Industiral and Technological Catch-Up and Global Competition: the EU and China compared with US Since 2001

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Introduction

Industrial and technological competition has become one of the important issues of global politics and economy in the 21st century. For a long time, the United States has maintained an economic and technological leadership in the global value chain with its first-mover advantage in key industries and technology. At the same time, since joining the WTO in 2001, China has made remarkable progress in industrialization and technological upgrading and has gradually grown into an important global technology competitor. The improvement of the national coordination capacity, the expansion of the scale of the manufacturing industry and the continuous promotion of industrial upgrading have jointly promoted this development process. In contrast, although the European Union still has a strong industrial foundation and strong scientific research strength, its competitive advantage is facing increasingly severe challenges in the new technological competition environment.

Based on this background, the core question of this article is: Since 2001, why has China's progress in industrial and technological catch-up surpassed that of the European Union, while the technological frontier represented by the United States has continued to maintain a leading position? This article believes that this difference is not only related to the ability to innovate itself, but also closely related to the interaction between national capabilities, policy coordination, industrial ecosystems and dynamic mechanisms to promote the continuous accumulation of technology. With the intensification of global value chain competition, whether an economy can effectively integrate institutional resources, industrial capabilities and technological innovation resources is becoming an important factor affecting its long-term technological competitiveness.

To analyze the above problems, this paper adopts the research perspective of comparative political economy and builds a multi-level analysis framework including macro system, medium-view industrial structure, cumulative dynamic mechanism and technical achievements. The full text is divided into three main parts: the first chapter introduces the research background, literature review, research problems and research methods; the second chapter builds a theoretical analysis framework and explains the relationship between the main research variables; the third chapter uses the framework to compare and analyze the development path of the United States, China and the European Union; finally, the conclusion part is general It summarizes the main research results and further explores its significance for understanding industrial and technological competition in contemporary global political economy.

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Chapter1: Problematization

1.1 Research Background

Before the arrival of the 21st century, the European Union has long been regarded as one of the most important industrial and technological centers in the world. Europe not only has a developed manufacturing system and advanced scientific research foundation but also has cultivated a number of internationally competitive enterprises in the fields of automobiles, aerospace, machinery manufacturing and telecommunications. For a long time, Europe and the United States have jointly occupied an important position in the global economy.

After entering the 21st century, the global industrial and technological competition environment began to change. The rapid development of digital technology, semiconductors, artificial intelligence and platform economy has promoted the adjustment of the industrial and technological competition pattern. The United States relies on digital platform enterprises and highly integrated technology ecosystems to continue to maintain its leading position in the global field of science and technology; while China relies on industrial policy guidance, manufacturing expansion, infrastructure construction and continuous technical learning to continuously improve its industrial and technical strength and gradually grows into an important scientific and technological competition. In contrast, the European Union faces greater pressure in responding to this round of technological change. Although Europe still has an advanced industrial base and strong scientific research capabilities, compared with the United States and China, there is still a certain gap in the development speed and market influence of some emerging technologies and digital industries.

1.2 Literature Review

1.2.1 Industrial and technological catch-up

The concept of industrial and technological catch-up was originally closely related to the theory of 'advantages of backwardness' proposed by Gerschenkron (1962). The theory believes that less advanced economies do not necessarily need to completely copy the development path of leading countries but can achieve industrialization and economic growth in a relatively short time by absorbing and introducing existing technologies. However, it doesn't mean catch-up is an automatic process. Abramovitz (1986), put forward the concept of 'social capacity', pointing out that institutional arrangements, governance capacity and social organizational structure will directly affect whether a country can effectively use external technologies and complete domestic industrial transformation. Since then, relevant research on developing countries has paid more attention to the role of the country in the process of industrial upgrading. Wade (1990) believe that for underdeveloped economies, industrial policies and government intervention are often important conditions for cultivating domestic industrial capacity and enhancing international competitiveness.

After entering the 21st century, the research on catch-up theory began to pay more attention to the impact of technology diffusion and learning and global economic integration. Keller (2004) pointed out that technology diffusion provides an important channel for underdeveloped economies to acquire advanced knowledge and production technology, thus promoting industrial upgrading. At the same time, León-Ledesma (2002) proposed that catching up should be understood as a dynamic process of continuous accumulation, the core of which lies not only in technical imitation, but also in continuous learning and improving ability through production practice. Relevant studies also explore different policy tools and development mechanisms. For example, the 'flying geese' model explains how industries can be transferred between different economies and promote industrial upgrading in the global value chain; the infant industry emphasizes that in the early stage of industrial development, moderate protection and government support are crucial to cultivating domestic competitiveness (Zambakari , 2012).

The concept of catch-up has then been widely used to explain the development experience of late-industrializing economies, especially in the study of developing countries and emerging economies. Due to insufficient institutional capacity, structural constraints and high dependence on the international market, Latin American countries tend to show greater volatility and uncertainty in the catch-up process (Tzeremes, 2019). A study of Mexico by Kehoe and Meza (2011) shows that some economies still face serious vulnerability to economic development in a global competitive environment. In existing studies, East Asia is usually regarded as one of the most successful regions in technological catch-up. Japan's post-war industrialization process is considered an important starting point for this development model, which is characterized by the close connection between national coordination and industrial upgrading (Samuels, 1994). Subsequently, the 'Asian Tigers' have achieved rapid economic growth and industrial upgrading through export-oriented industrialization and continuous productivity improvement. In recent years, China has gradually become one of the most concerned cases in the research of catch-up theory. More and more literatures have begun to discuss China's industrial upgrading process and link it with state intervention, global production networks, and development strategies that combine 'Bringing-in' and 'Going Global' (Komesaroff, 2017). China has gradually grown from a latecomer economy to an important participant in global technology competition, which has also made it an important research object for catch-up theory.

In contrast, the relevant research on developed economies such as the European Union is relatively limited. The existing literature generally believes that although the European Union has a strong economic foundation, advanced industrial system and high scientific research capabilities, in the process of fast-paced competition with the United States, China and other scientific and technological powers, it still faces problems such as governance fragmentation, insufficient policy coordination, and limited industrial integration capacity. This phenomenon shows that institutional arrangements and policy coordination not only affect the catch-up of underdeveloped economies, but also the relative position of developed economies in a new round of technology competition.

1.2.2 Industrial policy and development models

China: State-led development model and industrial policy

Existing studies show that government intervention and long-term industrial planning have always dominated China's economic growth and technological upgrading. Most of the research on China's early industrialization and technology catch-up focuses on technology introduction and its localization process. Conroy (1984) pointed out that in the early days of reform and opening - up, the Chinese government introduced foreign technology, thus promoting industrial modernization. At this stage, the state plays an important role in the rational allocation of resources and the vigorous coordination of external technical resources and the construction of the domestic production system. With China's gradual integration into the global economy, the combination of 'Bringing-in' and 'Going Global' strategies enables China to continuously improve domestic industrial production capacity while integrating into the global value chain. At the same time, industrial policies, export-oriented growth and large-scale infrastructure construction are also considered to be important factors in promoting structural transformation and improving the competitiveness of the manufacturing industry (Gurol, J. 2022).

In recent years, more and more studies have begun to pay attention to China's transformation from technology-introduction development to local innovation-driven development. "Made in China 2025" is generally regarded as an important sign of this transformation. Its goal is to promote the development of advanced manufacturing, artificial intelligence and other strategic industries, and promote the upgrading of industrial structure (Gurol, J. 2022). Some studies believe that this reflects the strong long-term planning ability of the Chinese government; at the same time, it has also triggered discussions about the extent of state intervention and the impact of international competition, especially in the context of Sino-US technology competition (Glaser, 2019). In addition, the construction of science and technology industry policies and innovation systems under the coordination of the state has also attracted much attention. The growth of R&D investment and the continuous support for key industries have played an important role in improving technical capabilities. Industrial policies play a significant role in promoting the formation of regional industrial clusters and industrial upgrading. In general, the existing literature generally believes that although China's development model has gradually shifted from simple technology introduction to innovation-driven, the leading role of the Chinese government in industrial upgrading and economic transformation is still very prominent.

United States: Market-led and strategic government intervention

The study of U.S. industrial policy is usually described as a development model in which market mechanisms coexist with government support. Compared with highly concentrated industrial planning, Goodman (2020) pointed out that the U.S. government's support for industrial development is mainly achieved through defense procurement, public research and development funds and industry-academic cooperation, with less direct intervention in enterprise management.

Lincicome and Zhu (2021) believe that this model allows private enterprises to maintain a dominant position in innovation activities, while the government plays a more supporting and guiding role. The innovative ecosystem is one of the important features of the American model. There is a close relationship between public scientific research funds, scientific research institutions and science and technology enterprises to jointly promote technological innovation and commercialization. Goodman (2020) pointed out that the U.S. government usually does not directly select specific enterprises to support but is more inclined to create an institutional environment conducive to innovation and development. This model is especially obvious in high-tech industries, with a strong complementary relationship between public investment and market vitality.

With the increasingly fierce competition in science and technology between China and the United States, relevant studies have begun to pay attention to the changing trend of U.S. industrial policies in recent years. The Chip and Science Act is regarded by many scholars as an important sign of the adjustment of U.S. industrial policy. The bill focuses on improving the semiconductor production capacity of the United States, strengthening supply chain security, and reducing dependence on overseas manufacturing. At the same time, the link between industrial policy and national security is getting closer and closer. Measures such as restricting enterprises from expanding advanced production capacity and strengthening export control in China show that technological competition and geopolitical strategy are intertwined. However, some studies point out that the current policies of the United States still face problems such as high manufacturing costs, limited subsidy efficiency, and insufficient policy coordination. In general, the development model of the United States at this stage not only emphasizes the improvement of domestic technical capabilities but also emphasizes maintaining its technological advantages through export controlM and international cooperation.

European Union: A Regulatory and Coordinated Industrial Model

The study of the EU's industrial and technological policies usually emphasizes its governance characteristics with regulatory and coordination as the core. Tagliapietra and Veugelers (2020) pointed out that European industrial policy has shifted from post-war state-led intervention to market integration and competition orientation. In this process, the construction of a single market and the coordination of rules have gradually become an important basis for industrial development. However, with the intensification of global technology competition, the European Union has begun to re-emphasise industrial policies in recent years, especially in the field of strategic high-tech.

European Industrial Strategy reflect this trend of change. Semiconductors, artificial intelligence and digital infrastructure are listed as important areas to improve European competitiveness, while relevant policies rely more on regulatory frameworks and coordination mechanisms to promote implementation, such as Important Projects of Common European Interest (IPCEIs) and the EU-level industrial funding program, etc. These measures not only reflect the EU's concern for technological sovereignty, but also its desire to improve industrial competitiveness while maintaining the principle of open market (Tagliapietra & Veugelers, 2020).

At the same time, "Industry 4.0" and digital transformation have become important issues of EU industrial policy. The European Union attaches more and more importance to technology diffusion, cross-border cooperation and innovation ecosystem construction, rather than directly supporting individual enterprises. Tools such as data governance rules, digital market supervision and standard setting have gradually become important means to promote industrial upgrading. This practice shows that the European Union is more inclined to rely on institutional coordination and rulemaking to influence industrial development than to adopt a highly centralized industrial intervention model.

1.2.3 Literature Gap

The existing research on industrial policies, developmental state, innovation systems and technological competition has accumulated rich results, but there is still a certain degree of disconnect between different research fields. On the one hand, some studies focus on the role of state intervention and industrial policies, while others pay more attention to the market-driven innovation process. There is still a lack of systematic explanation of how national coordination affects the formation of industrial ecosystems in the process of long-term development, which in turn affects the accumulation of technology and industrial upgrading. On the other hand, most of the existing literature analyzes the situation of the United States, China or the European Union respectively. The relevant comparative research on the different catch-up paths presented by China and the European Union in the face of the technological frontier represented by the United States is still relatively limited.

At the same time, how the interaction between dynamic mechanisms such as macro-level institutions arrangements, meso-level industrial structures, and dynamic mechanisms such as economies of scale, learning-by-doing, network effects, and first-mover advantages in shaping long-term technological competitiveness and positions within global value chains has not been fully explored. Existing research usually focuses on a single-level explanation, and less examines the links between systems, industrial ecosystems and technological development from a cross-level perspective.

Based on the current situation of the above research, this paper tries to build a multi-level analysis framework that combines institutional coordination, industrial ecosystems and technological accumulation dynamics to explain why China has made more significant progress in industrial and technological catch-up than the European Union since 2001. This article believes that technological competition is not only related to innovation ability itself but also affected by the ability of state organization and coordination of industrial resources. For contemporary economies, the ability to build a large-scale, closely linked industrial and technological ecosystem with sustainable expansion is increasingly becoming an important factor in determining long-term competitive advantages.

1.3 Research Questions

The central research question of this study is:

Why has China achieved more successful industrial and technological catch-up than the European Union relative to the technological frontier represented by the United States since 200?

To answer the above question, this paper has built a multi-level analysis framework, focusing on macro-level institutions, meso-level industrial structures, dynamic mechanisms of technological competition, and technological outcomes within the global political economy. Based on this framework, this study further explores the following sub-questions and hypothesis:

Sub-Question 1
How do differences in state capacity, policy coordination, and innovation systems shape industrial and technological development in the United States, China, and the European Union since 2001?
Hypothesis 1
Stronger state capacity and more coherent policy coordination facilitate industrial upgrading and technological catch-up.

Sub-Question 2
How do industrial clusters, technological ecosystems, and network-based industrial structures contribute to cumulative technological development?
Hypothesis 2
Large-scale industrial ecosystems and network-based technological infrastructures reinforce cumulative technological advantages through industrial concentration and technological integration.

Sub-Question 3
How do economies of scale, learning-by-doing, network effects, and first-mover advantages generate cumulative technological dynamics under global competition?
Hypothesis 3
Economies of scale, learning-by-doing, network effects, and first-mover advantages generate self-reinforcing technological dynamics that strengthen long-term competitiveness.

Sub-Question 4
Why has China developed stronger cumulative technological catch-up dynamics than the European Union since 2001?
Hypothesis 4
China's stronger manufacturing scale, centralized coordination, and industrial ecosystem integration have enabled more successful technological catch-up than EU since 2001.

Sub-Question 5
How do different institutional structures, industrial ecosystems, and cumulative technological dynamics shape long-term technological competitiveness and positions within global value chains?
Hypothesis 5
Fragmented governance structures and weaker ecosystem integration limit the European Union's ability to generate cumulative technological competitiveness under global competition.

These sub-questions and hypotheses provide the basis for the comparative analysis conducted in the following chapters. By integrating macro-level institutions, meso-level industrial structures, dynamic mechanisms, and technological outcomes, this thesis aims to explain why the United States, China, and the European Union have experienced increasingly divergent trajectories in the global technological economy since 2001.

1.4 Methodology

1.4.1 Comparative Political Economy Approach

This article analyzes the different development orientations of industrial and technological capabilities in China, the United States and European Union under different institutional arrangements. Rather than treating technological development as a purely market-driven process, the thesis emphasizes the interaction between state institutions, industrial structures, and technological ecosystems in shaping long-term competitive advantages.

1.4.2 Comparative Case Study Design

This article chooses the United States, China and the European Union as comparative cases because they have formed different governance paths in the process of industrial and technological development. The United States mainly embodies the market-oriented innovation model, supplemented by strategic state intervention; China is mainly characterized by the state-led development model; the European Union relies more on regulatory coordination and institutional governance to promote industrial development. This difference shows how different institutional arrangements affect industrial and technological development and competitiveness formation.

1.4.3 Multi-Level Analytical Framework

This study constructs a multi-level analysis framework to examine the development process of industrial and technological competition. At the macro level, it pays attention to institutional factors such as national capacity, policy coordination and innovation system; at the meso level, it analyze the organizational characteristics of industrial clusters, enterprise networks and technology ecosystems; at the dynamic level, it examine the role of mechanisms such as economies of scale, learning-by-doing, network effects and first-mover advantage. Factors at different levels are interrelated, which jointly affect the formation of technological leadership, industrial catch-up and the development of long-term competitiveness.

1.4.4 Path Dependence and Historical Perspective

This article analyzes industry and technology competition from the perspective of path dependence and historical development and understands technological leadership and industrial catch-up as a long-term accumulation process. This process is not only influenced by institutional evolution, but also closely related to industrial restructuring and ongoing policy coordination. The advantages formed in the early stage of innovation system, manufacturing scale and technical infrastructure tend to accumulate in the subsequent development through mechanisms such as learning-by-doing, economies of scale and network effects, thus affecting industrial upgrading and technical capacity improvement. Based on this analytical perspective, this article tries to explain the different development results of the United States' long-term technological leadership, China's rapid catch-up and the European Union's lag.

Chapter2: Theoretical and Analytical Framework

2.1 Conceptual Definitions

2.1.1 State Capacity

In the process of industrialization and technology catching up, state capabilities are often regarded as the core factors affecting the effectiveness of development. This study believes that the government's ability to design, coordinate and implement industrial policies refers to whether it has the ability to carry out long-term strategic planning and organize resource mobilization through market intervention. Whether state institutions and their operating mechanisms can play an effective role often has an important impact on national industrial transformation (Evans, 1995; Weiss, 1998). At the same time, state ability cannot be simply equated with economic strength. Although economic resources provide the necessary conditions for industrial development, it does not mean that state intervention can automatically work. Judging from the concept of "embedded autonomy" proposed by Evans (1995), whether state capacity can play a role depends on the organizational structure, and it closely related to the relationship between the government and various economic entities. Weiss (1998) also pointed out that the key to state capacity does not lie in the number of resources, but in the ability to allocate resources. Judging from the development experience of less developed countries, some countries with relatively limited resource conditions can also rely on strong national policy arrangements to promote industrial upgrading and achieve economic catch-up in a relatively short time (Amsden, 1989; Wade, 1990).

Therefore, state capacity can be quantified through three indicators: (1) the degree of state intervention in strategic industries, including subsidies, protection policies and support for "national champion enterprises", which reflects the extent to which the state actively promotes industrial upgrading; (2) whether there is a long-term plan, such as the national industrial strategy and plan, to examine whether the government has adopted long-term and forward-looking policy arrangements to promote technology catch-up; (3) The ability to mobilize financial and institutional resources, including the use of public investment, development banks and policy tools to support innovation and industrial transformation.

2.1.2 Policy Coordination

While state capacity determines whether governments can intervene, policy coordination determines whether such intervention is coherent and effective. For example, the multi-level governance framework helps to understand the more complex institutional arrangements of the European Union (Hooghe and Marks, 2001). The coordination ability at the governance level has become an important factor affecting the competitive advantage. Once there is a lack of effective coordination between different policy subjects, the implementation process of industrial strategies may be constrained, which will adversely affect the overall competitiveness.

This dimension is often quantified through three indicators: (1) the concentration of decision-making, which is used to examine whether industrial policies are coordinated by central institutions or scattered among multiple subjects; (2) the degree of coordination between governments at different levels, especially the degree of coordination between national, regional and institutions; (3) policy fragmentation or inconsistency is used to observe whether the overlap and conflict of laws and policies hinder industrial development. With the help of these indicators, the differences between centralized systems such as China and relatively decentralized governance structures such as the European Union can be compared more clearly.

2.1.3 Innovation Systems

Innovation ability has gradually become an important factor affecting the competitive advantage and leadership of the global industry. Studies by Freeman (1987) and Nelson (1993) show that the ability to interact effectively between governments, enterprises and scientific research institutions will greatly affect the development of innovation activities. On this basis, the Triple Helix model further enriches the relevant analysis framework, pointing out that the collaborative mechanism also plays an important role in promoting innovation activities (Etzkowitz and Leydesdorff, 2000). With the increasingly fierce competition in global technology, the role of the innovation system is no longer limited to technological innovation itself, but also the ability to move up global value chains and sustain long-term competitiveness.

This article selects three indicators for analysis: (1) R&D investment, which is used to examine the scale and intensity of investment in innovation activities; (2) The close contact between the government and enterprises, which is used to evaluate the level of cooperation and policy support, so as to evaluate the development of innovation activities; (3) Technology diffusion and business efficiency is used to examine the ability to transform innovative achievements into industrial performance and global competitiveness.

2.2 Theoretical Overview

2.2.1 Catch-up Theory

Catch-up theory mainly focuses on how late-developing economies can gradually narrow the gap in technology and industry with developed economies through technical learning, industrial upgrading and institutional transformation. Alexander Geshenkron (1962) made the earliest and most influential contribution to this theory. His view of advantage of backwardness is that less developed countries do not necessarily need to repeat the mistakes of developed countries but can achieve a faster industrialization process with the help of existing technological achievements. He also pointed out that post-industrialization is usually inseparable from strong institutional support, coordination and intervention at the national level.

Abramowitz (1986) further expanded the theory of catch-up through the concept of social capability. He believes that technology acquisition is important, but the factors that determine whether it can catch up are not limited to technology itself, but also include institutional capacity, education, industrial organization, and the ability to absorb and apply external knowledge. Armsden (1989), Wade (1990) and Evans (1995) believe that industrial policy and state coordination are important conditions for promoting technological upgrading and industrial transformation.

Recent research will link catch-up theory with innovation system, technological learning and globalization. Lee and Malerba (2017) believe that contemporary economies increasingly rely on the accumulation of innovative capabilities, the improvement of the technological ecosystem, and the effective participation in the global production network to catch up. From this perspective, catch-up is understood as a cumulative and institutionally embedded process shaped by industrial learning and long-term technological development.

2.2.2 Marshallian Industrial Districts

The concept of Marshallian industrial districts was first proposed by Alfred Marshall in Principles of Economics (1890). Marshall argued that firms located within geographically concentrated industrial clusters benefit from external economies of scale, specialized labour markets, supplier networks, and knowledge spillovers. According to Marshall, industrial concentration enhances productivity and innovation because firms can share technical skills, industrial knowledge, and production networks within localized industrial systems.

The core concept of this theory is the localization and diffusion of knowledge. Porter (1990) have further enriched the relevant research. They pay more attention to the role played by industrial clusters in innovation activities, professional division of labor and regional competitiveness improvement. From this perspective, the Marshallian industrial districts not only reveal the connection between industrial agglomeration and economic performance but also provides an important perspective for understanding the process of technological learning and industrial cumulative development. Continuous interaction and knowledge exchange in the industrial ecosystem will promote the innovation capacity to a certain extent and have a profound impact on improving the long-term competitiveness of the industry.

2.2.3 Network Economy

The concept of network economy was born in the booming digital technology, information system and platform industries at the end of the 20th century. Castells (1996) believes that modern economic activities are increasingly dependent on interconnected networks of information, production, finance and technology. From this perspective, economic strength depends not only on industrial production itself, but also on the ability to control technological infrastructure and communication networks. The core concept of network economy theory is network effect. Katz and Shapiro (1985) believe that as the number of users increases, the value of products, services or technology platforms will also increase. Therefore, digital platforms and technology systems often have the advantage of self-strengthening, which will improve market concentration and consolidate technological dominance over time. The theory explains how interrelated technology systems create cumulative competitive advantages in modern industrial competition and also emphasizes the growing importance of digital infrastructure and scale compensation in the contemporary global economy.

2.2.4 Learning by Doing

The concept of learning by doing was first proposed by the theoretical system of Kennedy Arrow (1962). He believes that the improvement of productivity and technological capability is gradually formed in the process of continuous accumulation of production experience. As enterprises and industries continue to carry out production activities, they will accumulate more technical knowledge, improve organizational efficiency, reduce production costs, and further enhance industrial capabilities. The theory emphasizes the cumulative nature of industrial learning. Through repeated production practice, enterprises can rely on experience accumulation to improve technical efficiency. Therefore, 'learning by doing' is closely related to economies of scale, productivity growth and technology upgrading. Krugman (1987) further linked the learning effect with international trade and industrial division of labor, believing that industry can gradually form a long-term competitive advantage by continuously reducing costs and accumulating industrial experience in the early stage of expansion. The theory further reveals the intrinsic connection between production experience, technical learning and long-term industrial competitiveness.

2.2.5 First-Mover Advantage

The concept of first-mover advantage mainly refers to the competitive advantage gained by an enterprise or economy by taking the lead in entering an industry or technology field, which is more prominent than that of the later one. Lieberman and Montgomery (1988) believe that pioneers can usually benefit from technological leadership, economies of scale, market dominance and influence on industry standards. Based on this logic, early entry into strategic industries often helps to build barriers to competition, making it more difficult for later to enter.

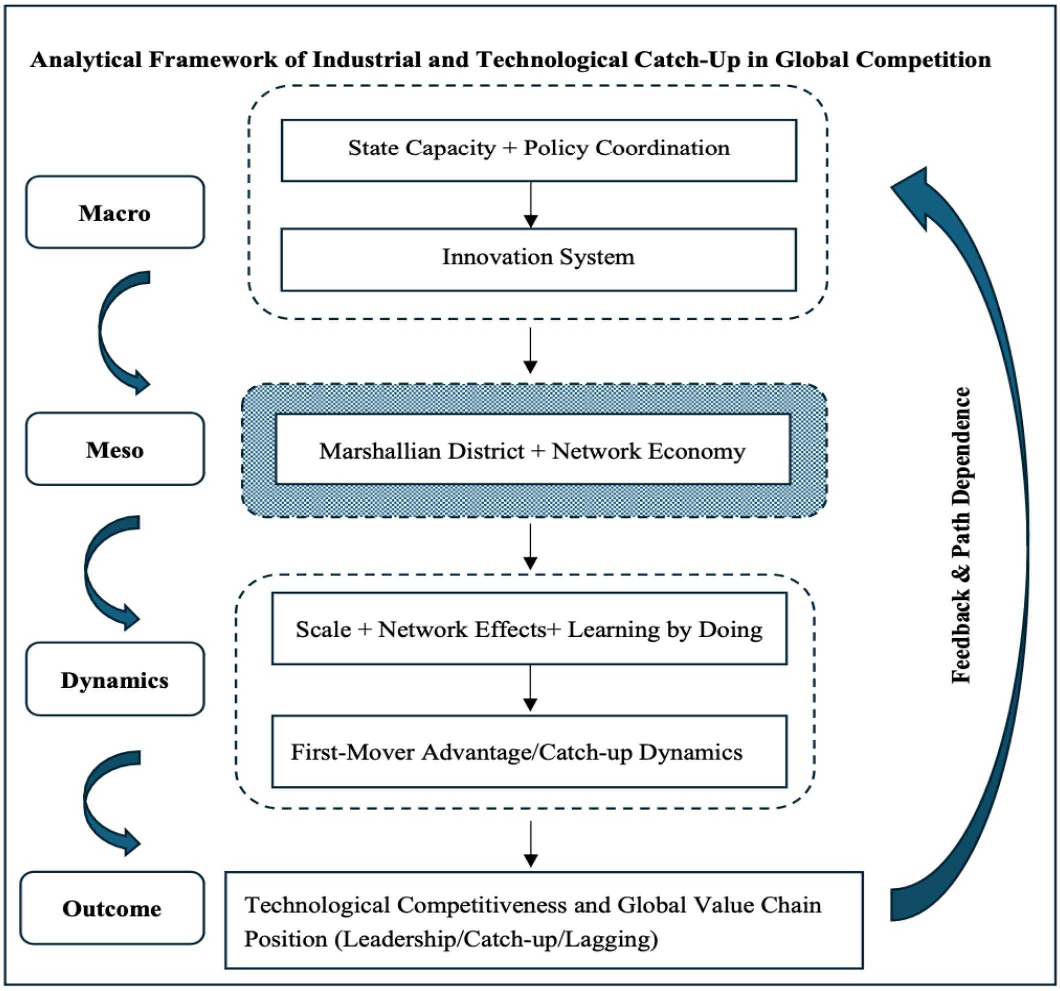
Path dependence is the core of the theory. Arthur (1989) pointed out that technology competition is often accompanied by a self-reinforcing dynamic process, and the advantages formed early will continue to accumulate over time and gradually become difficult to change. Especially in industries with the characteristics of scale effect and network effect, existing enterprises and their technical systems can usually rely on continuous expansion and user dependence to further consolidate their market position. From this perspective, the first-mover advantage is not only reflected in the leading time of market entry but also will continue to play a role through industrial accumulation, technology standardization and market self-strengthening mechanism, and eventually transform into a long-term competitive advantage.

2.2.6 Global Value Chain

The global value chain theory mainly focuses on how to better organize industrial production and technical activities by relying on international and decentralized production networks. Gereffi, Humphrey and Sturgeon (2005) believes that the global value chain is characterized by its hierarchical structure: leading enterprises control high value-added activities such as innovation, technical standards, brand building and platform coordination, while low-value-added production activities are scattered in other different economies. Follow-up research further found that the position of an economy in the global value chain is closely related to its technological capabilities and industrial upgrading level (Gereffi, Humphrey and Sturgeon, 2005). The economies that occupy the high value-added links of the global production network tend to have a more advanced innovation system, technological capabilities and stronger control over strategic industries. From this perspective, industrial and technological catch-up can be understood as a process of continuous progress, that is, the process of the economy gradually closing towards the links with higher added value and higher technology intensity in the global value chain.

2.3 Analytical Framework

This study constructs a multi-level analysis framework to analyze how the institutional structure shapes the industrial and technological competition in the contemporary global economy.



Source: Author’s own elaboration based on the theoretical literature reviewed in Chapter 2.

2.3.1 Macro level Institutions

The analysis framework starts from the macro level and focuses on state capacity, policy coordination and innovation system. These institutional arrangements affect the country's ability to formulate long-term industrial strategies and are also closely related to the allocation of financial resources, industrial upgrading and the development of innovation activities. The higher the level of institutional coordination, the more conducive it is to technology investment and industrial upgrading; while the innovation system connects the government, enterprises and scientific research institutions to jointly promote industrial and technological development.

2.3.2 Meso-Level Industrial Structures

Based on the above institutional conditions, the coordination at the macro level will further affect the industrial structure and industrial agglomeration mode at the meso level. Combined with the theory of Marshallian industrial districts and network economy, the analysis at the meso level focuses on the relationship between industrial clustering and technological development. A relatively perfect industrial structure can often form a professional labor market, supplier network and knowledge spillover effect, and create conditions for technical cooperation between enterprises and scientific research institutions. In this process, the industrial ecosystem contributes to the diffusion of knowledge and technical experience and gradually promotes the accumulation of innovative capacity. On the other hand, digital infrastructure, platform systems and interconnected technology ecosystems are also constantly strengthening the network-based economic structure. As more and more industrial activities focus on specific technologies and industrial networks, the meso-level industrial structure not only affects the interaction between enterprises but also provides a corresponding development environment for the continuous accumulation of industry and technical capabilities.

2.3.3 Dynamic Mechanisms

These industrial ecosystems will further form a series of cumulative dynamic mechanisms and continue to affect the development of industry and technology. Under this framework, economies of scale, network effects, learning by doing and first-mover advantages are important factors in promoting the cumulative of technological competition.

With the expansion of the production scale of enterprises and industries and the improvement of technical capacity, industrial knowledge is also constantly accumulating, thus promoting the improvement of productivity, the decline of costs and the enhancement of innovation capacity. At the same time, the network effect will enhance the utilization value of existing technology platforms and infrastructure, further expand their scope of influence, and strengthen the original technical advantages to a certain extent. From this perspective, industrial and technological competition is not a static market phenomenon, but a development process that gradually evolves in continuous accumulation and adjustment.

2.3.4 Technological Competitiveness and Global Value Chain Position

Institutional coordination, industrial ecosystems and cumulative dynamic mechanisms are not independent of each other, but influence and continuously interact with each other, jointly affecting technological competitiveness and the status of the economy in the global value chain. Economies with strong technological capabilities, innovation systems and industrial coordination are more likely to enter high value-added links in global production networks.

On the contrary, if the level of institutional coordination is insufficient or the accumulation of technical capacity is relatively limited, the economy is more likely to rely on external technology in the process of development, and its position in the global value chain may also be more concentrated in the low value-added production link. Technological competitiveness is not only related to the process of industrial upgrading but also has an important impact on the formation of technological leadership and the influence of the economy in the global strategic field.

2.3.5 Feedback Effects and Path Dependence

Finally, the long-term accumulated achievements of technological development will also have feedback to relevant countries. For economies that are already in a technological leadership position and occupy a higher position in the global value chain, this advantage can often further promote the development of innovation systems, attract more financial and technical resources, and promote the continuous accumulation of industrial clusters and technological capabilities. With the continuous advancement of these processes, the development of industry and technology will gradually show the characteristics of path dependence, making it easier to continue the advantages formed in the early stage. From this perspective, industrial and technological development is not a process of change that can be completed in the short term, but the result of gradual evolution and adjustment under the continuous influence of institutional continuity, technical learning accumulation and industrial dynamics.

Chapter3: Evolution and Comparative Analysis： United States, China, the European Union

Why has China achieved more successful industrial and technological catch-up than the European Union relative to the technological frontier represented by the United States since 2001?

3.1 Historical Evolution of Industrial and Technological Policy

3.1.1 United States

Historical Evolution of US Industrial and Technological Policy			
Period	**Governance Logic**	**Characteristics**	**Policies**
1776–1865	Protection of infant industries	tariffs, subsidies, protectionism, national market formation	Hamilton's *Report on Manufactures* (1791), National Bank, Canals and railroads
1865–1945	Mass industrialization, heavy industry	Fordism, Taylorism, standardized mass production, emergence of industrial giants	High tariff, Railroad expansion, New Deal
1945–1980s	National security-driven military–industrial technological leadership	Military-industrial complex, federal R&D, university–industry–government cooperation	DARPA, NASA, Defense procurement, Apollo Program
1980s–2008	Global value chain	WinTelism, ICT dominance, outsourcing, global, venture capital	Reagan-era deregulation, NAFTA, WTO, Silicon Valley
2008–Present	Strategic technological competition and industrial policy revival	Economic security, techno-nationalism, supply-chain resilience, reshoring, export controls, industrial subsidies	Obama's *Pivot to Asia*; Trump's Section 301 tariffs, Huawei sections, USMCA, and reshoring; Biden's CHIPS and Science Act, Inflation Reduction Act (IRA), Infrastructure Investment and Jobs Act (IIJA), semiconductor export controls, and Buy American policies

Source: Author's compilation based on Defraigne et al. (2022), Miller (2022), and Gerstel and Goodman (2020).

From 1776 to 1865, the industrialization of the United States relied mainly on the support of the federal government. Influenced by Alexander Hamilton's *Report on Manufactures* (1791), the government supported the local manufacturing industry through protective tariffs, subsidy policies, and infrastructure construction such as canals and railways, thus reducing dependence on British industrial products. From 1865 to 1945, the U.S. industrial system expanded rapidly, and the degree of integration of the domestic market continued to improve. The improvement of the railway network and the promotion of Fordism and Taylorism modes of production promoted the development of heavy industry and mass production, and the high tariff policy and the later 'New

Deal' program also consolidated the foundation for the development of industrial capitalism in the United States to a certain extent (Miller, C. 2022).

World War II and the Cold War (1945 to the 1980s) are often considered important stages of technological development in the United States. During this period, the military, universities and industry gradually formed a close connection, becoming an important source of technological innovation. Although the United States has long emphasized free market capitalism, the federal government has always participated in technological development through military procurement, defense research and public research and development investment. The procurement system of the Defense Advanced Research Projects Agency (DARPA), the National Aeronautics and Space Administration (NASA) and the Pentagon has had a profound impact on the development of semiconductors, aerospace, computer technology and the Internet, and has also made the military-working system occupy an important position in the formation of U.S. technological advantages (Defraigne et al., 2022).

After the 1980s, neoliberal globalization and financialization began to have a profound impact on the economic structure of the United States. From the 1980s to 2008, the global value chain capitalism and "Winterism" production models gradually became the dominant model (Defraigne et al., 2022). More and more manufacturing links have moved to East Asia, especially China, while American companies are more focused on high-value-added fields such as high-end innovation, software development, financial services, brand operation and intellectual property rights. At the same time, the deregulation policy promoted by the Reagan administration, the North American Free Trade Agreement (NAFTA) and the globalization process under the framework of WTO have jointly promoted a new international division of labor pattern, that is, American enterprises have mastered technology, standards and product design, while the manufacturing link is more many places have been transferred overseas (Miller, C. 2022).

After the global financial crisis in 2008, the pressures brought about by deindustrialization, supply chain dependence and the rapid rise of China's economy prompted the United States to re-examine its existing industrial policies. Since 2008, the industrial and technological policy of the United States has gradually shifted from neoliberal globalization to focusing more on technological nationalism and strategic industrial development. During the Trump administration, the United States introduced a series of protectionist and neo-mercantilist measures, including raising tariffs, implementing export controls in accordance with Section 301 measures. This policy imposes technical restrictions on Huawei and other Chinese enterprises. Since 2018, the competition between China and the United States in the field of technological nationalism has further intensified, and semiconductors and strategic supply chains have gradually become the focus of competition. Although the Biden administration attaches more importance to multilateral cooperation at the diplomatic level, it has generally continued this adjustment direction in industrial policy and strengthened it through state-led industrial investment. The Chips and Science Act, the Inflation

Reduction Act and major infrastructure programs all reflect the federal government's support for semiconductors, green technologies and advanced manufacturing. In general, contemporary U.S. industrial policies pay more attention to issues such as technological sovereignty, supply chain resilience and geopolitical competition (Miller, C. 2022).

3.1.2 China

Historical Evolution of China's Industrial and Technological Policy			
Period	**Governance Logic**	**Characteristics**	**Policies**
1949–1978	State-led socialist industrialization	Soviet-style central planning, Heavy industry	First Five-Year Plan, Great Leap Forward
1978–1990s	Market reform under party-state leadership	FDI, export-oriented and labour-intensive manufacturing, technology transfer, marketization	Reform and Opening-up, Special Economic Zones (SEZs), Technology" strategy
2000s	State-guided globalization and industrial upgrading	WTO accession, export boom, rise of Chinese MNEs, infrastructure expansion	Go Global Strategy, National champions，Indigenous Innovation (2006)
2010s	Technology-driven developmental state	Industrial subsidies, state financing, industrial clusters, high-speed rail, ICT	Made in China 2025, Strategic Emerging Industries, Belt and Road Initiative
Post-2018 / 2020s	Techno-nationalism, supply-chain security	US-China tech war, semiconductor localization, AI, ICT, robotics, EVs	Dual Circulation Strategy, 14th Five-Year Plan, New Generation Artificial Intelligence Development Plan (2017), semiconductor funds, "New Quality Productive Forces"

Source: Author's compilation based on García-Herrero, A. (2019), and Defraigne et al. (2022).

The historical evolution of China's industrial and technological policy has been closely connected to the country's transformation from a relatively underdeveloped socialist economy into a major industrial and technological power. Compared with the market liberalization development path emphasized by many western countries since the 1980s, China has always maintained a strong state-dominance feature, among which the Communist Party of China has played an important role in industrial upgrading and technology catching up for a long time. During the Mao era (1949–1978), China learned from the Soviet model to promote planned industrialization and to take heavy industry as the key direction of development. Policies such as the First Five-Year Plan also serve the construction of the industrial system during this period. Although the "Great Leap Forward" and the

"Cultural Revolution" had a great impact on economic operation, the industrial infrastructure formed during this period provided an important foundation for the subsequent industrialization process.

A decisive transformation occurred after the launch of Reform and Opening Up in 1978, China's development model has gradually changed. Export-oriented industrialization has become an important driving force for economic growth, and the establishment of Special Economic Zones (SEZs) has also made China more deeply integrated into the global production network. However, compared with the typical liberal reform path, the Chinese government did not abandon the guidance of strategic industries, but promoted technological learning and industrial capacity improvement by selectively attracting FDI. Policy practices such as joint ventures, localization requirements and technology transfer arrangements reflect the development concept of 'market-for-technology' (García-Herrero, A. 2019).

After joining the WTO in 2001, China's industrialization and technology catch-up accelerated further. Deep participation in the global value chain enables Chinese enterprises to accumulate technology on a larger scale. At the same time, the "Go Global" strategy of encouraging enterprises to invest overseas and obtain advanced technology has promoted the development of several "national champion" enterprises. The 'Indigenous Innovation' strategy put forward in 2006 shows that China has begun to pay more attention to improving independent research and development capabilities to reduce its dependence on technology on developed economies. After entering the 2010s, the focus of China's industrial policy turned to technological upgrading and strategic emerging industries. Semiconductors, artificial intelligence, ICT, robots, and electric vehicles are getting more and more attention.

The launch of "Made in China 2025" in 2015 symbolized the transition from manufacturing catch-up toward innovation-driven development and technological leadership. To achieve this goal, the government continues to use policy tools such as industrial subsidies, industrial cluster construction and long-term planning to guide enterprises to accelerate technological upgrading. Since 2018, Sino-US trade and technology competition have been escalating, which has had a significant impact on China. Against this background, the 'Dual Circulation Strategy' and the '14th Five-Year Plan' put semiconductor localization, technological autonomy, supply chain security and domestic innovation capacity building in the first place. Contemporary China's industrial policy is no longer only oriented by economic growth, but also further integrates considerations such as technological nationalism and strategic economic security (Defraigne et al. 2022).

3.1.3 The European Union

Historical Evolution of EU Industrial and Technological Policy			
Period	**Governance Logic**	**Characteristics**	**Policies**
1950s–1970s	State-led Reconstruction and Early European Integration	Postwar reconstruction, Fordism, Key sectors	ECSC, EEC, Common Market

1980s–1990s	Neoliberal and Single Market integration	Deregulation, privatization, competition policy, reduction of state aid,	Single European Act, Maastricht Treaty
2000s	Knowledge-based competitiveness Horizontal industrial policy(innovation-driven)	Innovation, R&D, labour flexibility, limited supranational coordination, digitalization	Lisbon Strategy, Europe 2020
Post-2008	Return of strategic industrial coordination	Deindustrialization debates, technological dependence, digital transformation, industrial alliances, sovereignty debates	Monti Report, IPCEI, Digital Strategy
Post-2019	Strategic autonomy and coordinated industrial governance ambitions	Green transition, supply-chain, semiconductor industrial alliances, supranational investment coordination	European Green Deal, NextGenerationEU, EU Chips Act, CBAM, Net-Zero Industry Act

Source: Author’s compilation based on Tagliapietra and Veugelers (2020) and Defraigne et al. (2022).

The development process of the EU's industrial and technical policy has changed from post-war development coordination to market-oriented governance, and strategic coordination and industrial support have been re-strengthened in recent years. In the post-war reconstruction stage of the 1950s and 1970s, state intervention, development coordination and European economic integration jointly influenced the development direction of European industry. The establishment of the European Coal and Steel Community (ECSC) and the European Economic Community (EEC) in 1951 provided a policy basis for regional industrial cooperation and economic reconstruction (Tagliapietra, S., & Veugelers, R. 2020). During this period, countries have widely used public investment, subsidies and coordination measures to promote the revival of heavy industry, the modernization of the production system and the development of strategic industries. Influenced by Fordism and the Cold War, European governments continue to protect their core industries while promoting industrial modernization and technological upgrading.

After the 1980s, with the promotion of single market construction and the spread of the neoliberal economic concept, the European economic governance model began to change, institutions are gradually promoting deregulation, privatization and competition. The Single European Act (1986) and the Maastricht Treaty (1992) further promoted the development of the single market and strengthened the market governance capacity at the supernational level. Compared with the past, industrial policies are increasingly emphasizing the principle of market efficiency and competition, state aid is more restricted, and the European Commission pays more attention to liberalization, capital flows and internal market competition (Tagliapietra, S., & Veugelers, R. 2020). Against this background, the focus of EU governance has gradually shifted from supporting the country's leading enterprises to market integration and competition policies, and industrial development is also more affected by market mechanisms and neoliberal economic integration.

Entering the 21st century, improving innovation and knowledge-based growth has gradually become an important direction for the European Union to enhance its international competitiveness. Both the Lisbon Strategy and the Europe 2020 Strategy try to promote the EU's transformation into a knowledge-based economy through R&D investment, digital construction and innovation-driven growth. At this stage, the policy focus is more on horizontal support measures than direct intervention for specific industries. EU institutions generally emphasize improving competitiveness, reforming the labor market and coordinating the market, and intervention in industrial cooperation at the transnational level is still relatively limited (Defraigne et al., 2022).

However, the 2008 global financial crisis exposed some long-standing structural problems in the European economy, including the trend of deindustrialization, underinvestment and dependence on external technology. At the same time, the rapid rise of China and the continuous expansion of the influence of U.S. digital platform enterprises have also significantly exacerbated concerns about the decline of European technological competitiveness. the EU's industrial and technological policies began to pay more attention to issues such as strategic coordination, technological sovereignty and industrial security. Through the IPCEI, industrial alliances and digital strategies, the European Union has strengthened its support for semiconductors, digital infrastructure and advanced manufacturing industries. Since 2019, the COVID-19 pandemic and increasing geopolitical tensions have further prompted the EU to place more important strategic autonomy, green transition and supply chain resilience. The launch of the NextGenerationEU recovery plan also reflects the new measures taken by the EU in supranational fiscal coordination and industrial investment. Policies such as the European Green Deal, the EU Chips Act, the Carbon Border Adjustment Mechanism (CBAM) and the Net-Zero Industry Act all show that the EU's attention to technology dependence, industrial vulnerability and geopolitical competition is increasing (Defraigne et al., 2022).

However, compared with the United States and China, the EU's industrial strategy still relies more on regulatory coordination, industrial alliances and market governance mechanisms than centralized industrial intervention, which is still institutionally constrained and fragmented.

3.2 Macro Level: Comparative Institutional Structures

How do the differences in state capacity, policy coordination and innovation systems between the United States, China and the European Union affect the catch-up of industry and technology? This section believes that stronger state capacity and more coordinated policy coordination can more effectively mobilize resources and coordinate the large-scale development of industries and technologies, thus promoting industrial upgrading and technological catch-up.

Table1. Macro-level Institutional Comparison

Dimension	United States	China	European Union	Outcome

State Capacity	Strong but indirect (R&D, defence)	Highly centralized	Fragmented across member states	US strategic, China centralized, EU fragmented
Policy Coordination	Relatively coherent	Highly centralized	Multi-level, fragmentation	US coherent, China coordinated, EU fragmented
Innovation System	Advanced private-led ecosystem	State-supported scaling ecosystem	Fragmented innovation structure	US leads, China scales, EU lags

Source: Author's own synthesis based on the literature and analysis presented in this study.

3.1.1 State Capacity: US, China, EU

As mentioned above, state capacity is mainly examined from three aspects: (1) the degree of state intervention in strategic industries; (2) whether there is long-term strategic planning; (3) the ability to mobilize financial and institutional resources to promote industrial upgrading.

The United States has a strong state capacity to promote industrial development through defense procurement, public research and development investment and innovative institution construction. After the global financial crisis in 2008, with the increasing attention of China's competition and supply chain dependence, industrial policies gradually returned to the important position of the U.S. strategy. The Advanced Manufacturing Partnership and the 'Pivot to Asia' strategies launched during the Obama administration aim to strengthen the manufacturing foundation and maintain technological advantages. The Trump administration has further strengthened technological nationalism and protectionism, reducing its dependence on China's supply chain through 301 tariffs, entity lists, semiconductor export controls and manufacturing reshoring policies. The Biden administration has expanded state intervention. The Chip and Science Act provides more than $50 billion in support for semiconductor manufacturing and R&D. the Inflation Reduction Act promotes the development of electric vehicles, batteries, renewable energy and clean technologies through subsidies and tax incentives. Combined with measures such as 'Buying American', the US government still has a strong ability to mobilize resources and continues to influence the development direction of strategic industries through policy tools (Miller, C. 2022).

China demonstrates the most centralized and interventionist form of state capacity among the three economies. After joining the WTO, industrial upgrading and technological catch-up have gradually been included in the core agenda of national development and coordinated by CCP. China relies more on long-term planning, administrative coordination and direct support for strategic industries. The National Medium- and Long-Term Program for Science and Technology Development (2006–2020), Indigenous Innovation, Made in China 2025 and the 14th Five-Year Plan and other policies reflect that the Chinese government vigorously promotes semiconductors, telecommunications and through various channels such as state-owned enterprises, policy banks, local governments and industrial subsidies. This development model provides a strong guarantee for industrial upgrading and technological capacity and has also enabled China to continuously improve its industrial and technical strength in the past 20 years.

The situation in the European Union is different. Compared with the United States and China, its national capacity is more reflected in the ability to coordinate under a multi-level governance system than in the ability to concentrate resources. Since the 1980s, EU governance has gradually focused on market liberalization, competition policy and regulatory integration, and industrial policy power has been distributed among EU institutions and member states. While promoting market integration, this institutional arrangement also limits the unified allocation capacity of the EU's resources and leaves the fragmented characteristics. After the crisis in 2008 and 2019, the pressure of international competition continued to rise, prompting the EU to pay attention to industrial policy issues again. Policies such as the IPCEI, the European Chip Act, the European Green Deal and the NextGenerationEU reflect the EU's desire to improve the competitiveness of the semiconductor, digital infrastructure, renewable energy and battery industries （MEGYERI, E., PELLE, A., & TABAJDI, G. 2023). However, due to the different positions of member states on fiscal integration and industrial investment, the EU faces certain constraints on industrial coordination. For example, Germany and the Netherlands are generally cautious about further expanding common fiscal spending, while countries such as Italy and Spain are more inclined to strengthen investment arrangements at the supranational level. These differences affect the promotion of the EU's unified industrial strategies and make it difficult for the EU to establish a highly concentrated industrial policy system and resource allocation system like China or the United States.

3.1.2 Policy Coordination: US, China, EU

According to the above-mentioned analytical framework, policy coordination is mainly examined from three aspects: the degree of concentration of decision-making, the level of coordination between different governance levels, and the degree of policy fragmentation.

Policy coordination in the United States does not rely on centralized planning but is more based on a network of cooperation between federal government agencies, research universities, defense departments, venture capital institutions and private enterprises. Especially after 2008, as the competition for science and technology between China and the United States continues to heat up, the U.S. industry and trade policies and national security are closely linked. The Trump administration's 301 tariffs, restrictions on Huawei and other enterprises, and export controls on advanced semiconductors and other measures show that the United States is gradually integrating scientific and technological competition into broader national strategic considerations. At the same time, after adjusting the NAFTA to the USMCA, the United States has also strengthened the layout of the North American supply chain by raising regional content requirements. The Biden administration continues this trend and further focuses on semiconductors, clean energy and supply chain security. The Chip and Science Act links federal subsidies to domestic production requirements, and the Inflation Reduction Act strengthens production through green manufacturing incentives and local-content rules to support industrial development. In addition, the export controls imposed on advanced AI chips and manufacturing equipment also show that the integration of technical policies and national security policies is increasing. The link between U.S. industrial policies, technological advantages and geopolitical goals is constantly strengthening.

China's policy coordination shows a stronger centralized feature. Industrial upgrading and technological catch-up are included in the national development strategy and promoted through the central-led hierarchical governance system. A closed coordination relationship has been formed between ministries, local governments, state-owned enterprises, financial institutions and key enterprises. Policies such as Made in China 2025, the Strategic Emerging Industries initiative, and the Dual Circulation Strategy reflect the concept of coordinating and promoting industrial policies, financial support, market expansion and technological upgrading under a unified framework. At the same time, local governments also play an important role in the process of industrial development, supporting strategic industrial development through financial subsidies, infrastructure construction and tax incentives. Shenzhen, the Yangtze River Delta region and Zhongguancun in Beijing and other places are relatively typical cases, forming high-tech industrial gathering areas. High policy coordination alleviates the problem of policy fragmentation, enabling resources to be more quickly concentrated in key industries such as semiconductors, telecommunications, artificial intelligence, batteries and electric vehicles.

The European Union presents another feature. Its policy coordination is based on a multi-level governance system, involving the joint participation of EU institutions, member governments and regional authorities at all levels. Compared with China's relatively centralized coordination model, EU industrial policies often require long-term consultation and compromise between member states, and there are significant differences in the economic structure and policy goals of each country. Since the implementation of the Single European Act and the Maastricht Treaty, EU governance has focused more on market integration, competition policy and regulatory coordination, and centralized industrial coordination has been relatively limited. After the 2008 financial crisis, the European Union began to strengthen its industrial coordination capabilities through measures such as the Lisbon Strategy, the Europe 2020, the Digital Strategy, the IPCEI Framework and the European Chip Act. The NextGenerationEU program launched during the COVID-19 pandemic has also further promoted discussions on strategic autonomy and supranational investment coordination. However, there are still differences between member states in terms of industrial policy and economic governance. France has long advocated strengthening European strategic autonomy and expanding industrial intervention, while Germany attaches more importance to market integration and export-oriented development; some Eastern European countries still maintain closed ties with the United States in the field of security and technology. Affected by these differences, the EU still faces challenges in transforming industrial strategies into unified and large-scale strategies.

3.1.3 Innovation System: US, China, EU

As mentioned above, the innovation system is mainly measured by three aspects: (1) R&D investment; (2) The close contact between the government and enterprises, which is used to assess the level of cooperation and policy support; (3) the efficiency of technology diffusion and commercialization.

The United States has the most influential innovation ecosystem in the world. Its advantages mainly come from research universities, venture capital systems, national defense scientific research networks and long-term cooperative relations between public and private enterprises. The formation of the American innovation system is closely related to the investment in military research and development during the Cold War. After entering the digital economy era, Microsoft, Apple, Google, Amazon, NVIDIA, Tesla and other enterprises have further promoted the development of this system. Since entering the 21st century, especially under the background that China is gradually becoming a major technological competitor, the link between innovation policies and strategic industrial goals has become increasingly close. The federal government has increased support for semiconductors, artificial intelligence, quantum mechanics and invested in computing, biotechnology and clean technology through the Chip and Science Act (Kilcrease, E., & Jin, E. 2022). Among them, the Chip and Science Act focuses on improving the semiconductor manufacturing capacity of the United States and strives to reduce dependence on the Asian supply chain. At the same time, the United States has also taken export control measures to restrict the export of advanced chips and semiconductor equipment to China. Compared with China and the European Union, the biggest feature of the U.S. innovation system is that its financial capital, entrepreneurial activities, digital platforms and technology commercialization are closely linked, which enables new technologies to complete large-scale expansion and enter the global market faster. However, the increased degree of financialization, the increased market concentration and the security of the supply chain have also made the United States pay more attention to state-supported and technological security-oriented innovative policies in recent years.

The development path of China's innovation system has changed from technology introduction to independent innovation. Since 2000, China has continued to increase investment in research and development, higher education, science parks and strategic industries, and strives to improve its independent innovation ability and core technology. Policies such as Thousand Talents Plan, Indigenous Innovation and Made in China 2025 have promoted cooperation between universities, scientific research institutions, state-owned enterprises, private enterprises and local governments, also attracted many overseas Chinese scientific research talents to return to China for development. Unlike the US, which relies more on venture capital and private enterprise innovation, China's innovation system pays more attention to industrial scale and technological coordination and upgrading under the leadership of the state. Relying on the huge domestic market and perfect industrial ecosystem, Huawei, BYD, CATL and other enterprises have gradually grown into globally competitive firms (KOMESAROFF, M. 2017). However, in terms of core technical capabilities, China still faces certain external dependence in some key areas, such as advanced semiconductors and high-end manufacturing equipment.

The European Union has significant advantages in scientific research base and talent resources, with a group of world-class scientific research institutions and a highly skilled workforce, but for a long time, innovative activities have been scattered in the markets and regulatory systems of various member states. After entering the 21st century, the European Union gradually focuses its innovation policy on R&D investment, digital construction and knowledge-based economic development. However, compared with the United States and China, the European Union still faces greater challenges in transforming scientific research results into science and technology enterprises with global influence and building a unified innovation ecosystem. The rapid development of large technology enterprises in the United States and China has also further showed Europe's external dependence on digital platforms and key technology infrastructure. At the same time, the differences in the level of development of innovation systems, the imbalance of investment capacity and the differences in industrial structure among member states have also weakened the ability to spread innovative achievements within the European Union. In recent years, the European Union has begun to pay more attention to technological autonomy and the construction of industrial alliances and continues to promote cooperation in the fields of semiconductors, batteries, artificial intelligence and clean technology. However, the relatively limited financial capacities and the difficulty of coordination among member states still constrained the speed of large-scale development of European technology and industrial catch-up（MEGYERI, E., PELLE, A., & TABAJDI, G. 2023).

There is a strong correlation between national capacity, policy coordination and innovation system. The United States and China have formed a relatively complete technological ecosystem and can promote the rapid industrialization and scale of innovative achievements. In contrast, although the European Union has a strong scientific research foundation, the fragmentation of its multi-level governance structure and innovation system still poses certain constraints on technology diffusion and industrial upgrading.

3.2 Meso-level Industrial Structures

The core contents of the middle-level industrial structure include industrial clusters, firm networks, production systems and technological ecosystems that connect governments, firms, universities, suppliers and users. This section combines the relevant views of Marshallian industrial districts theory and network economy theory to explore the reasons why different economies show different competitive advantages in industrial upgrading and technological development. Marshallian theory focuses more on the industrial advantages formed by geographical agglomeration, specialized labor markets, knowledge spillover and inter-enterprise cooperation; while the network economy theory points out that factors such as scale expansion, network connection, user interaction and data accumulation often form a continuous cumulative competitive advantage in the technology industry.

Especially in the fields of digital industry, semiconductors, artificial intelligence, ICT and platform economy, the role of these mechanisms is more prominent.

Table 2. Meso-level Industrial Structures and Network Dynamics				
Dimension	**United States**	**China**	**European Union**	**Key Difference**
Marshallian Districts	Highly developed clusters (e.g. Silicon Valley)	State-supported industrial clusters	Present but fragmented across countries	EU lacks integrated clusters
Firm Networks & Linkages	Strong firm–university–venture capital networks	State-coordinated firm networks	Weak cross-border firm integration	EU networks less cohesive
Economies of Scale	Large-scale production and global firms	Massive domestic scale	Limited by market fragmentation	EU lacks scale
Network Economy (User Base & Interaction)	Strong network effects driven by large user base	Rapidly expanding user base and data	Fragmented markets and smaller user base	EU weaker network effects

Source: Author's own synthesis based on the literature and analysis presented in this study.

3.2.1 Marshallian Industrial District

The United States has long been regarded as one of the typical cases of cluster technology development. Although the relevant industrial clusters were initially closely related to the military industry system formed during the Cold War, after entering the 21st century, scientific and technological innovation activities in the United States are increasingly concentrated on highly integrated innovation ecosystems, such as Silicon Valley, Seattle, Austin, along Highway 128 and around Boston and California biotechnology. For example, the development of Silicon Valley is based on the long-term interaction between research universities, venture capital, national defense scientific research investment and private science and technology enterprises and has gradually become an important center of the global digital economy. Since 2001, the knowledge spillover effect, platform ecosystem and network externality have further strengthened the technological advantages of these regions. The development of companies such as Google, Apple, Amazon, NVIDIA, Tesla and Meta are also closely related to the regional environment of scientific research institutions, suppliers, technical talents, start-ups and highly concentrated financial capital in the region. Compared with the European Union, U.S. industrial clusters usually have more mature capital markets, closer industry-academia-research cooperation, and stronger technology commercialization capabilities. With the increasingly fierce competition in science and technology between China and the United States, US policies have further strengthened support for key industry clusters and have promoted the construction of new semiconductor manufacturing centers in Arizona, Texas and Ohio (Kilcrease, E., & Jin, E. 2022).

After joining the WTO, China has gradually formed a state-led industrial cluster development model.

Industrial policies, infrastructure construction, policy financing, local government competition and technology introduction mechanism have jointly promoted the development of industrial clusters. Such as Shenzhen and Dongguan in the Pearl River Delta for electronics and telecommunications manufacturing, Hangzhou for digital platforms and e-commerce, Beijing's Zhongguancun for semiconductors and artificial intelligence research, Shanghai for integrated circuits and advanced manufacturing, and the Yangtze River Delta for electric vehicles and high-end industrial supply chains. Shenzhen, originally established as a Special Economic Zone, evolved into a global manufacturing and innovation hub specializing in telecommunications equipment, drones, semiconductors, AI hardware, and EV supply chains. Firms such as Huawei, Tencent, BYD, DJI, and SMIC benefited from those ecosystems.

the European Union demonstrates a more fragmented industrial cluster structure. Although Europe has an advanced manufacturing foundation and many internationally competitive enterprises, such as ASML in the Netherlands, Airbus in France, Siemens in Germany and Ericsson in Sweden, its industrial clusters are still highly fragmented. Compared with the United States and China, Europe has not yet formed a cross-border technology ecosystem that covers the entire region and can produce large-scale network externalities and unified industrial expansion effects. Most industrial fields still rely mainly on the development of member countries themselves, and the differences in the tax system, labor market, regulatory rules and industrial policies have also increased the difficulty of cross-border coordination. This decentralized feature has affected Europe's competitiveness in the key industries, although the EU continues to promote industrial integration through a series of policies, the differences in interests and fiscal capacity among member states still affect the implementation of relevant policies. Germany and France usually have stronger industrial financing capacity, while the financing capacity of some small and medium-sized member states is relatively limited, which also leads to obvious unbalanced industrial upgrading within the EU. Compared with the Silicon Valley model in the United States and industrial clusters such as Shenzhen and the Yangtze River Delta in China, the European Union still faces greater institutional and structural challenges in building transnational Marshallian industrial distracts that can support technology catch-up and large-scale technology diffusion (Defraigne et al., 2022).

3.2.2 Network Eonomy

Beyond geographical clustering, network economy structures have become increasingly important in shaping industrial and technological competition since 2001. In the field of digital economy and high-tech industries, competitive advantages not only come from production capacity or innovation ability itself but also are closely related to whether enterprises can build a technological ecosystem that connects users, suppliers, digital platforms and infrastructure. With the expansion of user scale, the continuous strengthening of inter-platform connection and the continuous accumulation of data resources, the network effect and economies of scale have gradually become important factors affecting the competitiveness of the industry.

After entering the 21st century, the United States has gradually formed a network economic structure with significant advantages by relying on the world's leading digital platform and highly integrated technology ecosystem. The development of enterprises such as Microsoft, Google, Apple, Amazon, Meta, NVIDIA and Tesla depend not only on a single industrial field, but also on interconnected network systems such as software, semiconductors, cloud computing, artificial intelligence, financial services, e-commerce and digital infrastructure. The huge domestic and foreign user group, mature platform ecology, growing data resources and advanced cloud computing capabilities have jointly strengthened the competitive advantage of the U.S. digital economy. At the same time, the long-term connection between science and technology enterprises, venture capital institutions, scientific research institutions, financial markets and national defense innovation systems also provides favorable conditions for technology diffusion and commercialization. This ecological environment enables American enterprises to quickly achieve technological scale and maintain a leading position in digital platforms, artificial intelligence and cloud computing services. Since the late 2010s, with the intensification of scientific and technological competition between China and the United States, the link between the network economy and industrial strategy and national security has been further strengthened. The United States still has obvious advantages in terms of market size, digital integration and platform network effect (Kilcrease, E., & Jin, E. 2022).

China's network economic development is advancing synchronously with digital transformation, manufacturing upgrading and domestic market expansion. After 2001, Alibaba, Tencent, ByteDance, Huawei, Meituan, Pinduoduo and other enterprises have achieved rapid growth by relying on the huge domestic market, digital infrastructure construction and mobile Internet diffusion. The development of China's network economy is not only reflected in the digital platform itself, but also deeply integrated with e-commerce, digital payment, logistics system, cloud computing, artificial intelligence applications, 5G communication and intelligent manufacturing. Platforms such as Taobao, Tmall, WeChat, TikTok and Huawei 5G network have formed a powerful network effect with large-scale user participation and data accumulation. At the same time, policies such as Internet +, Digital China, New Infrastructure, Made in China 2025 and the Dual Circulation Strategy have also promoted the closer integration of digital platforms with industrial upgrading and supply chain modernization. In recent years, China has continued to increase investment in data centers, high-speed railways, intelligent logistics and 5G infrastructure, so that industries such as financial technology, e-commerce, electric vehicles and AI have strong large-scale development capabilities (KOMESAROFF, M. 2017).

In contrast, the EU's network economy system shows more obvious decentralization characteristics. EU digital ecosystem is still scattered in different national markets and regulatory frameworks. As platform integration, user size, data resources and digital infrastructure gradually become important factors affecting competitiveness, the lack of global-leading digital platforms in Europe is also increasingly prominent. Compared with companies such as Google, Amazon, Microsoft, Alibaba, Tencent or ByteDance, it is more difficult for European companies to form the same scale of network effects and platform expansion capabilities. Differences in language, tax system, regulatory rules and digital governance models have also reduced the integration of the European digital market, making it more challenging to build a unified platform ecosystem. Most European enterprises still rely mainly on their own markets for development, which limits the rapid expansion of technology and platforms. As Defraigne pointed out, the rapid rise of digital platforms in China and the United States has also made Europe's dependence on external infrastructure in the fields of cloud computing, AI, semiconductors and platform technology more obvious (Defraigne et al., 2022). To improve this situation, the European Union has successively launched some stratrgies, hoping to improve digital sovereignty and technological coordination capabilities. However, compared with the highly integrated platform economy system of the United States and China's rapidly developing digital industry ecology, the European Union still faces greater structural constraints in building a large-scale network economy and cultivating global digital platforms.

3.3 Dynamic Mechanisms of Industrial Catch-Up

Since 2001, there have been significant differences in the dynamic mechanisms of industrial and technological development in the United States, China and the European Union, which is reflected in the scale, learning process, and the way network effects are generated and maintained.

Table 3. Dynamic Mechanisms of Industrial and Technological Catch-Up

Mechanism	United States	China	European Union	Key Difference
Economies of Scale	Large global firms and integrated markets	Massive domestic scale driven by state support	Limited by fragmented markets	EU lacks scale for competitive advantage
Network Effects	Strong network effects in advanced industries	Rapidly expanding networks with large user base	Weaker cross-border integration	EU unable to generate strong network effects
Learning by Doing	Continuous innovation through firm experience	Accelerated learning through scale and policy	Slower and uneven learning processes	EU lacks cumulative learning dynamics
First-Mover / Catch-Up Dynamics	First-mover advantage reinforces leadership	Fast catch-up through scale and coordination	Late and fragmented response	EU struggles to convert capability into leadership
Cumulative Dynamics	Strong self-reinforcing innovation cycles	Increasing returns through scale and state support	Weak feedback loops	EU lacks self-reinforcing growth mechanisms

Source: Author’s own synthesis based on the literature and analysis presented in this study.

The technological advantages of the United States mainly stem from the first-mover advantage and highly integrated innovation ecosystem. Before entering the digital economy era, American companies have occupied an important position in key fields such as semiconductors, software, operating systems and the Internet. The development of science and technology giants not only depends on a single technological breakthrough but also is closely related to the whole complete and active industrial and technological system environment. As enterprises gradually establish advantages in key technology fields, the network effect has also begun to play an increasingly important role. The expansion of users has brought more data resources, the platform ecosystem has attracted the participation of developers and investors, and the formulation of technical standards has increasingly concentrated in a few leading enterprises. These long-term accumulations of advantages enable the United States to maintain strong influence in innovation activities, enterprise expansion and global technology competition.

China's development path shows different characteristics, and its driving force comes more from the expansion of the scale of the manufacturing industry, learning by doing, and state-led industrial coordination. After joining the WTO, China quickly integrated into the global production network and continued to expand its industrial production capacity. The industrial clusters formed in the regions enable enterprises to continuously accumulate experience in professional division of labor and large-scale production. In this process, enterprises gradually improve their technical capabilities through gradual innovation and continuous production practice. At the same time, the huge domestic market has further amplified economies of scale and network effects, especially in the field of digital economy. The development of large enterprises is closely related to the expansion of user scale, the improvement of the manufacturing system and the accumulation of data resources. The interaction between production scale, industrial cluster, platform economy and state coordination has also promoted the gradual transformation of Chinese enterprises into technology-intensive industries (KOMESAROFF, M. 2017).

The cumulative effect of the relevant dynamic mechanisms is relatively limited in EU. Compared with the United States and China, European industrial activities are still mainly scattered in different national markets and regulatory systems, and it is difficult to form a unified large-scale industrial ecosystem. The economies of scale and network effects of the digital industry are also relatively weak. The differences in industrial policies and other aspects of various countries further increase the difficulty of cross-border coordination and affect the speed of technological expansion. In recent years, the EU has strengthened industrial cooperation and technical coordination, but the promotion of relevant policies often requires long-term consultation between member states and EU institutions.

The platform-based initiative innovation system of the United States and China's large-scale development model dominated by national coordination have formed a strong cumulative driving force mechanism. In contrast, although the European Union has a strong scientific research and industrial foundation, it still faces difficulties in further integrating these advantages into a unified large-scale technology ecosystem.

3.4 Technological Outcome and Feedback Effects

The interaction between macro-level systems, meso-level industrial ecosystems and constantly accumulating technological dynamics eventually leads countries to occupy different positions in the global value chain.

Table 4. Technological Outcomes and Feedback Effects

Dimension	United States	China	European Union	Outcome
Technological Position	Global technological leader	Rapid catch-up in key sectors	Relatively lagging	US leads, China catching up, EU behind
Industrial Competitiveness	Strong high-tech dominance	Expanding industrial capabilities	Uneven and fragmented	EU lacks global competitiveness
Innovation Performance	High and continuous innovation output	Rapidly improving innovation capacity	Strong research capacity, weaker commercialization	EU innovation less effective
Feedback Effects	Strong cumulative advantages and global network effects (first-mover advantage)	Positive feedback through scale and state support	Weak feedback and limited upgrading	EU lacks cumulative advantage
Global Value Chain Position	Dominates high-value innovation, standards, and digital infrastructures	Rapid upgrading toward higher-value technological production	weaker industrial-technological integration	EU weaker
Long-term Trajectory	Sustained leadership	Convergence toward frontier	Partial or slow catch-up	EU struggles to close the gap

Source: Author's own synthesis based on the literature and analysis presented in this study.

With its first mover and long-term accumulated technological advantages and established leading position in key industrial fields, the United States has long been in the high value-added link of the global value chain. Because these industries generally have scale compensation effects and significant network effects, the advantages formed in the early stage can often be accumulated in subsequent development. The control of technology standards, intellectual property rights, advanced chips, cloud computing infrastructure and global digital platforms has also made the United States maintain a strong influence in the global technology system. With the continuous expansion of technological advantages, the United States has attracted many international capitals, high-end research and development talents and innovative resources, further supported the development of the innovation ecosystem and strengthened its competitive advantage in the global technology field (Defraigne et al., 2022).

China shows a more typical technological catch-up path. After joining the WTO, China relies on manufacturing expansion and export-oriented development to deeply integrate into the global value chain, and coastal areas gradually form large industrial clusters. With the enhancement of the industrial cluster effect, China has begun to gradually extend to industrial chains with higher added value. Economies of scale help enterprises reduce production costs, and learning by doing promotes the continuous accumulation of technical capabilities. At the same time, the huge digital market also provides favorable conditions for the development of the platform economy and technology ecosystem. Through infrastructure construction, industrial policy guidance, technology localization and support for key science and technology industries, national strength has further promoted the process of industrial upgrading. In the past two decades, China's role in the global value chain has gradually changed from low value-added manufacturing to high value-added production and technological innovation.

The development model of the European Union is different. Although Europe has an advanced bases, these advantages are scattered among member countries and have not yet formed a highly integrated cross-regional technology ecosystem like the United States or China. The multi-level governance structure, the difference in industrial coordination and the fragmentation of the digital market limits the accumulation of network effects and industrial learning effects. Compared with the United States, the European Union lacks a globally dominated digital platform and data ecosystem; compared with China, its internal market integration and industrial coordination capabilities are also relatively limited. Therefore, although European enterprises maintain advantages in some subdivisions, it is difficult to form a broader technology ecosystem and overall industrial expansion capacity.

There are also significant differences in the feedback mechanisms formed by the three development paths. The United States relies on its long-term accumulated technological advantages to continuously attract innovative resources and maintain its strong global influence; while China continues to improve its catch-up ability through industrial scale expansion, technological learning and centralized policy support, and promotes the upgrading of industries to high value-added fields. In contrast, although the European Union has a strong industrial and scientific research foundation, its decentralized characteristics have weakened the formation of cumulative effects. Since 2001, the development gap between economies has continued to widen, further affecting their relative position in the global technology competition pattern.

Conclusion

This study revolves around a core question: why China achieved more successful industrial and technological catch-up than the European Union relative to the technological frontier represented by the United States since 2001?

By developing a multi-level analytical framework combining macro-level institutions, meso-level industrial ecosystems, dynamic mechanisms, and technological outcomes, the study argues that technological competition in the contemporary global political economy increasingly depends not only on innovation itself, but also on the ability to construct cumulative and self-reinforcing industrial and technological ecosystems.

Judging from the comparative results, the United States, China and the European Union present three different development paths respectively. With a mature innovation system, a global technology ecosystem and a long-term accumulation of first-mover advantage, the United States still maintains a strong technological leadership position. The state-supported innovation system and the technology ecology led by the private sector have formed a mutually promoting relationship, which has continuously consolidated the dominant position of the United States in the high value-added links of the global value chain.

China has relied more on industrial and technological learning under state coordination to promote technological upgrading in the past 20 years. Infrastructure construction, industrial policy support, industrial ecosystem integration and domestic market expansion have jointly promoted the continuous accumulation of economies of scale, learning by doing and network effects. Under the continuous superposition of these factors, Chinese enterprises have gradually expanded from low-value-added manufacturing to high-value-added industries and have established strong international competitiveness in some strategic industries. This development process shows that later-coming economies can also achieve faster technology catch-up with the support of national coordination, industrial scale and continuous industrial learning.

In contrast, the development path of the European Union has different characteristics. Europe still has a strong industrial base, the world's leading scientific research institutions and enterprises with competitive advantages, but these resources have not been fully transformed into a unified and globally influential technology ecosystem. The key to the problem is not the lack of innovation in Europe, but how to further integrate scientific research advantages, industrial foundation and market resources to form a technical system that can sustainably generate network effects and accumulate advantages. Compared with the United States and China, the EU's multi-level governance structure and industrial coordination differences still restrict the further improvement of the EU's technological competitiveness.

This difference is especially obvious in the fields of digital economy and platform technology. With the increasing importance of data accumulation, economies of scale and network effects, technology competition increasingly depends on the size and degree of integration of the ecosystem, rather than just on individual enterprises or individual technological innovation. Although the European Union still has strong strength in scientific research and advanced manufacturing, its digital market is relatively dispersed, the venture capital system is relatively weak, and the degree of technology integration is insufficient. It is difficult to form a cumulative technical advantage like the US or China.

From a broader perspective, the research in this thesis shows that the industrial and technological competition in the 21st century is essentially a long-term cumulative development process with path-dependent characteristics. Technological leadership, technological catch-up and relative backwardness depend not only on the innovation ability itself, but also gradually form in the process of long-term interaction of various factors such as institutional coordination, industrial ecosystem, economies of scale, doing by learning, network effect and feedback mechanism. Those economies that can effectively combine institutional arrangements, industrial development and technological innovation, and continue to promote ecosystem expansion, are usually more likely to maintain a long-term competitive advantage and occupy a higher position in the global value chain.

The development experience of the United States, China and the European Union also reflects three different technological development models in the context of contemporary global economies. The United States mainly relies on cutting-edge innovation and platform ecosystems to maintain its technological leadership; China promotes rapid catch-up through national coordination, industrial scale and ecosystem integration, while the European Union shows more the characteristics of technological development under the conditions of institutional fragmentation. The fragmentation of the EU's political policy coordination has led to the fragmentation of the ecological cluster of industry and technology. This fragmented feature answers this question: why China has made more progress in industry and technology catching up since 2001 than the European Union.

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