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REVIEW ARTICLE

Catch-up and Beyond Catch-up in the Context of Windows of Opportunity: Theoretical Origins and Research advances

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Abstract

With the rapid transformation of global technology and industry, as well as the development of economic globalization, analyzing how latecomers catch up with incumbents has become a unique perspective for scholars to observe the growth of latecomer nations or firms. The concept of windows of opportunity integrates multi-level contextual factors such as technology, market, and institutions, serving as an important theoretical foundation for understanding the successful catch-up of latecomer countries or firms. In recent years, research on windows of opportunity in the context of latecomer catch-up has attracted widespread attention. Based on a review of relevant international literature, this paper examines the theoretical origins and logical structure of the windows of opportunity by focusing on four key aspects: the connotation and influencing factors of catch-up and leapfrogging, theoretical origins and typological expansion of the windows of opportunity, windows of opportunity-driven catch-up cycle and strategic pathways, and strategic action system of latecomer firms in responding to windows of opportunity. Building on an analysis of the shortcomings of existing research, it proposes future research directions concerning the impact of sustainable development and the green economic paradigm shift, solutions for the "standardization gap" encountered in latecomer catch-up, the practice of latecomer catch-up in the Chinese context, and the expansion of the theoretical framework and research methods related to the window of opportunity.

Keywords: Catch-up; Beyond Catch-up; Windows of Opportunity; Technological Paradigm; Literature Review

1. Introduction

Against the backdrop of rapid technological and industrial transformation and the rise of emerging economies, analyzing how latecomers achieve catch-up and leapfrogging has become a globally prominent topic, offering scholars a unique perspective to observe the growth of latecomer nations or firms as they advance toward the

technological frontier. Academics usually divide catch-up into economic catch-up and technological catch-up—the process by which a latecomer nation narrows income gaps (economic catch-up) while enhancing its technological capabilities relative to leading nations (technological catch-up) (Odagiri et al., 2010). Behind "economic catch-up" lies "technological catch-up," which focuses more on the improvement of technological and innovative capabilities. Early research primarily examined the learning paths and catch-up models of latecomer firms in the initial stages of development (Hobday, 1995; Wu, 1995; Kim, 1997). As capabilities accumulated and technology advanced, latecomer firms gradually shifted from imitation to innovation, with many transitioning from followers to leaders in "leapfrogging." Consequently, the catch-up strategies of latecomer firms at the innovation frontier have become a new research focus (Paik & Chang, 2015; Wu et al., 2019).

The concept of "window of opportunity" was introduced precisely to explain such latecomer catch-up phenomena. Perez & Soete (1988), in their analysis of latecomer catch-up, first proposed the concept of windows of opportunity from a cross-paradigm perspective, arguing that these windows represent critical moments for latecomers to leverage technological paradigm shifts to achieve catch-up. This theory was later expanded to multidimensional contexts such as markets and institutions, explaining the dynamic process of industrial leadership transfer among different countries and firms (Perez, 2001; Lee & Malerba, 2017). Integrating multi-level contextual factors including technology, market, and institutions, the windows of opportunity theory has become an important theoretical foundation for analyzing successful catch-up by latecomer countries or firms. In the intense competition of the business environment, seizing windows of opportunity to gain competitive advantages and escape the "backwardness-imitation-catch-up-backwardness" trap is key for latecomers to achieve leapfrog development.

In recent years, the global technological, market, and institutional environments have been undergoing "unprecedented changes in a century." Issues such as geopolitical restructuring, supply chain reshaping, the development of digital technology, and the green industrial revolution collectively define a critical period of paradigm shift between the old and the new. While this macro-level transformation poses challenges, it also opens multiple, overlapping "windows of opportunity" for emerging economies and their firms, particularly China (Wu & Wu, 2023). The achievements of Chinese latecomer firms in multiple high-tech sectors—such as new energy vehicles, digital infrastructure, and the photovoltaic industry—in catching up and even leapfrogging have attracted global attention, further enriching and advancing catch-up theory (Zhao et al.,2024).Current research is demonstrating several emerging trends. First, the commercial application of disruptive technologies like artificial intelligence is creating entirely new technological trajectories and market ecosystems, providing latecomers with new opportunities for "path creation"(Xie ,Liu & Deng, 2025). Second, the urgency of global green transformation has deepened theoretical and empirical research on the "green window of opportunity," with scholars beginning to focus on how latecomer firms can transform sustainability constraints into competitive advantages (Lema et al., 2020). Furthermore, issues of technology protection and the "standardization gap" are becoming increasingly prominent, shifting research focus toward how latecomer firms can overcome barriers in international technical standard-setting (Wei & Zhang, 2025). This paper aims to

systematically review the origins and international cutting-edge developments of the window of opportunity theory in the context of catch-up and surpassing catch-up. Through reading and analyzing representative literature in international journals, it reviews core topics including the conceptualization of catch-up and surpassing catch-up, the theoretical evolution and typological expansion of windows of opportunity, the dynamic relationship between windows of opportunity and catch-up cycles, and the response mechanisms of latecomers, while also examining the limitations of existing research. Building on this, the paper proposes future research directions from perspectives such as sustainable development and green transformation, bridging the "standardization gap," the particularities of the Chinese context, and the refinement of theoretical frameworks and research methodologies, thereby providing insights for subsequent theoretical innovation and latecomer catch-up practices.

2. The Connotation and Influencing Factors of Catch-up and Leapfrogging

2.1 The Connotation and Types of Catch-up

Against the backdrop of economic globalization, academia has paid significant attention to how latecomer firms achieve catch-up when competing with industry leaders. Catch-up by latecomer firms essentially refers to the process of gradually narrowing the technological and market gaps with leading firms (Perez & Soete, 1988). It can be categorized into two types: Technological Catch-up and Market Catch-up. Research on these two concepts is extensive, with representative literature summarized in Table 1.

Table 1. The Connotation and Main Approaches of Different Catch-up Types

Catch-up Type	Meaning	Main Approaches	Representative Literature
Technological Catch-up	Latecomers narrow the technological gap with leaders through technological learning, innovation, and imitation to enhance their own technological capabilities	Imitation, reverse engineering, technology introduction, technology licensing, technical cooperation, etc.	Abramovitz (1986) Fagerberg (1988) Lee & Lim(2001)
Market Catch-up	Latecomers reduce the market share gap with leaders through market strategies, brand building, and channel expansion to improve competitiveness	Market research, product positioning, brand building, marketing strategies, distribution networks, etc.	Porter (1990) Dawar & Frost (1999) Mathews (2002)

Catch-up does not merely involve simple imitation of new technologies, but also requires creative adaptation and innovation along or even beyond the development paths followed by first-movers (Lee & Lim, 2001). Some latecomers may skip certain stages in the catch-up process or forge entirely new paths distinct from those of their predecessors (Altenburg, 2008). In their study of industrial catch-up in Korea, Lee and Lim (2001) proposed a representative model of technological and market catch-up patterns, as illustrated in Figure 1.

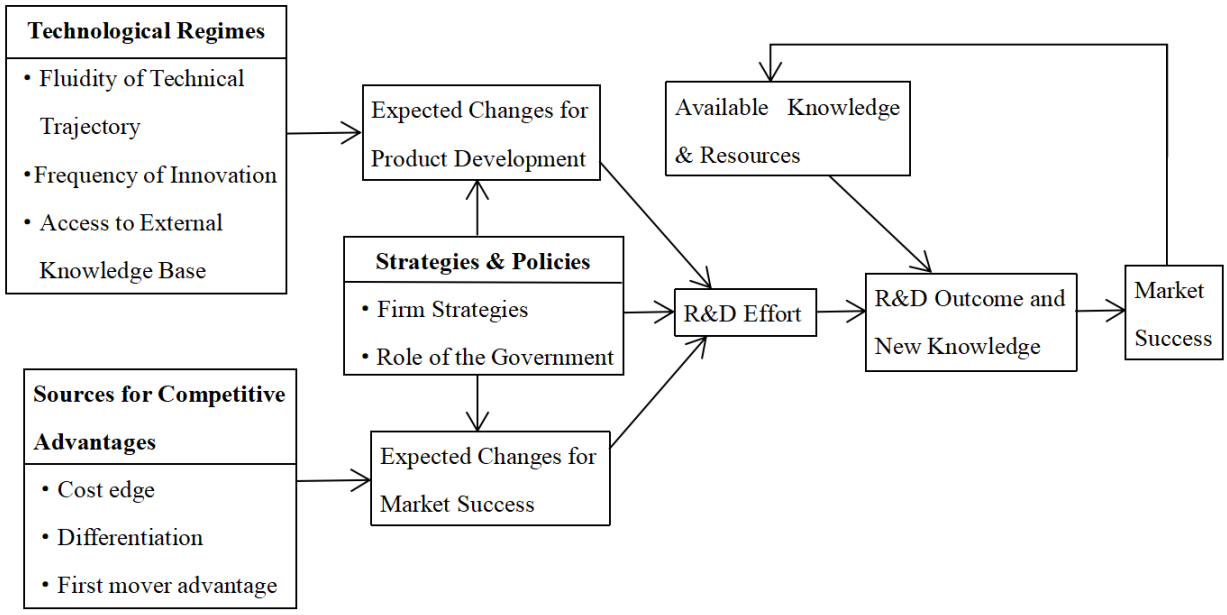

Figure 1: Model of technological and market catch-up

Source：Lee K, Lim C. Research policy, 2001, 30(3): 459-483

This model demonstrates that a firm's technological capability results from the interaction between existing knowledge, resources, and R&D efforts. The technological regime serves as a determinant of the expected opportunities in product development, while market factors such as cost advantages, product differentiation, and first-mover advantages determine the anticipated competitiveness of the products to be developed. Both corporate strategies and government policies can influence product development as well as market competitiveness, thereby directly shaping the firm's developmental trajectory.

Influenced by Lee and Lim (2001), numerous scholars have studied the phenomenon of catch-up by integrating both technological and market dimensions, emphasizing their synergistic role in enterprise development. For instance, Schmitz (2007) found that latecomer firms pursue coordinated catch-up with the dual objectives of technological and market catch-up performance, identifying "technological gaps" and "market gaps" as the two primary obstacles to their development. Lee and Malerba (2017) introduced the concept of "catch-up cycles"，analyzing how technological and market catch-up jointly drive changes in industrial leadership. Giachetti and Marchi (2017) examined the global mobile phone industry to demonstrate how technological windows and demand windows collectively influence the catch-up process of firms.

In summary, technological catch-up focuses on enhancing technical capabilities, while market catch-up emphasizes the improvement of market share and competitiveness. Technological catch-up largely depends on pre-existing knowledge and routines, as well as interactions between users and producers (Altenburg, 2008). The complexity and diversity of industrial knowledge bases are major hindering factors in achieving technological catch-up. Market catch-up, on the other hand, primarily relies on attaining internationally competitive quality and price levels. Technological catch-up and market catch-up are interrelated and mutually reinforcing.

Technological advancements can enhance product quality and innovation, thereby strengthening the competitiveness of nations or firms in domestic and international markets (Lee & Malerba, 2017). Conversely, improved market competitiveness generates revenue and profits, providing critical knowledge and financial resources to support technological R&D and refinement (Schmitz, 2007). Latecomer nations and firms can achieve comprehensive competitiveness and sustainable development through the coordinated integration of technological innovation and market strategies.

2.2 Key Factors Influencing Catch-up

Catch-up is a long-term learning process where technological and learning regimes, as well as innovation patterns, may evolve throughout an industry's lifecycle. Given the variations in technological characteristics across different countries or economic sectors, differences in customer profiles and competitive landscapes faced by domestic firms, as well as disparities in required skills and organizational structures, the factors affecting catch-up are multifaceted (Malerba & Nelson, 2011).

2.2.1 Corporate learning capability

For most latecomer enterprises, acquiring new resources presents significant challenges due to constraints such as high costs and limited access channels. Integrating existing resources through ambidextrous learning serves as an effective approach to achieve rapid technological catch-up(Tong, Peng & Gan, 2024). A representative case involves Indian pharmaceutical companies that initially developed basic formulation manufacturing and packaging capabilities by importing active pharmaceutical ingredients (APIs). Subsequently, they invested in engineering capabilities to gain API production competence. Through vertical integration of pharmaceutical production stages, the firm eventually became participants in multinational supply chains and global markets (Guennif & Ramani, 2012).This demonstrates that strategic investments in learning can help overcome initial resource constraints and thereby facilitate technological catch-up.

2.2.2 Acquisition of Foreign Proprietary Technology

Hobday (1995) emphasizes that latecomer firms face the challenge of competing against incumbents when entering major overseas markets. Due to technological protection measures, patent rights, barriers to technology transfer, or the significant technological gap between leading nations and latecomers, latecomer firms often lack direct access to or means of acquiring internationally advanced technologies. However, obtaining foreign proprietary technology is essential for successful catch-up, and actively striving to understand and master the specialized knowledge possessed by firms in frontier countries serves as a critical input for the learning process of domestic firms. The channels for such learning vary by country and sector. For example, South Korea extensively utilized licenses from foreign manufacturers, while China established numerous R&D and production joint ventures with multinational corporations. In industries where foreign technology cannot be widely or consistently accessed—such as the telecommunications sectors in India and Brazil—domestic firms

struggle to obtain advanced knowledge and technology, severely hindering the catch-up process (Mani, 2013).

2.2.3 Skilled Labor Capital

This factor is particularly crucial for industries that heavily rely on skilled labor, entrepreneurship, and the creation of new firms. Niosi and Reid (2007) argue that the catch-up efforts of various countries in the software industry are fundamentally based on the supply of engineers and programmers trained in technical schools and universities. Guennif & Ramani(2012) found that India's successful catch-up in the pharmaceutical industry also depended on an advanced workforce. The international mobility of skilled labor facilitates the global flow of knowledge, technical expertise, and entrepreneurial spirit. As catch-up progresses, developing countries often become more self-sufficient in technical training, eventually enabling their own scientists and engineers to play significant roles within the international community of technical professionals in their respective industries.

2.2.4 Corporate Behavior Mechanism

The behavioral decisions of enterprises also have a direct impact on the effectiveness of catch-up. When latecomer enterprises face windows of opportunity, the internal resource reorganization, organizational transformation, and strategic adjustments collectively form the micro-foundation of catch-up. This is specifically manifested in: resource orchestration behavior, which refers to how enterprises dynamically allocate limited technical, financial, and human resources to seize windows of opportunity; organizational learning mechanisms, including experimental learning, reverse engineering, cross-boundary knowledge integration, and other methods; and strategic decision-making logic, which refers to how enterprises employ effectual logic or causal logic, among others, to respond to windows of opportunity under high uncertainty. For example, during the digital technology window, Qianfen Yi Company achieved a transition from imitation to innovation by reorganizing its internal R&D department and building an open innovation platform (Tong Hongzhi, Peng Zhanli, and Gan Jiawei, 2024). These micro-level behaviors explain why, under the same windows of opportunity, the catch-up performance of different enterprises varies significantly.

2.2.5 Proactive Government Policy

proactive government policies. Proactive government policies can also stimulate the development of learning capabilities in domestic firms, with interventions varying in form and intensity. Measures such as R&D subsidies, tax incentives, and market access support provided by governments can help local enterprises overcome latecomer disadvantages and foster the growth of key industries and firms. This is especially true in sectors where the knowledge base relies on skilled labor and new firms to drive development and growth, such as the software industry. Beyond policies supporting education and advanced human capital formation, additional measures include R&D funding for startups and small enterprises, preferential corporate tax rates, and incentives to attract foreign direct investment (Niosi & Reid, 2007). In science-intensive industries like pharmaceuticals, where research is closely tied to academic knowledge, support from universities and research institutions is vital

for catch-up. Governments can also establish and refine legal, policy, and institutional frameworks to support innovation and enterprise development, such as intellectual property protection, contract enforcement, and market regulation. Furthermore, regulatory policies can be used to restrict the expansion of foreign competitors in domestic markets (Guennif & Ramani, 2012). In high-tech industries like semiconductors and automobiles, government policies have successfully attracted foreign direct investment while simultaneously supporting the development of domestic capabilities (Lee & Lim, 2001).

3. Theoretical Origins and Typological Expansion of the Windows of Opportunity

3.1 Theoretical Development Overview of the Windows of Opportunity

Perez and Soete (1988) first introduced the concept of "windows of opportunity," referring to the role played by the emergence of new techno-economic paradigms in enabling latecomers to leapfrog incumbents through paradigm shifts. These windows create possibilities for latecomers to achieve catch-up. They examined technological entry barriers and windows of opportunity, identifying the introductory and mature phases of a technology's lifecycle as optimal windows for technological catch-up. This seminal work established the prevailing view that technological change can generate windows of opportunity for latecomers' catch-up, with numerous studies subsequently adopting technological paradigm shifts to explain industry leadership transitions.

As research on latecomer catch-up deepened, the mechanisms generating windows of opportunity were further developed. Mathews(2005) also demonstrated that shifts in market demand and business cycles could also create new windows of opportunity for catch-up. Guennif and Ramani (2012) found that changes in government industrial policies and regulatory frameworks could provide latecomers with leapfrogging opportunities. Building on these foundations, Lee and Malerba (2017) proposed a framework to explain catch-up cycles. From the perspective of industrial dynamics, they refined the concept of windows of opportunity by categorizing them into three types: technological, demand and institutional. They also demonstrated that in different sectors, changes in industrial leadership depend on the type of windows of opportunity and the strategic responses of incumbents and latecomers.

The 2017 special issue on "Catch-up" in the leading journal “Research Policy” marked widespread academic recognition of the windows of opportunity concept, which has since been extensively cited to explain catch-up phenomena. Scholars generally agree that successful catch-up correlates strongly with the density and frequency of windows of opportunity (Giachetti & Marchi, 2017). With the theoretical foundations and generative mechanisms now well-established, recent research has expanded to examine their typological features, relative importance, sequential patterns and co-evolutionary mechanisms.

3.2 Types and Related Characteristics of Windows of Opportunity

In summary, the three types of windows of opportunity—technological, demand and institutional/policy (as detailed in Table 2)—incorporate multi-level contextual factors in latecomer catch-up , serving as an important theoretica foundation for analyzing how latecomer nations or firms achieve successful catch-up and beyond

catch-up (Huang, Zhang & Xiong, 2020).

Table 2. Types and Meaning of windows of opportunity

Types	Meaning	Representative Literature
Technological Windows	Technological changes or shifts in technological paradigms create opportunities for latecomer firms or nations to catch up with or even surpass industry leaders.	Perez and Soete (1988) Lee and Lim (2001)
Demand Windows	Changes in market demand or adjustments in market structure provide opportunities for latecomer firms or nations to enter markets or expand their market share.	Christensen (1997) Dawar and Frost (1999) Mathews (2002)
Institutional/Policy Windows	Shifts in policy interventions or broader institutional changes create opportunities for latecomer firms or nations to achieve catch-up.	North (1990) Lee and Ki (2017)

Source: Adapted from Lee, K., & Malerba, F. (2017). Research Policy, 46(2), 338-351

The "technological window" refers to the paradigm-shifting opportunities brought about by new technologies or breakthrough innovations. Leveraging the technological windows and continuously increasing R&D investment to internalize external technologies can significantly enhance catch-up efficiency. However, when a new paradigm emerges, both latecomers and incumbents start on the same technological footing, threatening the existing technological advantages of incumbents. For incumbents, emerging technologies entail high uncertainty, leading them to often overlook the disruptive potential of new technologies or products, thereby falling into the "incumbent's trap." For example, the shift from analog to digital technology provided Korean electronics firms with an opportunity to seize market dominance from Japanese companies (Lee, Lim & Song, 2005).

The "demand window" arises from shifts in market demand or business cycles. New demand creates fresh opportunities, and the emergence of new consumer segments enables latecomer firms to enter the market. The role of business cycles is particularly pronounced in industries characterized by large-scale investments. Economic upturns offer incumbent firms opportunities to generate profits and expand production and market share, while downturns lead to the bankruptcy of weaker firms, releasing resources at lower costs and creating entry opportunities for latecomers. Furthermore, during business cycles, mismatches often occur between investment and production dynamics on one hand and market demand dynamics on the other. This requires both incumbents and latecomers to make strategic choices regarding timing and production capacity—missteps in these choices can lead to market exit (Mathews, 2005). For instance, the jet aircraft industry experienced two leadership changes due to shifts in demand.

The "institutional/policy window" emerges primarily from public policy interventions or changes in institutional conditions. Governments can intervene by establishing R&D programs that influence the learning processes and

capability-building of domestic firms, or by providing subsidies, tax incentives, export support, regulations, and public standards. These measures create an asymmetric environment that latecomers can exploit to offset initial cost disadvantages associated with market entry. Some scholars argue that while government interventions often conflict with fair competition, they can be justified because incumbents frequently employ unfair tactics to block latecomers (Kim & Lee, 2008). The importance of proactive government policies varies across sectors, and windows of opportunity may open simultaneously or sequentially within the same industry. In the steel industry, for example, the governments of Japan and Korea played a pivotal role in facilitating latecomer firms' market entry by providing substantial investment funds, ensuring operational capital chains, and supporting technological R&D (Malerba & Nelson, 2011). Similarly, in the biopharmaceutical industry, windows of opportunity emerged due to government regulatory policies (Guennif & Ramani, 2012).

Windows of opportunity can be either exogenous or endogenous, depending on the responses of various actors within a sectoral system. For instance, a technological window may arise from a firm's R&D investments in new technologies, while emerging market demand can create new opportunities for latecomer firms in terms of both R&D and marketing. In a country aiming to catch up, new public policies can generate institutional/policy windows for businesses. These three types of windows of opportunity do not exist in isolation; they interact with one another and may appear simultaneously or sequentially within the same industry (Lee & Malerba, 2017). For example, the emergence of new technologies, coupled with changes in government regulations on foreign firms, served as windows of opportunity for domestic Indian companies to succeed in the IT services sector (Lee, Park & Krishnan, 2014). Similarly, the technological window associated with digital GSM technology was linked to a demand window driven by individual users, as well as an institutional window created by the European Union’s support for digital GSM standards (Giachetti & Marchi, 2017). Moreover, the same type of windows of opportunity can be shaped by multiple factors, while identical triggering factors may lead to different windows of opportunity (Guennif & Ramani, 2012). Therefore, when analyzing windows of opportunity that emerge during the catch-up process, latecomer firms should consider both internal and external environments to better understand the underlying patterns of these windows.

4. Windows of Opportunity-Driven Catch-Up Cycle and Strategic Pathways

4.1 Research on the Types and Mechanisms of Catch-Up Cycles

4.1.1 Phases and Specific Manifestations of Standard Catch-Up Cycles

With the continuous deepening of academic research, scholars have widely adopted the term "Catch-up Cycle" to describe the sequential changes and ongoing shifts in industrial leadership among firms and nations. The catch-up cycle refers to the dynamic evolution of industrial leadership between latecomers and incumbents. And a standard catch-up cycle consists of four phases: entry, incremental catch-up, ascent and decline (Lee & Malerba, 2017). This framework effectively captures the comprehensive process through which latecomers

attempt industry entry, gradually accumulate advantages, respond effectively to opportunities, attain leadership positions, and eventually face decline due to emerging new challengers.

During the entry stage, latecomers attempt to enter an industry and overcome initial disadvantages relative to incumbents by leveraging low factor costs, among other means. Enterprises primarily engage in resource bricolage and minimum viable product development to explore the market through low-cost trial and error. In the incremental catch-up stage, latecomers focus on catching up in terms of market share or productivity, typically relying on cost advantages and the gradual accumulation of investment, learning, and capabilities. They achieve continuous efficiency improvements by establishing standardized processes and knowledge management systems.

In the ascent stage, latecomers effectively respond to opportunity windows. They may initially follow the path of pioneers but later engage in radical innovation and steady progress in organization, products, processes, and markets. At this stage, the original incumbents continuously decline, while latecomers assume leadership positions and pursue breakthrough innovations, implementing organizational restructuring to adapt to new technological paradigms. In the decline stage, new leaders may themselves decline due to the rise of new challengers. Enterprises need to build dynamic capabilities to address the threats posed by these new challengers. Each stage of the catch-up cycle corresponds to specific micro-level corporate behaviors. Taking Samsung's memory business as an example, throughout its catch-up cycle, it not only consistently increased R&D investment but, more importantly, established a "crisis management" mechanism and a rapid decision-making system, enabling the company to swiftly adjust resource allocation when external opportunity windows emerged (Shin, 2017). This micro-level behavioral mechanism is key to achieving enduring leadership.

4.1.2 Phases and Specific Manifestations of Non-Standard Catch-Up Cycles

Depending on the degree of technological disruption, the extent of lock-in effects, and the initial capabilities of incumbents, catch-up cycles may manifest in alternative forms. Landini, Lee and Malerba (2017) developed a history-friendly model to examine the effects of successive leadership changes under technological conditions, while distinguishing four "non-standard" patterns of catch-up cycles: Aborted catch-up, Persistent leadership, Return of former leadership, and Coexistence of latecomer and incumbent leadership. The first type is "Aborted catch-up" where latecomers fail in their catch-up efforts, stalling at some point during the gradual catch-up phase and eventually declining. For instance, Ireland's software industry initiated a catch-up process against the incumbent (the U.S.) but failed to achieve leadership (Mani, 2013). Numerous failed catch-up cases demonstrate that in aborted cycles, latecomers cannot gain sufficient momentum to keep pace with leaders due to the limited scale of windows of opportunity, eventually stagnating and declining. Some latecomer nations fall into this category, with key obstacles being their inability to learn and upgrade in value-added products, as well as the lack of an effective, clear system to support firm-level catch-up—especially when new technologies emerge or new markets open.

In the "Persistent leadership" cycle, incumbents adopt a long-term perspective rather than focusing on a single

technology. They invest in adapting to new technologies or demand conditions while successfully navigating rapidly changing environments, thereby maintaining leadership across multiple generations of technological waves (Landini et al., 2017). This sustained leadership is exemplified by Japanese firms and Korean firms. For example, in the camera industry, Japan gained market leadership from Germany in the mid-1960s and has successfully maintained it despite competition from other latecomers (Kang & Song, 2017). In the memory chip industry, Japan overtook U.S. leadership in the 1980s, only for Korea's Samsung to seize leadership from Japan in the 1990s and sustain it for over two decades (Shin, 2017).

The third atypical catch-up cycle is the "Return of former leadership" where the original incumbent is initially displaced by a latecomer but later regains dominance. Landini et al. (2017) argue that this resurgence occurs due to improvements in the incumbent's initial average capability levels and the strengthening of the national innovation system supporting the incumbent. For instance, Italy regained market share in the wine industry in the early 21st century (Morrison & Rabellotti, 2017). In the "Coexistence of latecomer and incumbent leadership" cycle, incumbents and latecomers share leadership. This coexistence is facilitated by the introduction of smaller-scale discontinuities and diminishing returns on technological investments. A classic example is the wine industry, where latecomer nations (e.g., the U.S., Australia) joined traditional leaders (e.g.,France) as new industry leaders (Morrison & Rabellotti, 2017).

4.2 Diversified Catch-up Strategic Pathways

The catch-up process is not an overnight achievement, it requires long-term strategic planning, sustained effort, and well-timed adjustments. Different latecomers may choose distinct pathways in their catch-up endeavors. By categorizing various types of catch-up cycles and examining their underlying mechanisms, latecomers can better leverage their comparative advantages and global opportunities to achieve rapid growth and modernization. This understanding holds particular significance for emerging economies, with China being a prime example, as they navigate their developmental trajectories.

The applicability of latecomer firms' catch-up strategies and their dynamic innovation capabilities are crucial to the outcomes of technological leapfrogging (Lee & Malerba, 2017). In the industrialization process, latecomer countries face intense competition from developed economies, where adopting the most advanced and efficient technologies proves critical for success. Latecomer firms in heavy industries can enhance their competitiveness by establishing state-of-the-art production facilities and leveraging scale effects to capitalize on latecomer advantages. Moreover, shifts in technological systems and techno-economic paradigms influence market entry costs and create opportunities for latecomers to catch up (Perez & Soete, 1988).

Lee and Lim (2001) developed a model of technological and market catch-up to analyze the divergent evolutionary paths of six major industries in Korea (D-RAM, automobiles, mobile phones, consumer electronics, personal computers, and machine tools). They identified three distinct catch-up strategies: The first is the path-following strategy, where latecomer firms progress along the established technological trajectory of incumbent firms. However, due to lower productivity levels, these firms cannot compete directly with

incumbents in the same market segment and must instead target different, lower-end niches. The second is the path-skipping strategy, where latecomer firms partially follow the same trajectory as incumbents but bypass older generations of technology by adopting the latest available technologies. In this scenario, intellectual property protections may pose barriers to catch-up. Once latecomers resolve technology transfer or acquisition challenges, they gain significant latecomer advantages—achieving productivity levels comparable to incumbents while potentially benefiting from lower labor costs, thereby becoming formidable competitors. The third is the path-creating strategy, where latecomer firms pioneer their own technological development path using next-generation technologies. A key advantage of this "leapfrogging" approach is its focus on technologies with high long-term potential or productivity gains. However, it also entails substantial upfront costs and may incur losses in the early stages of market development (Lee & Ki, 2017).

However, for certain specialized industries, a dynamic catch-up strategy proves more appropriate. Unlike the "leapfrogging" concept proposed by Perez and Soete (1988), the dynamic catch-up strategy can be understood as partial leapfrogging: in the steel industry, latecomers achieve "leapfrogging" development in new technologies while incumbents stagnate with old technologies; whereas in the memory chip industry, although latecomers follow the same product development path as their predecessors, they "overtake" pioneers in process innovation. Furthermore, for industries like semiconductors characterized by rapid product iteration, firms must leverage new technologies to achieve greater economies of scale (Lee & Lim, 2001). Consequently, both incumbents and latecomers continuously compete to develop new products and processes, requiring substantial ongoing investments in R&D and equipment to avoid market obsolescence (Shin, 2017). These unique technological demands compel latecomers to adopt dynamic catch-up strategies. The dynamic catch-up strategy pursues rapidly moving targets, aiming not only to catch up with pioneers in current-generation technologies but also requiring latecomers to simultaneously develop next-generation technologies—essentially pursuing two generations of technological development concurrently. A prime example emerged during Japan's catch-up with the U.S. in memory chip manufacturing during the 20th century. To achieve effective catch-up, Japanese manufacturers strategically focused their R&D more on process rather than product technologies. Their development of VLSI technology generated over 1,000 patents during the R&D process, including breakthroughs like electron beam lithography.

The resources and technologies available to latecomer firms vary significantly across different catch-up stages, as does the intensity of market competition they face. Windows of opportunity are closely linked to corporate strategy and play a crucial role in catch-up cycles (Lee & Malerba, 2017). Consequently, when encountering different types of windows of opportunity, latecomers can adopt tailored catch-up strategies that align with their internal capabilities and external environments, thereby more effectively leveraging their latecomer advantages.

4.3 Incumbent's Trap" and Corporate Strategic Responses

The opening of windows of opportunity requires precise timing, which is closely related to the "incumbent's trap." It refers to the disadvantages that arise when a firm, by virtue of being ahead of competitors in timing,

takes certain strategic actions that lead to high costs, high risks, increased susceptibility to errors, and competitive advantages that latecomers can easily imitate or even surpass (Lee & Malerba, 2017). Compared to latecomers, incumbents typically possess superior resources and capabilities. However, the emergence of a new techno-economic paradigm can threaten the dominance of their existing technologies. Incumbent firms may fall behind due to ineffective responses, primarily for the following reasons: First, incumbents often become complacent with their current success, neglecting new technologies, emerging demands, and untapped markets while stubbornly adhering to their established technologies. Second, adopting new technologies may entail higher costs, lower productivity, and reduced reliability compared to existing solutions, making technological shifts risky for incumbents. Third, the institutional and organizational systems in which incumbents operate may resist change, preventing adaptation to new windows of opportunity. In contrast, periods of paradigm shift create favorable conditions for latecomers. Latecomers face lower entry barriers in new markets and enjoy the advantage of freely selecting the latest or emerging technologies. Moreover, as R&D costs rise, the latecomer advantage tends to increase monotonically (Hoppe & Lehmann, 2001).

The likelihood of falling into the "incumbent trap" is closely related to the nature of "response." While previous research typically conceptualized "response" as referring to latecomers' strategies and institutional arrangements, Lee and Malerba (2017) expanded this notion to encompass responses from both incumbents and latecomers. The evolution of sectoral systems may open different windows of opportunity, to which incumbents and latecomers respond differently, leading to continuous shifts in industrial leadership (Shin, 2017). Incumbents generally possess superior resources and capabilities compared to latecomers. When incumbents adopt a long-term perspective on enterprise development—not limiting themselves to specific technologies but investing in responses to new technologies or demand conditions while adapting to rapidly changing environments—they can maintain their leadership positions (Landini et al., 2017). For latecomers, their ability to respond effectively to windows of opportunity determines whether they can fully capitalize on latecomer advantages. Successful responses from latecomers are typically associated with high-level learning capabilities, technological absorption capacity, and marketing competencies, which enable them to identify and seize new opportunities while implementing innovations for their benefit. When latecomers successfully identify and exploit windows of opportunity, particularly when supported by complementary institutional factors—such as effective institutional arrangements in public policy and regulation, well-developed higher education institutions and public research systems, availability of advanced human capital, networks of suppliers and partner firms, and accessible innovation financing—they become significantly more likely to achieve beyond catch-up.

5. Strategic Action System of Latecomer Firms in Responding to Windows of Opportunity

5.1 Establishing an agile opportunity identification and response mechanism

During industrial development, various types of windows of opportunity emerge. These include shifts in new economic-technological paradigms, changes in market demand, consumer preferences and business cycles, as

well as transformations in public policies and relevant institutional frameworks. Incumbents and challengers demonstrate different response patterns, primarily manifested as "incumbent traps" or "other lock-in behaviors" and and taking advantage of latecomers.Under the dual drivers of globalization and rapid technological advancement, the key to successful catch-up for latecomer enterprises lies in their ability to leverage inherent advantages through innovation and strategic adaptation. This success depends not only on whether the window of opportunity is opened, but also on whether late-developing countries or enterprises and their institutional components respond effectively to the window of opportunity.

Incumbents typically possess superior resources and capabilities compared to latecomers. However, for incumbents, adopting new technologies often entails higher costs, lower productivity, and poorer reliability than existing technologies. Those achieving maximum productivity from current technologies may be reluctant to take risks. Consequently, when new techno-economic paradigms emerge, incumbents may respond to windows of opportunity slowly or ineffectively, easily falling into the "incumbent's trap" (Lee & Malerba, 2017).

In contrast, latecomers have the freedom to choose whether to adopt emerging technologies, and even if they make the wrong choices, their sunk costs remain relatively low. The responsiveness of latecomers to opportunity windows determines whether they can fully leverage their latecomer advantages to achieve catch-up. This primarily encompasses the following aspects. First, the ability to identify opportunities, which refers to the core competence of enterprises in scanning the environment and interpreting technological or market signals. For example, Huawei employs a "Strategic Reserve" mechanism specifically tasked with identifying emerging technological opportunities. Second, the speed of resource mobilization, including the capacity to rapidly allocate financial resources and redeploy human resources. For instance, during the smartphone demand window, Xiaomi quickly scaled up production capacity through "blitzkrieg"-style supply chain integration. Third, organizational adaptability, which is the ability of enterprises to adjust their structures and drive cultural change to support strategic transformation. For example, in its green transition, Gree Electric established an independent new energy division to circumvent innovation resistance from traditional business departments. These micro-level mechanisms determine whether enterprises can translate macro-level opportunities into tangible competitive advantages and are key to explaining the differences in catch-up performance among different firms within the same industry.

Moreover, the case of Motorola illustrates this point. Despite the advent of digital technology, the company persisted in refining its existing analog communication technology and even continued investing heavily in analog mobile phone technology. It mistakenly believed that consumers would consistently accept its dominant technological path(Giachetti, 2013).However, if the incumbent can leverage exceptional capabilities and abundant resources to navigate the new wave of technological advancements, continuously enhance its competitiveness, address the various alternative directions of technological change, and succeed in developing new technologies and establishing industry standards, it remains highly likely to maintain its leadership position.The best evidence comes from Samsung Electronics, which replaced Japan as the new leader in the 1990s and has maintained its dominant position in the memory chip industry for over two decades (Shin, 2017).

Beyond individual firms, other components of the incumbent sectoral system may also fail to respond effectively to windows of opportunity. Numerous cases demonstrate that research or training organizations, financial systems, governments, and other institutions in developed countries often exhibit delayed responses when windows of opportunity emerge. For instance, education systems may remain confined to obsolete technologies, financial support may be too short-sighted to fund anything beyond existing technologies, regulations may prove overly restrictive, and public policies may lack vision by favoring only low-risk R&D projects.

5.2 Bridging the "Standardization Gap" and Developing Technical Standards

By consolidating the meaning of technological products into a shared understanding, standards serve to stabilize the variability of technological change and direct it toward specific trajectories, thereby shaping technological pathways. When standards that influence the pace and direction of technological change become established, latecomer firms face reduced risks in committing to particular technological trajectories and find it easier to develop complementary products and services (Lee, Lim & Song, 2005). Technical standards represent codified specifications that harmonize technical requirements within standardized domains. As primary drivers of technological convergence, they create catch-up opportunities for latecomer firms while undergoing iterative updates throughout technology lifecycles (Kim, Lee & Kwak, 2017) .

International technical standards serve as crucial means to enhance corporate competitiveness, promote high-quality economic development, and participate in global economic governance. However, as Western developed countries have long dominated the formulation of international technical standards with strong systemic advantages and standard-setting discourse power, developing country firms often face a "standardization gap"—even when achieving internationally advanced technological capabilities, their influence in international standard-setting remains weak (Schott & Schaefer, 2023). Therefore, alongside technological advancement, latecomer firms must transform advanced technologies into standards and leverage technological superiority to accelerate standard iteration and upgrading, thereby increasing their international standard-setting influence.

5.3 Integrating Internal and External Resources to Achieve Collaborative Development

Windows of opportunity are closely linked to corporate strategy, relating to technology and knowledge, demand conditions, catch-up cycles and public policies/institutional arrangements. During catch-up, latecomer firms should align suitable strategies with their development stage and external environment to better utilize latecomer advantages. Some studies combine windows of opportunity with internal resources, noting that effective utilization requires corresponding internal capabilities. China's smartphone industry exemplifies this (Guo, Zhou & Cai, 2016), the early stage of industrial catch-up primarily relied on external knowledge and complementary assets, while the later stage requires the support of internal innovation capabilities. Tong et al. (2024) propose that latecomer catch-up involves two phases: initial catch-up and leadership maintenance. Firms first internalize windows of opportunity and align with strategic trajectories to reduce gaps with incumbents, then transition from

dependence to independence through enhanced innovation. This dynamic process transforms latecomers from "imitators" to "pioneers."

Government and research institution support proves equally critical. While inter-firm collaboration and knowledge sharing face limitations, governments can aggregate resources across channels and provide legitimacy for major projects. R&D funding supports firms in scaling up and improving product quality, while regulatory functions facilitate standardization implementation. For instance, during digital TV development, Korean consortiums monitored standardization processes among developed country incumbents, enabling domestic firms to develop compatible products (Lee et al., 2005). India's IT service sector benefited from policies restricting foreign firm expansion, fostering unique business models (Lee et al., 2014). Cases from China's telecom equipment (Mu & Lee, 2005) and Korean/Taiwanese high-tech industries (Lee & Lim, 2001;Mathews, 2002) further demonstrate government's pivotal role. Therefore, latecomer firms should promptly identify open windows of opportunity and leverage them to enhance their competitiveness. They need to integrate internal and external resources while ensuring efficient resource utilization. And it is imperative to strengthen organizational learning, boost innovation capabilities, and focus on specific technological domains or market segments to drive corporate performance.

6.Conclusion

6.1 Research Limitations

This paper focuses on the theme of catch-up theory and its practical applications, reviewing foreign literature on this topic in terms of corporate catch-up strategies, industrial catch-up and windows of opportunity, and catch-up practices. While the windows of opportunity theory plays a significant role in explaining latecomer catch-up phenomena, and there is a substantial body of literature examining windows of opportunity in catch-up cycles, certain limitations remain. First, some studies suffer from ambiguities in key concepts, application boundaries, and mechanisms of action. The research hierarchy regarding windows of opportunity in catch-up processes is not clearly defined, and the relevance of research content remains relatively weak. Second, while studies focusing on individual countries or specific industries facilitate cross-sectoral comparisons and help examine the unique characteristics of intergovernmental organizations, allowing analysis of how sector-level differences in factors like technological dynamics, market conditions, and institutional frameworks shape catch-up trajectories, they often fail to thoroughly assess whether their findings apply to other nations or industries with similar characteristics. This limitation weakens the generalizability of research conclusions and hinders the practical application of theoretical outcomes. Third, existing research largely neglects the process of standard-setting during technological catch-up and the enhancement of international technical standard discourse power. Some literature merely treats the formation and internationalization of technical standards as an inevitable outcome of latecomer firms' improved technological capabilities, without conducting in-depth analysis of the underlying mechanisms.

Fourth, there is insufficient exploration of the micro-level interactions between windows of opportunity and enterprises. Studies have yet to adequately examine the finer dimensions of windows of opportunity or develop systematic research on the technological catch-up pathways of latecomer firms. This gap limits our understanding of how different types of windows of opportunity influence corporate strategies and outcomes at the operational level.

6.2 Future Prospects and Recommendations

In terms of the impact of the sustainable development and green economy paradigm shift. The global transition toward a green economic paradigm has positioned green development and its associated industrial-technological revolution as a new driving force to pull the world economy out of downturn and into prosperity. The "Green Window of Opportunity (GWO)" provides emerging economies with a critical chance to attain leadership in new sustainability-related industries (Mathews, 2018; Lee, 2019; Yap & Truffer, 2019). However, given the continuously rising global sustainability requirements, knowledge-centric strategies are becoming increasingly limited. The green techno-economic paradigm will reveal new long-term economic and social trends, presenting latecomers with the dual challenge of promoting economic growth while addressing environmental sustainability issues. Currently, high-quality research in this area remains scarce, necessitating in-depth exploration. Under the "standardization gap" scenario, latecomer nations and enterprises encounter challenges in participating in international technical standard-setting. Future research should conduct in-depth, substantive studies on enhancing latecomer firms' influence in international technical standards. This would improve the explanatory power of windows of opportunity theory and its accuracy in interpreting catch-up practices in high-tech industries.

The global technological, market, and institutional environments are undergoing fundamental transformations. This "unprecedented changes unseen in a century" has presented China with significant windows of opportunity. Chinese latecomer firms have achieved globally remarkable results in catch-up and leapfrogging. However, few international studies have examined the contextual particularities, theoretical innovations, and practical breakthroughs—even leadership—of Chinese firms' catch-up processes based on the evolutionary logic of China's innovation-driven transition from catch-up to leapfrogging (Wu & Wu, 2023). Research on the characteristics of latecomer catch-up and innovation in the Chinese context requires further deepening.

And further expansion can be undertaken regarding the theoretical framework of windows of opportunity and its logical implications. This includes enhancing the analysis of how segmented dimensions of windows of opportunity at different research levels function in the catch-up process of latecomer enterprises, as well as conducting in-depth examination of how windows of opportunity at various tiers interact and even transform. Clarifying the specific mechanisms through which windows of opportunity operate is essential. Moreover, given the interdisciplinary and comprehensive nature of research on windows of opportunity in economic and technological catch-up contexts, there should be continued refinement and expansion of relevant research tools and methodologies. Equal emphasis should be placed on case studies and econometric empirical analysis, with

increased focus on mechanistic analysis of different types of windows of opportunity within the same industry, alongside enhanced comparative studies of international cases.

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