structure) through their corresponding response strategies (technological learning, business focus, and resource utilisation).

Our results illustrate the interplay between external catch-up environments and internal catch-up strategies, offering insights into how SOEs and non-SOEs in the CoPS field navigate their catch-up trajectories. In the context of Chinese CoPS, the importance of government-controlled enterprises in establishing industry standards, which further contribute to the catch-up, has been acknowledged [10]. Our findings emphasise the importance of strategic alignment with external conditions, technological learning, and resource utilisation for successful catch-up, while also highlighting the distinct challenges faced by non-SOEs in adapting to environmental changes. This comprehensive understanding sheds light on the post-catch-up phases of Chinese CoPS enterprises and provides both theoretical contributions and practical implications.

We contribute to the current literature in several key ways. First, it provides a comprehensive understanding of the varied catch-up performance of latecomer firms in CoPS. Through a configurational analysis of the catch-up environment and strategy alignment, this study unveils the complex causal relationships underlying the catch-up processes of China's CoPS firms. Second, beyond its theoretical contributions to the domains of catch-up and CoPS, this study highlights the value of applying fsQCA in catch-up studies within the CoPS sector. The fsQCA approach enables us to investigate and capture the configurations driving catch-up of SOEs and non-SOEs [26], thus enhancing the methodological rigor and specificity needed to decode the "black box" of catch-up processes in latecomer firms. Finally, this study offers new practical insights for other CoPS latecomers engaged in the catch-up process. By better understanding the mechanisms to effectively cope with the challenges of catching up to leaders in the CoPS field, this research can assist policymakers and business executives in their strategic decisions.

II. THEORETICAL FRAMEWORK

A. The Catch-up Strategy and Environment

The catch-up as a strategic decision involves internal firm decisions and actions that capitalize on the catch-up environment, leveraging available opportunities and mitigating challenges. The catch-up environment comprises external factors such as institutional stability, technological advancements, and market structure [27]. These factors crucially influence the scope and nature of the opportunities available for latecomer firms to catch up.

First, contingency theory posits that organizational effectiveness results from the alignment of an organization's strategies and structures with the contingencies presented by the institutional environment [28]. The initiation of "Made in China 2025" strategic plan in 2015, aimed at transforming and upgrading the equipment manufacturing industry, exemplifies this alignment. This policy initiative has fostered a stable and supportive environment conducive to technological innovation and industrial upgrading, thereby shaping the catch-up dynamics of Chinese firms. The strategic emphasis on advanced manufacturing sectors under this plan has provided Chinese firms with enhanced government support, regulatory frameworks, and financial incentives, facilitating their efforts to bridge the technological gap and improve competitive performance in the global market.

Second, technological opportunities are the availability of new and disruptive technologies that latecomer firms can leverage to close the gap with industry leaders. This antecedent is critical as it provides a window of opportunity for firms to innovate and enhance their competitive position. When disruptive innovations are introduced, incumbents are often constrained by existing technology trajectories, creating a first-mover disadvantage that opens a catch-up opportunity for latecomers [7].

Third, the degree of market concentration influences the competitive dynamics and the potential for firms to catch up [5]. Latecomers, particularly those with large-scale and monopolistic capabilities in the domestic market, can respond to global market competition by building technological capabilities and other related competencies. The concept of springboarding explains the rapid development and internationalisation of Chinese automobile industry, which benefited from the market demand evolution [29]. Additionally, Jung and Lee [30] find that a monopolistic market structure is more conducive to catch-up by comparing the total factor productivity gap between Korean and Japanese firms.

These environmental factors set the stage for latecomer firms, significantly influencing the scope and nature of available opportunities for catch-up.

B. The Catch-up performance

Catch-up performance refers to the achievements of latecomer firms in narrowing the gap with leading firms; and this gap may pertain to the advancements either market-wise or technology-wise [31].

Market catch-up performance involves latecomer firms'

ability to gain market share, expand their customer base, and compete effectively in domestic and international markets [32]. This dimension of catch-up involves achieving commercial success by increasing sales [33], capturing new market segments [34], and establishing a strong presence in value chains [35]. Notably, non-SOEs, driven by market competition and efficiency, tend to outperform SOEs in expanding their market presence and capturing new customer segments [36].

Technological catch-up involves acquiring and developing technological capabilities, knowledge, and expertise to match or surpass the technological standards set by industry leaders [31]. Measures of technological catch-up performance may include indicators such as advancements in R&D [37] and patent filings [31]. Compared with SOEs, non SOEs show advantages in innovation output and innovation efficiency [38].

Latecomer firms must strategically allocate resources, build innovation capabilities, and adapt their business models to both close the technological gap and capitalize on market opportunities. For instance, niche market strategies have shown advantages in improving catch-up performance in CoPS industries [11].

The performance of catch-up in both technological and market dimensions is closely related to the external environment in which latecomer firms operate. Government policies, funding initiatives, and regulatory frameworks shape the institutional environment. Favourable institutional conditions can facilitate access to technology [6], research collaboration [39], and innovation ecosystems [40], thus enhancing technological catch-up performance. Conversely, market entry barriers, trade regulations, and intellectual property protections impact market catch-up performance [27]. The availability of technological opportunities in the external environment can significantly affect technological catch-up performance [41]. Latecomer firms benefit from disruptive innovations and technological advancements that create windows of opportunity for leapfrogging [42]. The competitive environment, characterized by the presence of incumbents and emerging competitors, influences market catch-up performance. Consequently, latecomers must differentiate themselves and offer unique value propositions to gain market share [43].

C. The catch-up in Complex Products and Systems

Studies on catch-up point out the importance of latecomer firm strategies in coping with technological complexity [44]. This complexity and uncertainty also shape the catch-up patterns of latecomers across different industries [42]. Catch-up in CoPS presents unique challenges and dynamics compared with other industries, influencing the strategies employed and the interactions with the environment [27]. Ownership heterogeneity influences firms' technological catch-up strategies, where SOEs initially focus on technology importation and later on innovation, while non SOEs prioritize technology assimilation and subsequently integrate various technological activities [19].

The technological complexity of CoPS is evident in both the breadth and depth of technological knowledge [45],

necessitating refined catch-up strategies. The breadth signifies the range of technological fields a firm engages in, while the depth reflects the degree of organisational understanding of the problem [46]. This understanding is demonstrated by the firm's capabilities related to the combination of CoPS components and the knowledge of each component [8]. Moreover, the development of CoPS is characterized by greater unpredictability due to the uneven rate of technological knowledge development among its components and the complex dependencies between them [47]. Thus, a firm's scope of technological knowledge must extend beyond what is required for production alone [8].

In the global competition landscape, merging economy fast-followers may catch up with forerunners in advanced economies in terms of productivity but not necessarily innovation [48]. To address this, CoPS latecomers must build their "horizontal" and "vertical" absorptive capacities. This strategy corresponds to the application of technological diversity knowledge (breadth) and distance knowledge (depth) [12]. Especially for catch-up's "last mile", where latecomers strive to forge ahead, domestic R&D and endogenous innovation capabilities become increasingly critical sources of knowledge [49].

Moreover, business diversification significantly impacts the performance of CoPS firms [50], characterized by a non-linear relationship with varying perspectives on its impact. Palich et al [51] argue that performance increases with increasing diversification up to a certain point, beyond which performance begins to decline. Other studies suggest a U-shaped relationship between product diversification and market growth [52]. Ahuja and Novelli [53] point out that the relationship between diversification and performance is complex, mainly because performance can be measured in various ways. The limited literature links diversification to reduced productivity performance [54]. Based on these insights, we propose a complex relationship between business focus (diversification) and CoPS firm performance.

Organisational resources and capabilities are vital for latecomers' catch-up in CoPS, where resource utilization, technological expertise, and a focused business scope are critical determinants of catch-up performance [9], [55]. Although organisational theory suggests that resource slack can cushion firms from shocks caused by drastic changes in the external environment, and thus benefit organisational performance [55], agency theory contends that slack may create agency problems, reducing efficiency [56]. The relationship between resource slack and organisational performance is not linear but contingent [57]. In the context of CoPS, with stable technology trajectories and extended product life cycles, firms often struggle to leverage resource slack effectively [11]. Chinese firms, in their catch-up process, typically require increased resource investment to transition successfully from technological imitation to innovation [58]. The presence of slack resources might indicate challenges in improving catch-up performance due to inefficiencies in resource allocation.

Generally, the presence of a technological window of

opportunity and a more concentrated market structure are conducive to catch-up within CoPS firms. Robust catch-up performance among latecomers depends on efficient resource utilization, technological expertise, and a focused business scope. Therefore, this study proposes a CoPS catch-up theoretical framework from a configuration perspective (Figure 1). The proposed framework comprises two conditions: the catch-up environment and the catch-up strategy. The former includes technological opportunities and market structure, while the latter involves technological complexity, business diversification, and organisational slack.

To explore the causality between the catch-up strategy, catch-up environment, and catch-up performance, we employ the fsQCA method. Previous studies indicate that the premise of fsQCA considers causality often conjectural [59] and that outcomes may result from multiple conditions [15]. Therefore, utilizing the fsQCA method is considered particularly suited for analyzing how combined catch-up strategies and environmental conditions can lead to the catch-up performance, which is configural in nature [15]. Additionally, fsQCA allows the use of smaller data sets to elaborate theory [60], aligning well with our research objectives.

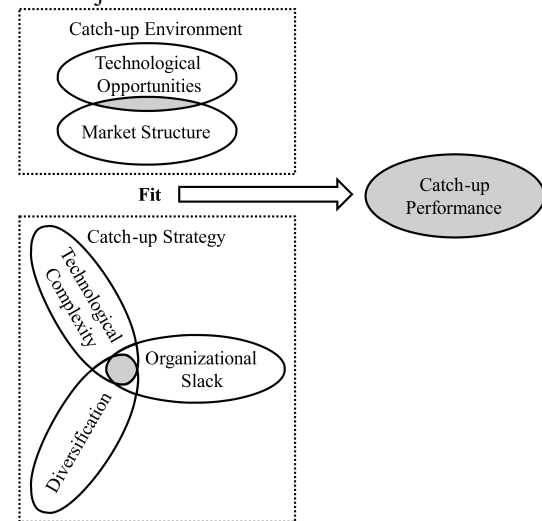


Fig. 1. A theoretical framework of catch-up environment and catch-up strategy

III. METHODOLOGY

A. Research design

The case study method is frequently utilized in research on CoPS firm catch-up due to its effectiveness in providing detailed insights into specific contexts [4]. However, one limitation of this approach is its tendency to yield conclusions that are specific to individual cases, which may limit the generalizability of the findings [61]. On the other hand, some firm-level catch-up studies employ large-sample statistical methods that presuppose independent conditions and portray the relationship between external catch-up environments and internal characteristics as linear and unidirectional [62].

In contrast, the complex interplay between the external catch-up environment and the structural characteristics of CoPS firms can result in multiple combinations and concurrent causal

effects on catch-up performance. Therefore, this study opts for configurational methods like fsQCA, which are particularly well-suited to capture and explain these intricate interactions [63].

This qualitative comparative analysis method enables the examination of how combinations of multiple conditions (both external environment factors and internal strategies) interact to produce specific outcomes. In the context of catch-up, where conditions may not always be binary (e.g., high or low technological opportunities), fsQCA is adept at handling varying degrees of condition membership, capturing the relationships between catch-up strategies and environmental factors which can be non-linear [64]. Understanding how different combinations of catch-up strategies and environmental conditions function within CoPS remains a central concern in this study. Utilizing fsQCA facilitates the incorporation of contextual specificity into our analysis [15].

B. Sample and Data

This study used the EU Industrial R&D Investment Scoreboard 1 to construct the research sample. Published annually by the European Commission Joint Research Centre since 2004, this scoreboard analyses R&D innovation trends in major economies based on statistics from companies with the highest amount of R&D investment worldwide. The dataset, stabilized at 2,500 entries in 2014, includes indicators such as R&D investment, net sales, capital expenditure, operating profit, and the number of employees, making it well-suited for comparing the disparities in innovation performance between firms across different areas.

We first selected scoreboard data released from 2017 to 2020 as the research sample, which reflects the innovation input of each firm in the scoreboard from 2016 to 2019. The “Made in China 2025” promulgated by the Chinese government in 2015 has a systematic impact on the catch-up of China’s manufacturing industry; hence, limiting the timeframe of this study to post-2016 helps to mitigate systematic biases.

Second, to focus on CoPS as the research subject, we filtered out companies within the industrial engineering industry based on the industrial classification provided in the scoreboard. Most companies in this category specialize in large equipment manufacturing and exhibit high technological complexity, aligning with the characteristics of CoPS. After excluding samples with incomplete data, we obtained Sample A, which included 136 companies distributed in China, the U.S., the EU, Japan, and other regions, to assess the catch-up performance of Chinese firms.

Finally, we isolated 18 firms listed in mainland China (Sample B) from Sample A, to analyze the antecedent conditions. We refer to the pooled Qualitative Comparative Analysis (QCA) approach proposed by Hino [65], in which each sample firm’s observation in different years is used as an analysis case, resulting in 54 analysis cases for the subsequent QCA.

Additionally, we utilized the China Stock Market and Accounting Research Database (CSMAR) and the SooNY patent database as data sources. From CSMAR, we retrieved financial data such as R&D investment, operating income, current ratio, and total assets of the sample companies. From SooNY, we extracted patent data including the number of patent applications and grants from sample companies and their industries.

C. Outcomes (Catch-up performance)

The outcomes analysed in this study focus on the catch-up performance, which is influenced by various antecedents, including “Technological Opportunities”, “Market Concentration”, “Technological Complexity”, “Organizational Slack” and “Diversification”.

To measure the catch-up performance of Chinese CoPS firms, we employ the Malmquist Productivity Index (MPI). MPI is a linear programming method based on Data Envelopment Analysis (DEA) and has been widely used to compare productivity among countries [66]. It measures firms’ productivity changes by calculating the geometric mean of productivity frontier shifts over a certain period and is also used to assess and compare the relative competitiveness between firms [67].

TABLE 1.
MALMQUIST PRODUCTIVITY IN FIVE REGIONS OF THE WORLD FROM 2017 TO 2019

Year	Country/ Region	n	Min	Max	Mdn	M	Std Dev
2017	China	22	0.381	3.454	1.090	1.156	0.647
	U.S.	28	0.771	1.528	0.976	0.998	0.141
	EU	47	0.364	1.711	1.021	1.037	0.242
	Japan	34	0.615	1.535	0.976	0.994	0.182
	Other	4	0.126	1.410	1.256	1.012	0.595
2018	China	22	0.679	1.830	1.007	0.992	0.244
	U.S.	28	0.577	1.255	1.073	1.018	0.164
	EU	47	0.464	1.283	0.964	0.935	0.177
	Japan	34	0.806	1.384	1.060	1.060	0.130
	Other	4	0.678	0.870	0.793	0.783	0.081
2019	China	22	0.445	1.555	1.021	1.020	0.242
	U.S.	28	0.647	1.452	0.987	0.989	0.158
	EU	47	0.699	1.592	1.013	1.032	0.150
	Japan	34	0.620	1.388	0.938	0.934	0.127
	Other	4	0.822	1.356	0.979	1.034	0.228

Specifically, following Wu et al. [67], we select R&D investment, number of employees, and capital expenditure from Sample A as inputs for calculating MPI, and use operating income as the output. Table 1 presents the MPI and its descriptive statistics for China, the EU, the U.S., Japan, and other regions. Since firms in the U.S., EU, and Japan generally possess strong technological capabilities in CoPS and represent the benchmarks for Chinese firms’ catch-up efforts, in line with Jung and Lee [30], we define catch-up performance as the difference between the MPI of Chinese firms and the average MPI of the EU, U.S., and Japanese firms. We calculate the catch-up performance of Chinese firms as follows:

$$C_i = \frac{m_i}{\bar{M}} - 1 \quad (1)$$

where m_i is the MPI of firms and $\bar{M}$ is the geometric mean of

¹
https://iri.jrc.ec.europa.eu/scoreboard/2022-eu-industrial-rd-investment-scoreboard#field_data.

the MPI of all firms in the US, the EU, and Japan.

D. Antecedents

1. Technological opportunities. The catch-up literature emphasizes that technological opportunities are critical factors that emerge at the industry level and significantly influence firms' catch-up performance [7]. Due to the knowledge-intensive nature of CoPS, opening a technology opportunity window is particularly crucial for successful catch-up [11]. Following Baysinger and Hoskisson [68], we measure technological opportunity in (2) as follows:

$$TO_j = \frac{\sum_{i=1}^n rd_{ij}}{\sum_{i=1}^n r_{ij}} \quad (2)$$

Where j represents the industry to which firm i belongs, rd_{ij} is the R&D investment, and r_{ij} is the operating revenue.

2. Market structure. We use the Herfindahl-Hirschman index (HHI) to measure market concentration [69]. Economic theory and empirical evidence suggest that market concentration, all other factors being equal, is a vital factor affecting an industry's market structure and competitive situation [69]. We measure market concentration in (3) as follows:

$$M_j = \sum_{i=1}^n \left(\frac{r_{ij}}{R_j} \right)^2 \quad (3)$$

Where j represents the industry, i represents the firm, r_{ij} is the operating revenue, and R_j is the sum of the operating revenue of all firms. The larger the value of M_j , the higher the market concentration.

3. Technological complexity. Although CoPS are regarded in the literature as products with unique characteristics, they often span multiple industries [1]. The degree of technological complexity varies significantly among industries and even among firms within the same industry due to differences in capabilities, resources, and strategies [47]. While there are no direct measures of technological complexity in existing studies, similar concepts are measured through technological diversity [70], technology resource breadth [71], and technological knowledge depth [72]. Referring to Lin and Wu [72], we operationally define technological complexity in (4) as follows:

$$TC_i = \sqrt{\sum_{j=1}^K \left(\frac{p_{ic}}{\sum_{c=1}^K p_{ic}} \times \frac{p_{ic}}{P_c} \right)} \quad (4)$$

where p_{ic} is the number of applications for category c patents by firm i , K is the number of patent classes involved by all sample firms, and P_c is the total number of category c patent applications in China. Thus, $\frac{p_{ic}}{\sum_{c=1}^K p_{ic}}$ is the proportion of category c patents filed by firm i to the total number of patent applications by the firm, and $\frac{p_{ic}}{P_c}$ is the proportion of category c patents filed by firm i to the number of category c patent applications in China. This weighted calculation reflects both the breadth and depth of technological knowledge, thus comprehensively reflecting the connotation of technological complexity [8].

4. Diversification. Some firms in the sample are involved in multiple industries, and the primary measures of diversification include the entropy [73] and HHI methods [74]. Both approaches measure the degree of business diversification

based on the ratio of main business income to total corporate income in different industries. We employ the HHI method to measure the degree of business focus, which is calculated in (5) as follows:

$$D_i = \sum_{j=1}^n s_{ij}^2 \quad (5)$$

Where j represents the industry, i represents the firm, and s_{ij} is the proportion of the business revenue of firm i in industry j to the total revenue of the firm i . The higher the value of D_i , the higher the firm's business focus.

5. Organisational slack. In alignment with Bourgeois [55], we measure organizational slack by using financial indicators such as the current ratio [75], debt-to-equity ratio [75], and expense-to-income ratio. The current ratio reflects the firm's existing assets and liabilities; a higher current ratio indicates more short-term slack resources. The debt-to-equity ratio reflects a firm's long-term financial solvency; a higher ratio suggests greater capacity for investment and financing. The expense-to-income ratio reflects the slack resources integrated into a firm's system; a higher ratio suggests more resources available for product or process innovation. A principal component analysis of these three indicators confirms that they all fall under one factor and have similar eigenvectors. Therefore, we use the average of these three indicators to measure organisational slack.

E. Constructing Subsamples

The analysis comprises two stages to derive refined results. Initially, we analyzed the full sample. Subsequently, we categorize the sample firms into two groups— SOEs and non-SOEs— based on ownership characteristics. This categorization is crucial as the behavioral logic of SOEs may differ significantly from that of non-SOEs [76], potentially leading to distinction in catch-up patterns. The two resulting subsamples consist of 12 SOEs and six non-SOEs.

F. Analyses

Primary analyses were performed using the QCA package in R [77]. In the analysis, all measures were converted into sets for calibration to enable the fuzzy-set analysis. We utilized a direct method of calibration based on existing theoretical and empirical knowledge, transforming raw variable scores into sets that require specification of full membership in a set of interests, full non-membership, and a crossover point of maximum ambiguity regarding membership [59].

Catch-up performance was measured using the difference in the MPI between Chinese firms and firms in the EU, the U.S., and Japan. A positive result indicates that the productivity of Chinese firms exceeds the average productivity of these developed economies, and vice versa. The attribute was calibrated as follows: 0.1 as the threshold for full belonging, 0 as the crossover point of maximum ambiguity, and -0.1 as the threshold for non-belonging [30].

The five antecedents in this study are all continuous variables with values greater than zero but varying across different ranges. Referring to the calibration criteria [15], the three calibration points of full belonging, crossover, and non-belonging are set at the 75%, 40%, and 15% quartiles,

respectively. In addition, because six cases in each technological opportunity and market structure have a calibration score of 0.5, we add 0.001 for calibration scores equal to 0.5 before conducting subsequent analyses [78]. Table

2 details the calibration of the outcome and antecedents and presents their descriptive statistics.

TABLE 2
CALIBRATION

	Results and Conditions	Fuzzy-Set Calibration			Descriptive Statistics				
		Non-beloning	Crossover point	Fully belonging	Mean	Standard deviation	Median	Minimum	Maximum
State-Owned companies	Catch-Up Performance	-0.1000	0.0000	0.1000	0.1231	0.4980	0.0749	-0.5456	2.4750
	Technological Opportunity	0.0417	0.0421	0.0449	0.0431	0.0038	0.0432	0.0280	0.0499
	Market Structure	0.0378	0.0915	0.2003	0.1246	0.0698	0.1110	0.0321	0.2143
	Technological Learning	0.0174	0.0356	0.0672	0.0658	0.0764	0.0481	0.0116	0.3116
	Business Focus	4	2	1	1.306	0.7863	1	1	4
	Resource Utilisation	0.7303	0.6637	0.6097	0.6981	0.1030	0.6858	0.5124	0.9916
Non-State-Owned companies	Catch-Up Performance	-0.1000	0.0000	0.1000	0.0237	0.0237	-0.0255	-0.3504	1.0808
	Technological Opportunity	0.0397	0.0421	0.0440	0.0429	0.0041	0.0425	0.0356	0.0499
	Market Structure	0.0341	0.0443	0.0826	0.0638	0.0287	0.0620	0.0321	0.1110
	Technological Learning	0.0414	0.0522	0.0713	0.0741	0.0476	0.0567	0.0357	0.1866
	Business Focus	4	2	1	1.3890	0.5016	1	1	4
	Resource Utilisation	0.8424	0.7338	0.6521	0.7731	0.1249	0.7534	0.6138	1.1072

TABLE 3
NECESSARY CONDITION ANALYSIS (SOEs)

Conditions	High Catch-up performance			Low Catch-up performance		
	Consistency	PRI	Coverage	Consistency	PRI	Coverage
Technological Opportunity	0.6240	0.5840	0.6193	0.4321	0.3717	0.6548
~ Technological Opportunity	0.6587	0.6249	0.4364	0.4253	0.3682	0.4302
Market Structure	0.6618	0.6289	0.6290	0.4082	0.3508	0.5925
~ Market Structure	0.6211	0.5712	0.4375	0.4733	0.4039	0.5091
Technological Learning	0.5576	0.5175	0.5219	0.4781	0.4307	0.6832
~ Technological Learning	0.7114	0.6875	0.5115	0.3350	0.2797	0.3678
Business Focus	0.7284	0.6975	0.1215	0.3736	0.3025	0.0952
~ Business Focus	0.6018	0.5732	0.8955	0.4097	0.3673	0.9308
Resource Utilisation	0.7350	0.7090	0.5032	0.3430	0.2785	0.3585
~ Resource Utilisation	0.5670	0.5218	0.5502	0.4880	0.4345	0.7230

Note: ~ indicates the absence of the condition.

TABLE 4
NECESSARY CONDITION ANALYSIS (NON-SOEs)

Conditions	High Catch-up performance			Low Catch-up performance		
	Consistency	PRI	Coverage	Consistency	PRI	Coverage
Technological Opportunity	0.4624	0.4108	0.6157	0.5939	0.5549	0.6581
~ Technological Opportunity	0.5278	0.4328	0.4592	0.5583	0.4695	0.4042
Market Structure	0.4938	0.4138	0.6331	0.5611	0.4918	0.5987
~ Market Structure	0.4756	0.4236	0.4373	0.6011	0.5615	0.4600
Technological Learning	0.5085	0.4564	0.6429	0.5419	0.4934	0.5701
~ Technological Learning	0.4489	0.3602	0.4208	0.6190	0.5577	0.4828
Business Focus	0.4602	0.4227	0.1300	0.6048	0.5773	0.1422
~ Business Focus	0.4629	0.4048	0.8883	0.5467	0.4976	0.8731
Resource Utilisation	0.6087	0.5485	0.5881	0.4569	0.3735	0.3674
~ Resource Utilisation	0.3847	0.3172	0.4752	0.6666	0.6301	0.6853

Note: ~ indicates the absence of the condition.

The next phase involves constructing the truth table, a data matrix summarizing the property space occupied by the five antecedents. The fsQCA method uses Boolean algorithms, which allow for the logical reduction of numerous random conditions [79]. The algorithm for building the truth table generates several probable solutions. Three solutions can be adopted in fsQCA: complex, intermediate, and parsimonious [61]. The results of the fsQCA analysis are assessed based on the consistency and coverage of the empirical data within the model. We follow established studies that at least 75% is considered the minimum acceptable standard for the consistency threshold [59]. However, the data coverage indicator indicates to what extent the adopted solutions explain the result. The model is considered sufficiently acceptable if coverage is set at 0.25–0.65 [61].

G. Analysis of necessary conditions

Before advancing to the subsequent stages of the fsQCA, we examined whether any of the causal conditions could be considered necessary. In fsQCA, we use consistency as a measure of the necessary conditions. Conditions are deemed necessary when the consistency value is greater than 0.9. As shown in Table 3 and Table 4, none of the five conditions are necessary for high or non-high catch-up performance. In other words, none of the antecedents constitute the necessary catch-up performance conditions.

IV. RESULTS

A. SOEs

Considering China's distinctive institutional environment, we consider the ownership nature of enterprises and separately examine the catch-up patterns of SOEs and non-SOEs [80]. The configurations leading to high catch-up performance among SOEs are detailed in Table 5.

TABLE 5.
CONFIGURATIONAL SOLUTIONS FOR SOE PERFORMANCE IN THE CoPS

	High Catch-up performance		
	S1	S2	S3
<i>Catch-up environments</i>			
Technological opportunities		●	
Market concentration	●	●	⊗
<i>Catch-up strategies</i>			
Technological complexity			●
Diversification	●		⊗
Organisational slack		●	●
Consistency	0.774	0.921	0.814
Raw coverage	0.059	0.249	0.123
Unique coverage	0.021	0.164	0.045
Solution consistency		0.865	
Solution coverage		0.324	

Solution 1 indicates that high market concentration and business focus are pivotal. Specifically, for SOEs operating within highly concentrated markets, a focused business strategy is crucial in driving their catch-up and enhancing performance.

Solution 2 highlights the central role of technological opportunities, highly concentrated markets, and high levels of

resource utilisation. In scenarios where technological opportunities are prevalent and market concentration remains high, firms that efficiently utilize resources are better positioned to improve their catch-up performance.

Solution 3 diverges from the first two solutions by emphasizing the strategy of the enterprises themselves. It shows that in industries characterized by high market concentration, SOEs can achieve high catch-up performance through profound technological learning and optimal resource utilization when faced with technological complexity.

B. Non-SOEs

This study further explores the configurations that lead to low catch-up performance among CoPS latecomer firms, specifically non-SOEs. The findings, detailed in Table 6, reveal distinct scenarios under which non-SOEs struggle to improve their catch-up performance.

TABLE 6.
CONFIGURATIONAL SOLUTIONS FOR NON-SOE PERFORMANCE IN THE CoPS

	Low Catch-up performance	
	S4	S5
<i>Catch-up environments</i>		
Technological opportunities	⊗	
Market concentration		●
<i>Catch-up strategies</i>		
Technological complexity		⊗
Diversification	⊗	⊗
Organisational slack	⊗	⊗
Consistency	0.735	0.962
Raw coverage	0.219	0.149
Unique coverage	0.156	0.087
Solution consistency		0.795
Solution coverage		0.305

Solution 4 illustrates that in the absence of technological opportunity windows, non-SOEs face significant challenges in catching up within CoPS sectors if they cannot effectively utilize resources. This scenario underscores the critical role of resource management in leveraging existing technological opportunities.

Solution 5 demonstrates that even in environments with high market concentration, non-SOEs that exhibit poor technological learning and resource utilization capabilities fail to achieve high catch-up performance. This configuration highlights the detrimental impact of inadequate enterprise capacity on non-SOEs' catch-up efforts, regardless of the external catch-up environment.

These configurations reveal a fundamental issue: the lack of strategic implementation in market, technology, and resource management by non-SOEs constrains their ability to catch up effectively.

C. Robustness checks

Robustness checks are essential to the QCA [81]. In our study, we conducted three robustness checks to validate the sufficiency analyses, ensuring the reliability of our results.

Firstly, in constructing the truth table, we reduced the consistency level from 0.80 to 0.78. The set relations of Solution 1 – Solution 5 remained unchanged, and there were no changes in the metrics of solution consistency or coverage. This

stability indicates that the identified configurations are robust to minor changes in the consistency threshold.

Next, we adjusted the PRI (Proportional Reduction in Inconsistency) consistency threshold. After increasing the PRI consistency threshold from 0.70 to 0.76, the generated configurations (S1-S5) and their corresponding consistency and coverage did not change. This indicates that our findings are robust to changes in the PRI threshold, further enhancing the robustness of our configurations.

TABLE 7.
CATCH-UP PERFORMANCE OF SOES

	High Catch-up performance		
	S1	S2	S3
<i>Catch-up environments</i>			
Technological opportunities		●	
Market concentration	●	●	⊗
<i>Catch-up strategies</i>			
Technological complexity			●
Diversification	●		⊗
Organisational slack		●	●
Consistency	0.778	0.929	0.826
Raw coverage	0.059	0.261	0.131
Unique coverage	0.021	0.171	0.048
Solution consistency		0.873	
Solution coverage		0.338	

TABLE 8.
CATCH-UP PERFORMANCE OF NON-SOES

	Low Catch-up performance	
	S4	S5
<i>Catch-up environments</i>		
Technological opportunities	⊗	
Market concentration		●
<i>Catch-up strategies</i>		
Technological complexity		⊗
Diversification	⊗	⊗
Organisational slack	⊗	⊗
Consistency	0.754	0.969
Raw coverage	0.226	0.142
Unique coverage	0.166	0.083
Solution consistency		0.807
Solution coverage		0.308

In addition, the calibration points for complete membership and non-membership of the outcome variable were adjusted to 0.12 and -0.12, respectively. Additionally, the calibration points for complete membership and non-membership of the

antecedent variables were adjusted to 76% and 16%. Upon re-analyzing the configurations with these adjustments, no changes occurred in the solutions generated for either state-owned (shown in Table 7) or non-state-owned enterprises (shown in Table 8). However, there were slight changes in the consistency and coverage metrics of their solutions. The minimal changes in metrics confirm that the identified configurations are robust across different calibration settings, supporting the stability of our results.

V. DISCUSSION

A. CoPS catch-up dynamics in China

Chinese CoPS enterprises have rapidly developed, matching or even surpassing the international frontier in terms of technical capabilities, market share, and production efficiency. This transition signifies their entry into the post-catch-up stage. However, traditional catch-up theories have not adequately addressed the nuances of CoPS at this stage, particularly failing to delineate the differences between SOEs and non-SOEs. To address this gap, our study adopts a configurational approach to explore the potential alignment between catch-up environments and strategies, aiming to elucidate the mechanisms underlying the divergent catch-up performances of latecomer firms in the CoPS sector. Utilizing the fsQCA method and data from the EU Industrial R&D Investment Scoreboard (2017–2020) alongside corresponding data from Chinese-listed companies, we analyze the conditional configurations and mechanisms distinguishing the catch-up results between SOEs and non-SOEs.

First, we find that in China's CoPS industry, the external environment—comprising factors such as technological opportunities and market structures—along with internal strategies involving technology learning, business focus, and resource utilization, creates various configurations for SOEs. These configurations are unified by the overarching objective of enhancing catch-up performance [61]. Notably, no single factor constitutes a necessary or sufficient condition for either high or low catch-up performance of Chinese CoPS enterprises. The interactions among multiple factors lead to two distinct models that facilitate high catch-up performance in SOEs, characterized as “complexity adoption” and “complexity decipher”. Conversely, the failure of non-SOEs to catch up is primarily attributed to a lack of opportunity, strategic alignment, and technological learning, compounded by insufficient resource utilization.

These findings reinforce the importance of considering how external environments and internal resource allocations shape the catch-up strategies and outcomes of latecomer SOEs and non-SOEs. SOEs, with their direct government support and preferential access to financial and technological resources, are strategically positioned to adopt “complexity adoption” and “complexity decipher” strategies, which are crucial in sectors dominated by large-scale technological projects. The favorable external environment is complemented by SOEs' greater flexibility in internal resource deployment, which facilitates their focus on technology importation during the early stages of catch-up, laying the groundwork for subsequent technological

leadership [20]. In contrast, non-SOEs are compelled to rely on resource efficiency and agile strategies, such as technology assimilation or reverse engineering, due to their lack of comparable state support. These disparities in internal resource allocation and external environmental conditions result in distinct strategic configurations, with non-SOEs often encountering challenges in catching up due to technological opportunities and resource constraints [22], [24].

Second, by comparing all antecedent configurations of the two patterns of SOEs, we identify technological opportunities and market concentration as critical environmental factors. Prior studies have highlighted the importance of technological opportunity windows in the catch-up of latecomer enterprises [7] and, to some extent, acknowledged the facilitative role of a centralized market structure [30], but ignore the potential interplay of these two aspects in latecomers' catch-up. Our study extends this understanding by recognizing how the combined influence of these factors can create an external environment conducive to enterprise catch-up within CoPS sectors. Usually, enterprises have a larger scale in industries with high market concentration and occupy more technological and innovation resources. This phenomenon allows latecomers to leverage their market position and resource advantages to improve productivity [29]. In some instances, these firms proactively create opportunities to transition from market to technology-led catch-up [31], thereby addressing the asymmetric development between output and innovation capabilities [48].

The contrasting performance outcomes of SOEs and non-SOEs are intricately linked to their differing configurations of internal resource allocations and external environments. As our findings show, the "complexity adoption" and "complexity decipher" strategies enable SOEs to maintain high performance, particularly benefiting from enhanced access to technological and financial resources [19]. Conversely, non-SOEs experience less favorable catch-up performance, hindered by limited access to resources necessary for learning and the misalignment between the windows of opportunity and their actual strategies.

Technological learning, business focus, and resource utilisation are pivotal for improving catch-up performance in the CoPS field. Subject to the effective use of resources, enterprises with in-depth technological knowledge or a business focus are more likely to achieve catch-up. These factors are somewhat interchangeable; some Chinese CoPS firms use technological backwardness as a lever to rapidly expand their depth of technical knowledge and enhance technological capabilities [37]. Others concentrate on their core business, adopting strategies of specialization or moderately related diversification to boost productivity and mitigate the disadvantages of limited resources [50]. Both approaches can enhance efficiency under certain conditions, and sometimes one can substitute for the other, allowing Chinese enterprises to choose between technological learning and business-focused strategies based on their specific circumstances.

Finally, comparing the reasons for non-SOEs' catch-up failures, we discern that the lack of a strategic response to

external environmental changes is the most critical impediment. Whether in environments devoid of technological opportunity windows or lacking a concentrated market structure, non-SOEs struggle to respond effectively to changes, preventing them from establishing a clear catch-up pattern. Furthermore, this study's findings suggest that causal asymmetry may exist in the factors influencing the catch-up of SOEs and non-SOEs, with only high catch-up performance configurations for SOEs and low configurations for non-SOEs being identified.

B. Successful catch-up pattern of SOEs

The "complexity adoption" configuration identifies two successful catch-up patterns for SOEs within the CoPS. The first pattern is characterized by SOEs possessing resource advantages and operating within a highly concentrated market environment [10]. These enterprises employ a business-focused strategy to facilitate catch-up. Corporate performance in this scenario is significantly influenced by both the market structure and individual enterprise strategies [44]. Echoing Schumpeter's view on the impact of market structure on innovation performance, catch-up is deemed more probable in monopolistic industries [30]. As most CoPS are also high-value capital goods, their production enterprises tend to be large-scale with considerable monopolistic power in the domestic market. This "monopoly advantage" transcends mere market dominance, extending to enhanced access to government support and premium human resources. Although several studies advocate that diversification strategies can boost profitability, especially in slow-growth competitive industries [76], if an enterprise lacks the resources and capabilities to leverage scope economies, diversification may not create value. Instead, a focused approach could maximize value creation. Also, the Chinese companies manage to catch up in global competition via agglomeration [82]. For latecomer enterprises, particularly those limited in resource acquisition capabilities and confronted with the complexities of CoPS, the challenges are exacerbated [11]. Lin and Wu [72] suggest that enterprises with weaker technological capabilities should concentrate on internal R&D to build knowledge of core technologies. Only those with robust technological capabilities should diversify strategic resources into other activities. Hence, latecomers in the CoPS sector are advised to focus on core businesses to accelerate their catch-up process. A typical case that exemplifies this pattern (configuration Solution 1) is Futian Automobile, which specializes in heavy trucks, large buses, and special construction machinery vehicles, emerging as China's most comprehensive and largest commercial vehicle enterprise.²

The second pattern emerges when a technological opportunity window appears in a highly concentrated market, compelling enterprises to effectively harness their organizational resources to enhance their catch-up performance. Traditional catch-up literature suggests that the emergence of technological opportunities might indicate

² <https://www.autothinker.net/report/content/id/680.html>.

technological discontinuities within the industry, potentially trapping incumbents (falling into the “incumbent trap”) and thus opening windows of opportunity for latecomers. However, in the CoPS sector, where technological trajectories are relatively stable, technological discontinuity may not be a primary factor for latecomer success. Given the government’s significant influence over SOEs, these opportunities can often be internalized through policy interventions or support [7], facilitating high-intensity, efficient, and large-scale technological learning among SOEs. The key to success along this path is the effective utilization of resources in response to technological opportunities. Enterprises that identify and respond to these opportunities are well-positioned to transition to the catch-up phase. A typical example of this pattern (configuration Solution 2) is Shanghai Electric, which delivers comprehensive solutions within the energy sector, covering nearly every aspect of the energy industry chain.³

The “complexity decipher” catch-up pattern explains that in-depth technological learning and effective use of resources are essential for SOEs to achieve high catch-up performance. Compared with large-scale manufactured products, CoPS production often requires enterprises to have broader and deeper knowledge [8]. This necessitates a diversified technology portfolio, enhancing production flexibility through the assimilation of various technology resource combinations, and thereby fostering distinct competitive behaviors [71]. Simultaneously, by fully deploying various organisational resources, including a combination of technological resources, enterprises can mitigate isomorphic pressures relative to leading firms [71]. This strategy enables latecomer enterprises to either skip paths or accelerate catch-up. Therefore, in a competitive market environment, enterprises can forge competitive advantages through intense technological learning and effective resource utilization, continually fostering efficient growth. A representative case of this pattern (configuration Solution 3) is Dongfang Electric, renowned for producing large-scale technical equipment like hydropower, thermal power, nuclear power, gas power, and wind power systems, becoming one of the world’s leading suppliers of power generation equipment and a general contractor in power plant projects.⁴

C. Failure of non-SOEs catch-up

Based on configurations Solutions 4 and 5, the lack of matching between the window of opportunity and strategy and the lack of complexity of technology learning are the two main reasons for non-SOEs’ catch-up failure.

Firstly, in industries that lack technological opportunities, insufficient organisational resource utilisation or the absence of diversified business strategies can lead to catch-up failure. The window of opportunity usually originates from industry-leading categories and concludes with the emergence of dominant designs [7]. As CoPS exhibit relatively stable

technical trajectories [1], the absence of technological opportunities means that the industry has settled on an established leading design, prompting most enterprises to reduce their R&D efforts. In such a relatively stable environment, organizational slack is less effective in buffering against significant external changes [55]. Consequently, enterprises that fail to utilize resources efficiently during this period will experience a reduced efficiency [56]. In addition, non-SOEs face greater challenges than SOEs in internalizing windows of opportunity through government policy support, potentially leading to stagnation or regression in their catch-up efforts.

Secondly, in markets dominated by a few large enterprises, non-SOEs lacking in technology learning complexity and failing to implement effective business diversification strategies or optimize resource utilization find it difficult to enhance efficiency. In essence, non-SOEs in the CoPS sector could potentially overcome the catch-up bottleneck by enhancing technological complexity, concentrating on core businesses, and effectively utilizing resources.

Our findings illustrate a configurational asymmetry between latecomer SOEs and non-SOEs. The successful catch-up of SOEs in the CoPS sector, as demonstrated through the “complexity adoption” and “complexity decipher” configurations, highlights the efficacy of the configurational approach. These SOEs excel by leveraging diverse combinations of internal slack, government support, and market concentration. In contrast, non-SOEs encounter more restrictive configurations, where limited organizational slack and misalignment with technological opportunities impede their catch-up performance. The configurational perspective elucidates why non-SOEs, even when operating in competitive environments, often struggle to achieve the performance levels of their SOE counterparts.

A pivotal concept from the configurational perspective is the notion of “fit,” where successful organizational performance emanates from aligning catch-up strategies with external environmental conditions [28]. This alignment enables SOEs to effectively utilize their capacity for managing complexity, navigating through the technological and market landscapes of the CoPS sector. Conversely, non-SOEs must focus on maximizing the efficiency of their internal resources while remaining adaptable to external market dynamics.

VI. CONCLUDING REMARKS

A. Conclusion

In recent years, Chinese CoPS enterprises have advanced significantly, achieving or surpassing international benchmarks in technical capabilities, market share, and production efficiency. This advancement signifies their transition into the post-catch-up stage, a phase where traditional catch-up theories do not fully explain the dynamics, especially the differences between State-Owned Enterprises (SOEs) and non-State-Owned Enterprises (non-SOEs). To bridge this gap, our study employed a configurational approach to explore how alignment between catch-up environments and strategies influences divergent catch-up performances in the CoPS sector.

³ <https://www.shanghai.gov.cn/nw31406/20230207/c9105ee5c04f482aa1a27f1f2b384040.html>.

⁴ <http://www.dec-ltd.cn/gjyt/gsjj.htm>.

Our analysis indicates that successful catch-up by SOEs is associated with a variety of configurations that integrate external factors—such as technological opportunities and market structure—with internal strategies, including technology learning and resource utilization. Two distinct models, “complexity adoption” and “complexity decipher”, underpin high catch-up performance among SOEs. In contrast, the catch-up challenges faced by non-SOEs are primarily due to mismatches in opportunities, strategic alignment, and resource utilization.

Comparative analyses highlight the pivotal role of technological opportunity windows and market concentration for SOEs, indicating that these joint environmental dynamics strongly influence latecomers’ catch-up in CoPS. Effective technological learning, focused business strategies, and adept resource management are identified as critical drivers of catch-up performance. This nuanced understanding underscores the need for adaptable strategies that leverage either technological depth or business focus, depending on the specific context, to enable successful catch-up in the complex and dynamic landscape of CoPS.

B. Theoretical contributions

This study contributes to the literature on CoPS and catch-up strategy in the following ways.

First, it adopts a configuration perspective to elucidate catch-up patterns of Chinese CoPS enterprises. By aligning the catch-up environments and strategies of latecomer enterprises, this research enriches the existing theoretical framework for CoPS catch-up, which traditionally has been analysed primarily from universalistic and contingency perspectives. For example, Lee and Lim [13] outline three catch-up pathways: path following, path skipping, and path creation. Similarly, Hain et al. [31] suggest that catch-up includes the market-technology and technology-market trajectories. From the perspective of the external environment of latecomer enterprises and the matching of catch-up strategies, this study adds depth to these analyses by identifying two successful catch-up patterns for SOEs and elucidating two primary reasons for catch-up failures among non-SOEs in the CoPS sector, providing a more detailed and context-specific exploration of catch-up mechanisms.

Second, our findings reveal that under specific boundary conditions, the catch-up patterns of CoPS enterprises may exhibit a substitutive relationship between different theoretical perspectives, rather than a complementary one. The discovery that CoPS catch-up can successfully follow either the “complexity adoption” or “complexity decipher” pattern, both effective in enhancing the efficiency of SOEs, challenges the traditional view that multiple strategies must be complementary. This insight expands the theoretical discourse by illustrating how different strategic configurations can independently drive catch-up performance.

In addition, this study innovates by integrating fsQCA and DEA methods into catch-up research, marking a pioneering application of this mixed-methods approach in the field. The use of fsQCA allows for the identification of causal configurations leading to distinct levels of catch-up performance, while DEA offers a quantitative measure of efficiency. This methodological contribution significantly enriches the toolkit for studying CoPS catch-up, providing a

robust framework for future research to examine complex causal relationships and efficiency dynamics.

This research also investigates the critical interplay between catch-up environments and strategies. The catch-up environment includes external factors such as government support, technological opportunities, and market structure, which create foundations that enable firms to pursue effective catch-up strategies. The “Made in China 2025” initiative exemplifies this, fostering a stable and supportive institutional environment that promotes technological innovation and industrial upgrading. Within such an environment, firms can adopt diverse catch-up strategies tailored to their specific contexts. The “complexity adoption” strategy involves leveraging external resources and support to integrate complex technologies comprehensively, while the “complexity decipher” strategy focuses on internally developing capabilities to decode and master technological complexities. This nuanced understanding of how catch-up environments and strategies interact enriches catch-up theory by illustrating how specific configurations can optimize performance outcomes in various contexts.

C. Implications

This study offers a valuable framework for guiding strategic decisions by practitioners and policymakers, aimed at fostering sustained innovation and competitiveness within the industry. The insights provided can help CoPS enterprises effectively formulate and adapt catch-up strategies to varying market conditions and technological trajectories. Furthermore, this research offers policy recommendations that support both identified catch-up patterns, enhancing the competitiveness of CoPS enterprises. Policymakers can facilitate this process by providing resources or incentives that align with patterns conducive to innovation and growth within the sector. By matching catch-up environments with appropriate strategies, this study broadens the current understanding, moving beyond conventional pathways identified in previous research and offering a new perspective on successful catch-up strategies for SOEs versus non-SOEs in the CoPS sector. This enhanced understanding will enable practitioners to leverage their strengths and address their weaknesses more effectively. Additionally, authorities may develop tailored policies and support mechanisms for SOEs and non-SOEs based on their respective successful catch-up patterns to promote balanced growth and competitiveness across the CoPS sector.

D. Limitations and future research

This study mainly focuses on the Chinese CoPS sector, potentially limiting the findings’ generalisability to other regions or industries. Expanding the research scope to include diverse industries and global contexts could provide a more comprehensive understanding of the catch-up phenomena. Additionally, the reliance on data from the EU Industrial R&D Investment Scoreboard and the fsQCA method may not fully capture the intricate dynamics of catch-up. Future research could benefit from incorporating alternative data sources and methodologies, such as qualitative investigations, to enhance the robustness and depth of the results.

In this study, we discuss configurational solutions for SOEs’ High Catch-up performance and non-SOEs’ Low performance.

Investigating other configurations may reveal underlying factors that influence the success or failure of different catch-up strategies, offering a deeper understanding of the mechanisms at play. This exploration could lead to more tailored and effective strategies for different types of enterprises, enhancing their performance in varying contexts.

Further exploration into how these catch-up strategies could be optimized or modified in different cultural or economic contexts would also be valuable, providing clearer insights into the universality and adaptability of the identified catch-up patterns.

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