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The Construction and Evolution of Technological Innovation Ecosystem of Chinese Firms: A Case Study of LCD Technology of CEC Panda

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Abstract: With a longitudinal case study on the development of Liquid Crystal Display (LCD) technology of China Electronics (CEC) Panda, this study examined how Chinese firms build their technological innovation ecosystem (TIE). We explored the evolution and the driving mechanisms of TIE. The results of the study found: (1) The enterprise's motivations for innovation and innovation efficiency can be improved when the core enterprise's TIE is constructed. (2) The evolution of the enterprise's TIE undergoes three stages: formation period, incubation period, and development period. (3) The interaction between the external factors from the environment and the internal factors from the agent drives the evolution of the TIE (4). Three types of driving modes develop, depending on the nature of the main factor affecting TIE development: extrapolation drive, hybrid drive, and internal drive.

Keywords: core enterprise; technological innovation ecosystem; evolution mechanism

1. Introduction

Innovation is considered to be the key for enhancing the competitive advantage of enterprises in a constantly changing environment [1]. Against the backdrop of economic globalization and fierce competition, it is difficult for enterprises to acquire all innovative resources at their disposal [2]. Cooperating and collaborating with other organizations through valuable cooperation network have become the focus of various research. In terms of open innovation, a number of leading global enterprises, especially technological enterprises, have successfully developed their own technological innovation ecosystem [3], which have rapidly advanced amidst fierce competition and they have generated a competitive advantage that cannot be surpassed [4]. These enterprises, with the ability to select partners, control supply chain, and regulate the energy flow and material circulation among the members of the system, are at the strategic center of the technological innovation ecosystem. They are the key to the operation and evolution of the entire ecosystem and they have become irreplaceable core members. However, many enterprises in China have become dependent on the "nutrition export" of leading enterprise technology networks to survive and develop. Under passive development, some Chinese enterprises have realized the importance of building their own core technological innovation ecosystem. A number of Chinese enterprises have gradually entered the stage of surpassing (or leading) and they have transitioned from being "pursuers" to becoming "leaders" [5,6]. However, some scholars have argued that the practice of technology catch-up among China's late-developing enterprises does not fully coincide with the "relative backwardness hypothesis" [7]. Thus, exploring the growth law of

technological catch-up and constructing the localization theory of technological innovation of China's late-developing enterprises would be of practical and theoretical significance. In previous studies, learning and innovation have been considered to be essential factors for late-developing enterprises to catch up with technology [8–10]; however, there is still a lack of in-depth research regarding the technological growth path for China's late-developing enterprises. To this end, this study aims to answer the following questions: in the context of China's transformation, how can late-developing enterprises overcome their disadvantages and achieve rapid technological growth? What are the growth and evolution mechanisms in this process?

Enterprises can move forward only through exploration due to the lack of successful practical experience in China. Constructing a technological innovation ecosystem that is based on core enterprises not only helps in enhancing innovation vitality, but also reduces development dependence and improves international competitiveness. Therefore, it is of considerable significance to explore the motivations in development and evolution of the technological innovation ecosystem in core enterprises. Based on longitudinal case study of Nanjing China Electronics (CEC) Panda Liquid Crystal Display (LCD) Technology Co., Ltd., this paper first explores the construction and evolution mechanism of innovation network in the process of technological catch-up of late-developing enterprises in China and then focuses on the matching and synergistic evolution of innovation strategy and innovation capability of late-developing enterprises. Finally, this study analyzes the influence of environmental factors, such as external system, in order to identify the key factors and realization path of technological catch-up of late-developing enterprises. This would bridge the knowledge gap resulting from the lack of in-depth analysis of the micro-foundations, particularly for late-developing enterprises.

2. Literature Review

2.1. The Concept of Technological Innovation Ecosystem

Similar to the natural ecosystem, various members of the innovation ecosystem are interconnected in a cooperation network, which can be either tight or loose. They exchange knowledge or product under such a network and they adapt to each other and evolve together [11]. From a functional division, the innovation ecosystem can be partitioned into the business innovation ecosystem and the technology innovation ecosystem. As opposed to the business innovation ecosystem, which matches the product to the customer's needs [12,13], the technology innovation ecosystem is used to achieve technical upgrades to meet (or exceed) consumer demands.

With dramatic changes in the innovation environment, the enterprise innovation paradigm has gradually shifted from "closed" to "cooperative" and from "independent" to "systematic" [14]. In the technology innovation ecosystem, enterprises are interdependent and synergistic. Ander (2006) concluded that the current innovation activities require companies to create business value through complementary collaboration with other companies [15]. Jiang et al. [16] pointed out that the innovation ecosystem is a series of related organizations around the core enterprise or platform, which includes suppliers, complements, customers, research institutions, government departments, and other entities. With the definition of innovation ecosystem gradually gaining recognition from the academic community, scholars have started to explore the evolution process of innovation ecosystem. For example, Ouyang Taohua et al. [17] took a leading enterprise in small satellites, the DFH, as a case study and discussed the dynamic evolution characteristics of the aerospace complex product innovation ecosystem and its implementation mechanism. Wang Hongqi et al. [18] took BYD's new energy vehicles as the research subject and explored the evolution mechanism of the new energy vehicle innovation ecosystem. These studies have significant theoretical value in understanding the evolution of the innovation ecosystem. However, the existing research fails to consider the transformation of a company's own innovation model when the innovation ecosystem evolves and rarely discusses the interaction between the transformation of the innovation model of the core enterprise and the evolution of the innovation ecosystem.

Most of the research have been based on leading companies in the construction of the enterprise technology innovation ecosystem. However, leading companies have natural advantages in both technology and social networks. They are more likely to build an innovation ecosystem that would be beneficial to them when compared with weak companies. Some studies on disadvantaged enterprises found a number of weak enterprises becoming attachments of strong innovation networks, emphasizing how backward enterprises can absorb innovative resources in a strong innovation network. Chinese companies, particularly in manufacturing, do not have this natural advantage in technology, and most are technology-introduced. Therefore, this research is based on the technology-introduced enterprise as a research subject in a technology innovation ecosystem. The Panda LCD is used as a case study to explore how late-developing enterprises construct its unique innovation ecosystem and undergo the process of technological catch-up.

2.2. Construction of Technological Innovation Ecosystem Based on Core Enterprises

Each innovation body forms a complex technical cooperation network, whose goal is to promote the development and innovation of technology [19]. The concept of the technological innovation ecosystem has changed the mode of technological innovation, and the innovation activities of core enterprises have transitioned from closed innovation of a single enterprise into open innovation of relevant enterprise groups. Clarysse B, et al. [20] suggested that, from the perspective of innovation network, core enterprises should have the ability to maintain the healthy development of cooperative enterprises within the innovation network, and core enterprise should continuously integrate other participants to innovate new technologies, develop new markets, and build the necessary infrastructure. In terms of technological capabilities, Gay and Dousset [21] found that core enterprises have technological levels that are difficult to surpass and replace. Therefore, core enterprises can attract other supporting enterprises and institutions by virtue of their own advantages and promote the establishment of technical cooperation networks. Core enterprises have the capacity of not only acquiring the knowledge they need, but also exporting their knowledge through a technical cooperation network [22]. Their technical cooperation includes vertical cooperation and horizontal cooperation [23]. Vertical is the cooperation of enterprises operating at different levels of production, while horizontal is when the actual competitors in the same industry and in the same stage of production work together. The core technology competitiveness can be effectively enhanced by finding ways to improve the value and reduce the cost in the upstream and downstream of the industrial chain.

In recent years, scholars have proposed a polycentric innovation ecosystem model. Neslen [24] suggested that, while corporate investment in efficient enterprises and organizational culture is vital in improving the innovation efficiency, organizations and corporate leaders must begin to move away from the "painfully slow" process of top-down approach towards a more 'shared' networks of creative innovation that cuts across the entire enterprise and "fits" with the complexity of environmental and socio-ecological factors. Taminiau & Lewis [25] highlighted the need for sustainable business model innovation as a key component of a polycentric collective creativity strategy. Nyangon & Byrne [26] argued that technological innovation ecosystems, customer enterprises, and business model innovation should mainstream polycentric innovation and efficiency innovations at multiscale levels in order to enhance policy effectiveness in institutional development and organizational culture and in order to optimize processes. Liu & Liu [27] also found a polycentric spatial structure in the context of China's urban development. This structure can take multiple centers as core and radiate into sub-centers to promote overall efficiency in city development.

Generally, there are two ways of constructing the technological innovation ecosystem: one is to construct directly while using a single or several core enterprises based on their own needs; the other is to form an innovation network through closed technological innovation cooperation or resource complementary cooperation among enterprises and, then, with the gradual expansion of the innovation network, naturally develop into an enterprise technological innovation ecosystem. In this process, a small number of enterprises grow rapidly, and their roles and positions become increasingly

prominent, thus becoming the core enterprises in the system. Based on the definition of core enterprise in innovation network and the connotation of technological innovation ecosystem, this study posits that core enterprise is in the strategic central position of technological innovation ecosystem, has the ability to select, lead, and coordinate partners, and is responsible for maintaining the development of the system and managing cooperative innovation activities.

2.3. Evolution Mechanism of Technological Innovation Ecosystem

The evolution and development of technology is a non-linear and complex dynamic process [28], and the evolution of the technological innovation ecosystem is the process of spiral advancement of technological level and network renewal and the perfection of innovators. There is a relationship with regards to inheritance, derivation, and variation of knowledge among old and new technologies. The inheritance of technological innovation refers to the gradual and continuous development of technology. Technological derivation refers to the auxiliary processing and transformation of technology under the conditions that the original technological route remains unchanged and that improvements are made on the original system. The variation in technology is manifested through breakthroughs in technological innovation that abandons the original technological route. This Leapfrogging strategy is often less effective than the original technology in the short term. However, the breakthrough technology will surpass and replace the original technology with improvements in the supporting system. After the completion of the breakthrough technological innovation, the industrial activities re-enter the genetic stage of technological innovation, thereby promoting the overall capability of the industry in the technological innovation ecosystem. The renewal of the network is reflected in the number of innovative subjects and the combination of modes of inter-subject networks. Different entities form a dynamic development network with complementary functions and create a system of cooperation and competition through close or loose combination due to heterogeneity of knowledge among the innovation subjects [29], in order to improve the innovation vitality and innovation space of the subject. Existing studies on the evolution of technological innovation ecosystem have been mostly confined to the various stages of evolution, with only few studies go deeper into the mechanism of evolution.

In recent years, scholars have studied the driving factors promoting the development of a polycentric innovation ecosystem. Nyangon & Byrne [26] investigated the relationship between corporate sustainability and changes in organizational members' norms and attitudes. They concluded that a shared or polycentric business model innovation approach is effective in optimizing the processes in enterprise design, practices, and development, thereby improving corporate (or organizational) goals and business practices. They found out that consumer choice and state and federal policy support are powerful driving factors in the development of polycentric innovation ecosystem. Taminiau & Lewis [25] suggested that the non-linear, uncertain, and unpredictable character of environmental degradation could be answered with a dynamic, non-linear, and experimental strategy organized through 'polycentric' networks of creative innovation and leadership. The evolutionary process of polycentric governance, which revolves around adaptation to new circumstances and iterative problem-solving, requires the equivalent of a 'natural selection' process that can uncover the 'genetic material' of innovation and contribute to its diffusion and further evolution. Unlike in biology, where the unit driving development is gene, in the field of social science, these drivers may include rules, skills, organizations, or any other entity that has internal cohesion and external isolation and can participate in the evolution process. From a study on the evolution of a polycentric development city in China, Liu & Liu [27] concluded that market forces and government interventions are the driving factors in the development of polycentric ecosystems.

The study found that the factors driving the evolution of the technological innovation ecosystem include internal and external components. Among them, the internal driving factors include the demand for technology, the willingness to innovate, and the development goals of the core enterprises, while the external driving factors are aspects of the innovation environment outside the technological

innovation ecosystem. In the evolution of the technological innovation ecosystem, internal and external driving factors always exist and influence each other, forming the driving force of "push and pull". Three processes have been identified in understanding which aspect serves as the dominant force affecting the evolution of the ecosystem: push-in drive, extrapolation drive, and mixed drive. If the evolution of the ecosystem is driven mainly by internal factors, the process is called the push-in drive. The process is called the extrapolation drive if the evolution is mainly due to external factors. The process is called mixed drive if the ecosystem evolved through a combination of internal and external factors.

3. Elements Composition and Relations of Technological Innovation Ecosystem

The technology innovation ecosystem consists of participants and the environment [30]. In this study, we divided the system into innovation subjects and innovation environment in which the innovation subjects are subdivided into core and auxiliary subjects in accordance with their role in the system. The core subjects, which include enterprises and scientific research institutions, are the leading innovators in the technological innovation ecosystem and the main contractors of the innovation network. Enterprises are the most important core subjects in the technological innovation ecosystem and they serve as innovative participants and transformers of technology, products, or services. Another core subject includes universities and scientific research institutions, which transport talents and innovative sources for enterprises. The auxiliary subjects, which are mainly composed by the government, intermediaries, financial institutions, and science and technology parks, provide energy and promote the development of the core subjects and innovation network. The government plays the role of institution building, providing guarantee and support for the construction and development of the innovation ecosystem. The intermediaries mainly provide connection and consultation services for innovators in the technological innovation ecosystem. The representative intermediaries include trade associations, technology trading institutions, talent intermediaries, accounting firms, law firms, and consultation institutions, among others. Intermediaries strengthen the collection of innovation resources, promote the transformation of scientific and technological achievements, and accelerate the innovation efficiency of the system. Financial institutions provide monetary support for innovators. Science and technology parks assemble dispersed innovators together to help them establish network relationships and enhance the internal stability of the innovation ecosystem by providing cooperative innovation places.

The innovation environment of the technological innovation ecosystem refers to the environment of the market, technology, resources, policy, finance, culture, and infrastructure. Among them, the market environment includes market demand for primary technological products, the various competitors, and the competitive pressures for similar products. The technological environment includes various technological information, such as the number of patents, reliability and extensiveness of sources, the degree of compatibility between the level of technological development and the innovation intention of the enterprise, the degree of industrial concentration, the driving force of technology innovation, and the speed of technology diffusion. Policy environment involves the market atmosphere that was created by the government through laws, regulations, and policy. Cultural environment mainly refers to the cultural atmosphere, development goals, and vision of the technological innovation ecosystem. The innovative resource environment includes material resources, human resources, and innovative capital required by enterprises for technological innovation. Economic environment refers to the availability and convenience of capital sources and financing channels when enterprises carry out technological innovation. The infrastructure environment includes the facilities that surround the enterprise technological innovation ecosystem, such as transportation facilities and power facilities. These innovative environments directly or indirectly affect the behavior of innovators in the technological innovation ecosystem. At the same time, the development of innovators alters the state of the innovative environment, thereby creating an interactive relationship.

The main role of enterprises is to produce and sell innovative products or services, so that the value of innovation can be realized. Enterprises can effectuate the flow of information and talents by establishing cooperative relations with universities and they can realize the flow of resources by establishing cooperation with financial and intermediary service institutions. Through the construction of supporting infrastructure, the government provides material support for the development of technological innovation ecosystem, optimizes the innovative soft environment of the ecosystem through policies and culture, stimulates the pioneering initiative of innovators, and steers the main bodies in the system through the construction of science and technology parks to enhance the stability of the technological innovation ecosystem. Financial institutions can provide economic assistance for the development and growth of enterprises, while intermediaries can provide various information and services for enterprises to improve their innovative functions. Figure 1 shows the relationship between different innovation subjects and innovation environments in the technological innovation ecosystem.

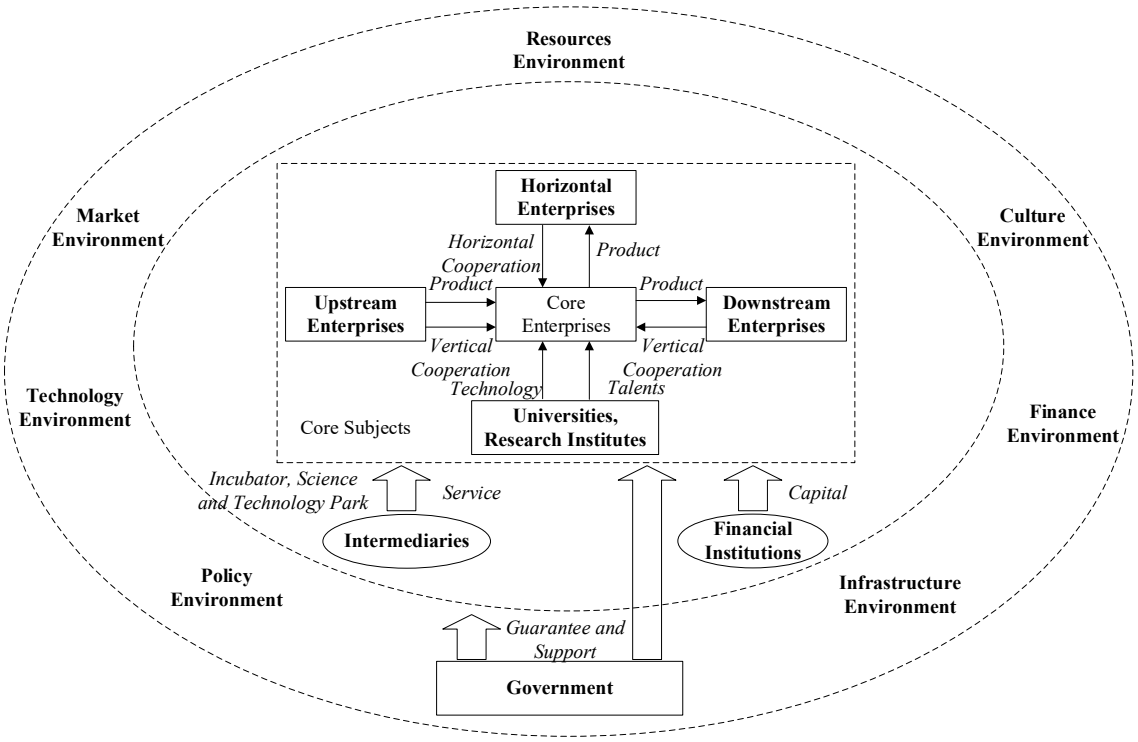

Figure 1. Model Diagram of Technological Innovation Ecosystem.

In the technological innovation ecosystem, the dominant logic of core enterprises has an important impact on the generation and development of the entire innovation ecosystem. This study examines the dominant logic of innovation transformation, discusses how enterprises can construct and promote the continuous development of innovation ecosystem, and analyzes the relationships among the main bodies in the development of the innovation ecosystem in connection with the transformation of enterprise innovation paradigm.

4. Research Design

4.1. Research Methods and Data Sources

Case studies can describe and analyze a particular phenomenon in depth based on abundant qualitative data. A single case study can reveal how cases change over time [31], which is more suitable for the study of vertical cases. For this reason, this paper followed the following procedure:

(1) Case selection. At the initial stage of the study, case studies are effective in explaining complex problems or analyzing new perspectives [32]. Therefore, as an exploratory study, we selected a single

case for in-depth analysis and considered the development of 6th generation and 8.5th generation LCD projects of CEC Panda Group from 2005 to 2017 as the research subject. In 2009, CEC Panda Group introduced a complete set of LCD technology production line of Sharp Company. This project is the first LCD panel production line for TV in mainland China. In a short period of time, it established a technological innovation ecosystem with its own core, realized large-scale production, carried out a series of innovative activities, and applied for a number of patents. In 2013, the construction of the 8.5 generation line was launched and the level of technological innovation was further improved to form a dual-core technological innovation ecosystem. The development process of the LCD technology ecosystem of the CEC Panda Group is complete, which corresponds well with the theme of this study.

(2) Data collection and analysis. We collected data by means of in-depth interviews, literature review, image data analysis, and on-site observation, and we used triangular verification to ensure the accuracy of the data. The data collected were analyzed and sorted while using coding and categorization. In coding, the development level and evolution mechanism of the technological innovation ecosystem were measured in terms of form, characteristics, and changes in innovation subjects and environment involved in the theoretical part. Meanwhile, loose conceptual types were maintained, so that key concepts can emerge from the case data [33]. At the time of encoding, the non-textual interview recordings and video materials were first textualized and encoded according to the timeline. The second step was extracting all of the statements related to the innovation subject and innovation environment based on the timeline. The third step involved classifying and encoding the extracted related content and sentences. The content of the innovation subject was classified based on the degree and type of role that was played by the innovation subject, while using the categories core subject, related cooperative enterprise, and scientific research. The content of the innovation environment in the document was classified into five categories: market, technology, resources, policy, finance, culture, and infrastructure, depending on the type of environment. Finally, while using the timeline and details of the innovation subject and innovation environment, the development of each stage of CEC Panda was summarized to understand the characteristics and reasons for enterprise development.

4.2. Case Description

The international image of China's television industry as a big manufacturing country has been established since the era of CRT television. Its advantages disappeared in the coming LCD era. Panda Electronics, the predecessor of CEC Panda Group, is the first TV manufacturer in China. Its registered trademark, "PANDA", is the first "well-known Chinese trademark" in the electronics industry, and the "Panda Television" has become a highly recognized brand. However, in the transition process towards high-end LCD TV, Panda Electronics failed to grasp the direction conducive to growth and missed critical development opportunities. Panda Electronics has been experiencing financial predicament since 2002.

In August 2009, Nanjing CEC Panda LCD Technology Co., Ltd. was established, which was jointly funded by China Electronic Information Industry Group Co., Ltd. (CEC Group), CEC Panda Group, Nanjing Xingang Development Corporation, and Nanjing New Industrial Investment Group Co., Ltd. The company was the first one to enter Nanjing LCD Valley Park. It invested 13.8 billion yuan in introducing Sharp's 6th generation LCD panel project, which was the first LCD panel production line that was imported to Mainland China. It also had the most advanced 6th generation LCD panel in the world at that time.

In July 2013, Nanjing CEC Panda Flat Panel Display Technology Co., Ltd. was jointly established by CEC Group, CEC Panda Group, Nanjing New Industrial Investment Group Co., Ltd., Nanjing Xingang Development Corporation, Guanjie Science and Technology Group, and Sharp Company. The construction of the IGZO 8.5th generation line project was launched with a total investment of 29.15 billion yuan and a registered capital of 17.5 billion yuan. It is the first 8.5th generation TFT-LCD production line in the world to adopt IGZO technology, and it was the largest industrial project in China at that time.

The technological development process of the LCD project of the CEC Panda Group corresponds to the development path of its technological innovation ecosystem. In this study, the growth of the technological innovation ecosystem was divided into three stages, in accordance with the development process of LCD technology of CEC Panda Group: the formation stage (2005–2009), the incubation stage (2009–2013), and the development stage (2013–2017). Table 1 shows the development process and key events of the enterprise.

Table 1. Development of Liquid Crystal Technology of CEC Panda Group.

Year	Event
2007	The restructured China Electronics (CEC) Panda Group was established in Nanjing
2009	Signed an import agreement with Sharp for the 6th generation Liquid Crystal Display (LCD) panel production line project
2010	Establishment of Nanjing Flat Plate Industry Association by joint Sharp Company and relevant research institutions and universities
2011	The 6th generation LCD panel production line project completed and put into operation
2012	Jointly with Fudan University to establish "China Electric Panda-Fudan University Flat Panel Display Technology Research Center"
2013	1. Complete the localization of most materials needed for LCD panel production 2. Startup the 8.5th generation production line project
2014	Invested 1.535 billion to build flat panel display engineering technology research center
2015	The 8.5th generation LCD panel production line project completed and put into operation
2016	Launched the world's first 98-inch 8K LCD TV named "Heaven View" with IGZO Technology

Table 2 shows the distribution of employees of CEC Panda Group over the years. From 2005 to 2017, the number of master's degree-holders (or above), those with college degrees, and full-time R&D personnel showed upward trends. The number of administrative staff, sales staff, and financial staff changed little. From 2005 to 2014, the number of total hired employees increased. Although the number of employees contracted from 2015 to 2017, the number of employees with a master's degree (or above) and the full-time R&D personnel increased. Additionally, the proportion of highly educated and percentage of R&D personnel grew. This suggests that CEC Panda Group concentrated on the recruitment and training of highly educated and technical R & D personnel and towards the innovation and development of the enterprise.

Table 2. Distribution of employees of CEC Panda Group over the years.

Year	Employees	Master Degree or Above	College Degree or Above	Administrative Staff	Sales Staff	Production Staff	R & D Staff	Financial Staff
2005	2025	35	924	288	39	1122	511	65
2006	1999	36	944	277	42	1158	457	65
2007	1900	31	802	173	210	864	578	75
2008	3262	50	1579	264	349	1523		137
2009	3276	83	1558	265	353	1534	985	139
2010	3147	63	1359	265		1369	1038	145
2011	3305	82	1349	270	358	1381	1099	156
2012	3378	88	1330	279	302	1548	1101	148
2013	3303	109	1267	273	322	1437	1113	158
2014	4138	114	1857	342	340	1874	1394	188
2015	4079	158	1965	341	335	1807	1406	190
2016	3819	176	1902	321	315	1590	1400	193
2017	3831	183	1942	322	303	1576	1429	201

Table 3 summarizes the major partners of CEC Panda over the years. As presented in the table, the only partner of CEC Panda during the first phase (from 2005 to 2009) was Sharp Corporation. At this stage, the technology and equipment production of CEC Panda was almost entirely from Sharp. In the second phase (from 2009 to 2013), CEC Panda's main partners were foreign companies. The production of CLP Pandas could not be separated from foreign imports since China lacked the core materials and technology of LCD screens at that time. Since 2013, in order to reduce dependency on technology and raw materials from foreign countries, CEC Panda has gradually promoted the localization of raw materials and strengthened joint research and development and cooperation with domestic enterprises.

Table 3. Major partners at different stages of CEC Panda.

Year	List of Major Cooperative Enterprises	Number of Domestic Cooperative Companies	Number of Foreign Cooperative Companies
2005–2009	Sharp Corporation	0	1
2009–2013	Sharp Corporation, Merck Corporation of Japan, Toppan Printing Co. Ltd., Toyota Motor Corporation, Sumitomo Chemical Co., Ltd., Dai Nippon Printing Co., Ltd., Nitto Group, CE Lighting, Solomon Systech Limited, Admiral Oversea Corporation	7	3
2013–2017	Sharp Corporation, Hefei IRICO Epilight Technology CO., Ltd., General Research Institute for Nonferrous Metals, Lida Optical and Electronic Co., Ltd., Kelead Photoelectric Materials Co., Ltd., Runma Chemical Co., Ltd., Beijing Asahi Electronic Materials Co. LTD., Slichem Display Material Co., Ltd., Shenzhen Shengbo Optoelectronics Technology Co., Ltd., Sunnypol Opto-electronice Co., Ltd	1	10

5. Case Analysis

5.1. Formation Period of Technological Innovation Ecosystem (2005–2009)

5.1.1. Innovation Environment

(1) Market Environment, Technology Environment, Resources Environment

The years 1992–2003 became the development period of TFT-LCD (Thin Film Transistor) liquid crystal technology, which gradually replaced the traditional CRT display technology. In the global market of liquid crystal products, Japan, South Korea, and Taiwan enjoyed monopolistic positions, with a market share that accounted to more than 80%. The supply of materials and major manufacturing equipment in the upstream of the LCD industry were also in the hands of Japanese and Korean companies. This compelled domestic TV manufacturers to spend huge sums of money to import critical components, such as LCD panels, from Japanese, Korean, and Taiwanese manufacturers. Unfavorable market and technical environment severely restricted the survival and development space of domestic TV manufacturers since the liquid crystal panel accounts for 70% of the overall cost of the TV set [34] During this period, China's TV industry was struggling.

(2) Policy Environment

Under this difficult situation, a series of guidelines and tax preferential policies have been issued to promote the development of the LCD industry in China. In February 2006, the State Council promulgated the "Outline of the National Medium-and Long-term Science and Technology Development Plan (2006–2020)", which listed high-definition large-screen display products as key support areas and priority development themes. In 2007, the National Development and Reform Commission issued a notice on the "Special Issues Concerning the Continuation of Organizing and

Implementing Industrialization of New Flat Panel Display Devices", which proposed the technology for supporting the design and production of new display devices, key supporting devices and materials, special manufacturing and testing equipment, modules, and whole machines. In April 2009, the State Council approved and issued the "Plan for the Adjustment and Revitalization of the Electronic Information Industry", which proposed the key technologies for supporting the vertical integration of color TV enterprises and chip design, display module enterprises, and breaking through new display devices. Since May 2009, the Ministry of Finance, the Ministry of Finance of the State Administration of Taxation, and the State Administration of Taxation have issued incentive policies for the flat panel industry.

Guided by the national policy and legal environment, Nanjing issued the "Ten Industrial Chains Development Action Program of Nanjing City" on August 7, 2006, which emphasized that the focus should be on the development of the flat panel display industry. On June 20, 2008, the "Software Industry Revitalization Plan and Electronic Industry Renaissance Plan" was launched to stress that the focus should be on building a flat panel display industry. During this period, the Nanjing Municipal Government created a good policy environment for technological innovation ecosystem, with the G6 project of CEC Panda Group as core, while using guidelines and preferential tax policies at the regional level and fostering auxiliary innovation subjects for later development with the construction of the liquid crystal valley.

5.1.2. Establishment of Core Enterprises

In the process of transforming high-end LCD TVs, CEC Panda's predecessor, Panda Electronics, missed the opportunity to enter the high-end TV industry, because it did not grasp the development direction of the company and gave up its own dominant TV industry. Since 2002, Panda Electronics has been in a quandary; its business scope and product types are still very complex, involving consumer electronics, communication software and processing, and manufacturing.

At the end of 2004, the CEC Group began to intervene in the reorganization and merger of Panda Electronics, resulting in a huge loss of more than 1 billion yuan due to poor management [35]. The process of reorganization and merger began to stagnate because of the economic cost from the operation problems of Panda Electronics. The share ratio of the reorganized company was finally determined in March 2007 in order to save and expand the old brand Panda, coupled with the vigorous efforts of the Nanjing Municipal Government. On May 15, 2007, the restructured China Electric Panda Group was officially launched in Nanjing. Mr. Bao, the leader of Nanjing, said in the CEC Panda listing, "For the restructured enterprises, the purpose is to use a brand-new platform to solve the problems of enterprise system, mechanism and insufficient technology investment, and seek development in a larger space [36]."

5.1.3. Construction of Technical Cooperation Network

From 2003, a number of foreign-funded enterprises, such as Sharp Company and LG Company, started setting up production bases in Nanjing for liquid crystal modules and whole machines. Nanjing gradually became a key downstream assembly production base of liquid crystal modules in China, but the added value and technical content of products remained low. The CEC Panda that was involved in the restructuring by the CEC Group still lacked major product development directions. In 2007, Mr. Shen, chairman of the CPPCC and general director of the Nanjing LCD Valley Construction, said, "The biggest problem in China's electronic information industry is 'the lack of chips and screens'" [37] Sharp Company, the leading enterprise of LCD panel production, was given the opportunity to transfer a six-generation LCD panel production line to China with guidance from national policy and legal environment. The Nanjing Municipal Government strongly advocated for the introduction of this production line by CEC Panda Group after restructuring. After two years of negotiation, the equipment and technology import agreement of the G6 project was signed with Sharp Company on August 31, 2009. The total amount of the agreement was 13.8 billion yuan, which became controversial

due to its high value [38]. However, unlike previous LCD technology import agreements elsewhere (e.g., Rainbow Co., Ltd. invested 688 million yuan in Qindu District, Xianyang, Shanxi Province as early as August 2006 to start the construction of the first phase of the fifth generation liquid crystal glass substrate project. According to the plan, the project should be put into production by the end of 2007. However, due to the refusal of Corning to transfer some core technologies, the project has not yet been fully mass produced.), the purpose of the Nanjing Municipal Government was to develop a world-class "LCD Valley" to be aided by this production line. The aim of CEC Panda Group was to promote the construction of a new generation LCD panels through the introduction and absorption of technology, build a complete LCD industry chain, and break through the technical bottleneck of LCD manufacturing. Therefore, the amount of the agreement included not only the price of the 6th generation line equipment, but also the technology patent and transfer fees. At the same time, the agreement also included Sharp's plan of establishing a "Global LCD R&D Center" in Nanjing and the cooperation with CEC Panda Group regarding the new generation LCD technology.

Tables 4 and A1 show the main innovation subjects and environment of technological innovation ecosystem in its formation period.

Table 4. The Constitution of Innovation Subjects in the Formation Period of Technological Innovation Ecosystem.

Innovation Subjects						
Core Subjects			Auxiliary Subjects			
Core Enterprises	**Related Cooperative Enterprise**	**Research Institutions**	**Government**	**Intermediaries**	**Financial Institutions**	**Science Park**
CEC Panda Group (G6 Project)	Sharp Company		The National and Local Government		Bank	

A core enterprise ought to be cultivated first during the construction period of the technological innovation ecosystem. The lack of foresight and independent innovation consciousness may easily lead enterprises to blindly follow in technological development, which can lead to growth restrictions by the market environment, technological environment, and resource environment. The Nanjing Municipal Government first advocated for the CEC Group to integrate resources of Panda Electronics and set up the CEC Panda Group in order to break the stagnation. Afterwards, with the support from the government, China Electric Panda Group established CEC Panda LCD Company as the core enterprise in the ecosystem of technological innovation for developing the G6 project. CEC Panda Group and Sharp established a horizontal technical cooperation relationship between core enterprises and related enterprises by introducing technology in order to rapidly improve the technological capability of core enterprises, since the technology level of CEC Panda LCD Company had been relatively weak. During the formation period of the technological innovation ecosystem, the technical cooperation network within the system had been relatively simple, and the government played a major role in the formation of the system.

5.2. Incubation Period of Technological Innovation Ecosystem (2009–2013)

5.2.1. Innovation Environment

The Nanjing Municipal Committee and the Municipal Government have constructed the LCD Valley Science and Technology Park in Nanjing Economic and Technological Development Zone in accordance with the "Plan for the Adjustment and Revitalization of the Electronic Information Industry" that was proposed by the State Council in April 2009. Nanjing has been the cradle of China's electronics industry. The LCD Valley, where the G6 project can be found, was initially situated in the Economic and Technological Development Zone of Qixia District, Nanjing, which is adjacent to Xianlin University City in order to fully utilize advantages in geography, skills, and education. The total planned area of the LCD Valley was about 17.32 km^2. In 2010, the four ministries and commissions jointly issued

a paper listing the 6th generation line in Nanjing as a "thin film transistor display manufacturer". The 6th generation line has acquired the crucial support of the state. The goal of Nanjing was to take the opportunity of G6 project construction to build the LCD Valley and seize the commanding heights of the LCD industry development. On October 29, 2009, Nanjing Municipal Government approved the Nanjing LCD Valley Industry Development Plan (2010–2015). At the same time, the CEC Group had also initiated the construction of the 6th generation line project as the first step in developing the LCD industry. The Nanjing Municipal Government and CEC both listed the construction of the 6th generation line project as the "No. 1 Project". Also, the Nanjing Municipal Government proposed to "take the whole city's strength" to promote the construction of the G6 project and LCD Valley. The "Nanjing New Display Industry Development Leading Group" had been established, being composed of city leaders delegated to directly deal with the various problems of the G6 construction project. The on-site construction headquarters have submitted more than 220 reports requesting assistance to the municipal government since the start of the construction of the G6 project in Nanjing LCD Valley on 1 November 2009. With the staunch support coming from the government, a large number of problems had been expeditiously solved, such as the importation of more than 70 million container equipment worth of more than four billion yuan. Municipal inspection and the quarantine and customs departments have also formulated green customs clearance programs specifically for them. The provincial and municipal fire departments helped design a reasonable scheme for fire protection of mega-workshops given the absence of existing norms in order to create a good infrastructure environment for the future development of the 6th generation line. With the help of the utilities departments (electricity, water, and gas), the 6th generation line was able to immediately build power, water, and gas facilities. Under the guidance of the Sharp Company (the transferor of equipment and technology), the Eleventh Design Institute, the Systems Engineering Corporation, and the Jiangnan Supervisory Company (Second Installation Company of CEC Group) became responsible for the design, construction, and installation of the 6th generation line, which ensured the smooth progress of the project. With full cooperation of the state, the local government, relevant companies, and cooperative enterprises, the construction of the 6th generation line project achieved the "Nanjing Speed" of 17 months' completion and commissioning [39]. The Nanjing Economic and Credit Commission and the Municipal Finance Bureau jointly issued the Notice on the Fulfillment of First Encouraging Policy Projects and Funds Plans for "Innovation Transformation" and "Upgrading of Thousand Enterprises" on September 7, 2011 in order to encourage enterprise construction, innovation, and development. The 6th generation line project was approved as "Key Investment for Promoting High-end Industrial Development". The project was supported by 10 million yuan of special funds [40].

5.2.2. Innovation Environment

In terms of technology, the equipment of the 6th generation line of the G6 project was transformed and upgraded when it was transferred from Kuishan, Japan to Nanjing. This production line introduced the latest technology of the 10th generation line (e.g., UV2A), with the design capacity increasing from 60K to 80K (Among them, 60K piece of equipment is the original equipment of 6th generation line of Sharp Kameyama, and 20K piece of equipment is a new equipment jointly purchased by CEC panda and Sharp.) and the monthly production capacity reaching 90K after expansion. With technical support from Sharp, the product yield rate reached over 93%, and the productivity and yield rates climbed to the international first-class level [41]. The G6 projects adopted Sharp's latest advanced LCD panel and module manufacturing technology, the drive circuit technology, and the light-emitting diode (LED) backlight technology in terms of technology. The CEC Panda Group considered skill and innovation to be integral in ensuring the company's long-term development. Thus, when the CEC Panda LCD Company was established, it recruited talents and senior R&D personnel from Japan (The Japanese experts introduced from Sharp have successively participated in the construction, production operation and product R & D of the world's first G6 production line, G8 production line and G10 production line, with the design and development capabilities of ASV technology, UV2A technology, single board

multi-screen technology, copper wiring technology, ultra-thin display technology, energy saving and consumption reduction technology, etc. The products developed by these experts cover all TFT-LCD panels for TV and display below 108".), Taiwan (The experts introduced from Taiwan are from the Chunghwa Picture Tubes, which is known as the "Taiwan LCD Pioneer Company". The Taiwan expert team has experience in building factories, including 3th generation, 4th generation, 4.5-generation, and 6th generation. It has development experience in 4MASK process product production, copper technology and other advanced process technologies, rich experience accumulated in cost reduction and efficiency, extensive experience in designing Netbook/NB/Monitor/TV, and product design experience in new-generation display applications such as 3D and multi-touch screens.), and the mainland (The experts introduced from mainland China are specialized in liquid crystal technology research and development, production and operation. These local experts have 4.5-generation and 5th generation factory construction experience and operation management experience.). The CEC Panda LCD Company organized 42 technicians to conduct a three-week technical training in May 2010 at the Sharp Kuriyama Factory in Japan in order to digest and learn Sharp's latest technology in-depth.

In August 2012, the supporting project of G6 color filter (CF) started construction and it was put into production in December the year after. In 2013, most of the peripheral materials that were produced by LCD panels, including chemicals and special gases, were locally imported, and the products on the 6th generation line were sourced from self-made CF, and the total output of CF has been increased to 60 K. The company was able to complete the development of the bare-eye 3D technology, the 31.5 "low-cost backlight technology, the 31.5"4K × 2K products, and other new technologies in terms of new product development. It was able to develop over 30 new products in three categories: the 21.5" 6 mm ultra-thin machine, the ultra-narrow frame technology, and the second-generation transparent display project (transmittance increased from 5 to 15%). It was the first to mass-produce UV2A technology on the 6th generation line. It successfully developed energy-saving technologies, such as the dynamic energy-saving LED backlight, the high throughput technology (transmission increased by more than 50%), the driving IC reduction, and the array substrate integrated scanning drive circuit (GOA). The 21.5" FHD, the 31.5" ASV, and the 64.5" UV2A products of CEC Panda LCD Company were awarded the title of high-tech products in Jiangsu Province in 2013 in terms of independent innovation, and many of its panel products won the Science and Technology Award of China Electronics Society and the Science and Technology Progress Award of Nanjing City [40]. In 2013, 137 patents were applied for by the CEC Panda LCD Company, including 72 invention patents and 50 authorized patents.

5.2.3. Expansion of Technical Cooperation Network

The CEC Panda Group established industry-university-research alliances with local universities in Nanjing (e.g., Southeast University and Nanjing University of Science and Technology), reaping the benefits of regional advantage in order to further enhance technological innovation. In September 2010, 68 flat panel display enterprises in Nanjing and its surrounding areas, such as CEC Panda Group, Sharp Corporation, CETC-55, CEC-11, and Southeast University, jointly established the Nanjing Flat Panel Industry Association [42], to assist the government in formulating the development plan and propose policies and suggestions with regards to the liquid crystal industry. The association also participates in the organization and decision-making of major projects in the ecosystem of technological innovation and guides the cooperative development, popularization, and application of technology in the system. Through this association, the communication mechanism between the interior and the exterior of the technological ecosystem could be established, and international exchanges can be carried out to enhance exchanges and cooperation within and outside the LCD industry. In December 2011, the CEC Panda LCD Company signed a strategic cooperation agreement with the Flat Panel Display Engineering Research Center of Fudan University to actively cooperate in personnel training, TFT technology research and development, project declaration, and other aspects, and professors from Fudan University were hired as senior consultants of the company's technical committee. In 2012,

CEC Panda&Fudan University Flat Panel Display Technology Research Center was established. In December 2012, Jiangsu Province (CEC Panda) Flat Panel Display Engineering Technology Research Center was also established.

The formation of a supply system of industrial chain and the expansion of horizontal and vertical cooperation with enterprises were also considered to be very important by the CEC Panda Group at the beginning of the G6 project construction. Since 2010, the CEC Panda Group has had a lot of contact with the core suppliers of panel materials and it has signed a confidentiality agreement and long-term cooperation letter of intent with the glass substrate supplier Corning. They also signed a long-term supply agreement with Japan Toppan on CF and signed a strategic cooperation agreement with Dainippon Printing Co., Ltd. (DNP). They cooperated with Merck in Japan on liquid crystal materials, cooperated with Nitto Denko and Sumitomo Chemical on polarizers, cooperated with upstream suppliers such as Toyota Synthetic and CEC Lighting on the backlight, cooperated with Panda Electronics on module, and cooperated with CEC's Solomon Systech on driver IC. The CEC Panda Group have also established a good communication mechanism with the downstream of the industrial chain, including having a regular communication mechanism with TPV to promote related cooperation issues. The CEC Panda LCD Company determined the product specifications with TCL, Skyworth, Konka, and other companies in order to enable the 6th generation line products to meet market demand. At the beginning of the G6 project construction, Sharp Company promised to underwrite 30% of the products. At the same time, the CEC Group has a complete downstream industrial chain. The good market environment helped to appease concerns regarding sales, allowing for the company to focus on technology research and development.

Tables 5 and A2 lists the innovation subjects and innovation environment in the incubation period. During this period, the focus had been to quickly get the entire technological innovation ecosystem running. Thus, the local government fully promoted the construction of core enterprises and infrastructure environment. It also created a suitable policy environment and cultural environment to steer all parties in providing convenience and services and boosting enthusiasm for enterprise construction. The primary goal at this stage was to learn, absorb, and apply the technology since CEC Panda Group had just introduced advanced technology. While studying the technology, the CEC Panda Group actively pursued cooperation with institutions to improve personnel training and technology research and development. It also started collaborating with different enterprises in the industry chain, laying the foundation for future development of the company. During the establishment of the technological innovation ecosystem, the technical cooperation network within the system became complex, with both horizontal and vertical cooperation. The innovation environment and willingness of the core subjects in this period also played essential roles in advancing the development of the technology innovation ecosystem.

Table 5. The Innovation Subjects in The Incubation Period of Technological Innovation Ecosystem.

Innovation Subjects						
Core Subjects			Auxiliary Subjects			
Core Enterprise	**Related Cooperative Enterprise**	**Scientific Research Institution**	**Government**	**Intermediaries**	**Financial Institution**	**Science and Technology Park**
CEC Panda LCD Company	Sharp, Japan Merck, Japan Toppan, Toyota, Sumitomo Chemical, etc.	Nanjing University of Science and Technology, Southeast University, Fudan University, Jiangsu Province (CEC Panda) Flat Panel Display Engineering Technology Research Center, etc.	National and local government	Nanjing Flat Panel Display Industry Association	Bank	LCD Valley

5.3. Development Period of Technological Innovation Ecosystem (2013–2017)

5.3.1. Innovation Environment

(1) Policy Environment Guidance

During this period, the liquid crystal display industry was in a stage of rapid development, and various manufacturing and process technologies related to liquid crystal displays were emerging. Under the guidance of the government, domestic LCD companies had been catching up, and the technology gap in the field of a-Si TFT-LCD had narrowed. In some respects, it had reached the level of international prominence. The domestic and international LCD industries attained comparable technical levels, particularly in the new display industry. The national government's policy guidance for the liquid crystal display industry had gradually shifted from technology catch-up to the cultivation of the "localized" LCD industry chain. In the tariff implementation plan that was announced by the Ministry of Finance at the end of 2013, the tariff of panels remained unchanged at 5%. Tariff improvement policies had been implemented to the key materials of the upstream part.

(2) Foundation of Innovation Environment for New Production Line Construction

The Nanjing Municipal Government promoted the development of the LCD industry by strengthening organizational leadership, guiding industrial planning and training, introducing talents, accelerating the construction of the Nanjing LCD Valley, promoting major projects of the new display industry, actively expanding financing channels, and creating an industrial development environment. Under the favorable policy support and the distinctive attributes of the 6th generation products, the CEC Panda Group expanded the production of the G6 project in a highly favorable market environment. Additionally, with the strong support of the CEC Group and the Nanjing Municipal Government, the CEC Panda Group launched the construction of the G108 project.

5.3.2. Technological Development of Core Enterprises

The talent team developed rapidly and the CEC Panda Group had become prepared for the development of a higher generation production line due to the addition of technical personnel training and practical experience in the G6 project. Under various conditions, the CEC Panda Group established the CEC Panda Tablets Co., Ltd., with an investment of 29.15 billion yuan for the construction of the G108 project. The G108 project was constructed on the north side of the G6 project, covering an area of 850 acres. From the pile foundation construction on July 20, 2013, it only took 20 months for the G108 project to be tested in 2015. The construction volume of the project was equivalent to two national grand theatres. The design capacity of the 8.5 production line that was used in the G108 project was 60K glass substrates (2200 × 2500 mm) per month, with an annual production capacity of 93.93 million LCD panels. The product specifications included 4.7 inch, 7.0 inch, 10.1 inch, 13.3 inch, and 55 inch ultra-clear (4K × 2K) TFT-LCD, and products comprised of smartphones, tablets, notebooks, TV panels, and modules. The new technologies included metal oxide TFT (IGZO), 4K×2K, UV2A, FFS, thinning, copper wiring, touch screen, low-power stop drive, ultra-narrow bezel, and 4Mask color film, among others [43].

In 2014, the CEC Panda Group started to implement localization promotion plans for raw materials, such as glass, targets, special gases, chemicals, liquid crystals, and polarizers. As of December 2016, the total number of patents that were filed by CEC Panda LCD Company had been 648, including 392 invention patents, and published the monograph "TFT-LCD Principles and Design". On January 6, 2016, the CEC Panda Tablets Company announced the world's first 55-inch 4K LCD TV with IGZO technology, which was launched in April 2016. On January 6, 2017, the world's first 98-inch 8K LCD TV Heaven View with IGZO technology was launched with a resolution of 7680 (RGB) × 4320 and a screen refresh rate of 120 Hz, the highest level in the industry. The 6th generation line and the 8.5th generation line have been put into the glass substrate for 150K per month, ranking third in the country [37] since the G108 project was put into production.

5.3.3. Platform of Technological Cooperation Network

In 2014 the CEC Panda Tablets Company invested 1.535 billion yuan to build the Flat Panel Display Engineering Technology Research and Development Center, while providing technical support for G6 and G108 projects in order to further improve the innovation capability of enterprises, with the support of the policies and funds of the national and local governments. The R&D center was built to become a leading leader hub in China and the world's advanced integrated R&D platform in the flat panel display field. Through the platform, a channel of technological innovation can be built for research institutions and related cooperative enterprises. The R&D center can drive the overall development of flat panel display technology, given the advantages of production, education, and research. By accelerating the industrialization of R & D achievements, technical bottlenecks in production can be resolved. By contributing and refining in the construction of the national technology standard system, the R & D center was able to establish technical command position of core enterprises. Cooperation among enterprises advanced the standardization in the construction of industry technology standards. At the same time, the R&D center had become active in training high-level professionals and innovative talents for creating the conditions needed for the development of new display technology in China and competitiveness with international first-class enterprises. Through the industry technology service platform provided by the R & D center, technical advisory services and product testing services for cooperative enterprises had been provided to enhance the cohesion of technological innovation network cooperation. Additionally, testing new technology on the R & D platform could significantly reduce the development cost of new technology and equipment.

Tables 6 and A3 list the innovation subjects and innovation environment in the development period of technological innovation ecosystem. In this period, the domestic technology level was no longer weak and passive. The policy environment at the national level began to guide the development of the LCD industry towards nationalization, in order to reduce dependence on raw materials in the upstream of the industry. The Nanjing Municipal Government shifted its function from directly participating in the construction of the technological innovation ecosystem of core enterprises into maintaining and fostering a good innovation environment. The core enterprises had been significantly upgraded through progress at the technological level. The demand for technological innovation, which made core enterprises as the leading innovators, has become the main driving factor for further development in the technological innovation ecosystem.

Table 6. The innovation subjects in the development period of technological innovation ecosystem.

Innovation Subjects						
Core Subjects			Auxiliary Subjects			
Core Enterprise	**Related Cooperative Enterprise**	**Scientific Research Institution**	**Government**	**Intermediaries**	**Financial Institution**	**Science and Technology Park**
CEC Panda LCD Company (G6), CEC Panda Tablets Company (G8.5)	Sharp, Hefei Rainbow, Beijing Youyan, Lida Optoelectronics, Collide, Jiangyin Runma, Beixu Electronics Chengzhi Yonghua, Shenzhen Shengbo, Shenzhen Sanlipu, etc.	Flat Panel Display Engineering Technology Research and Development Center	National and local government	Nanjing Flat Panel Display Industry Association	Bank	LCD Valley

5.4. The Whole Process Evolution of Technological Innovation Ecosystem

Figure 2 shows the development of the LCD technological innovation ecosystem of the CEC Panda Group and the change of relationship among the participants in the three stages of evolution based on the above case analysis.

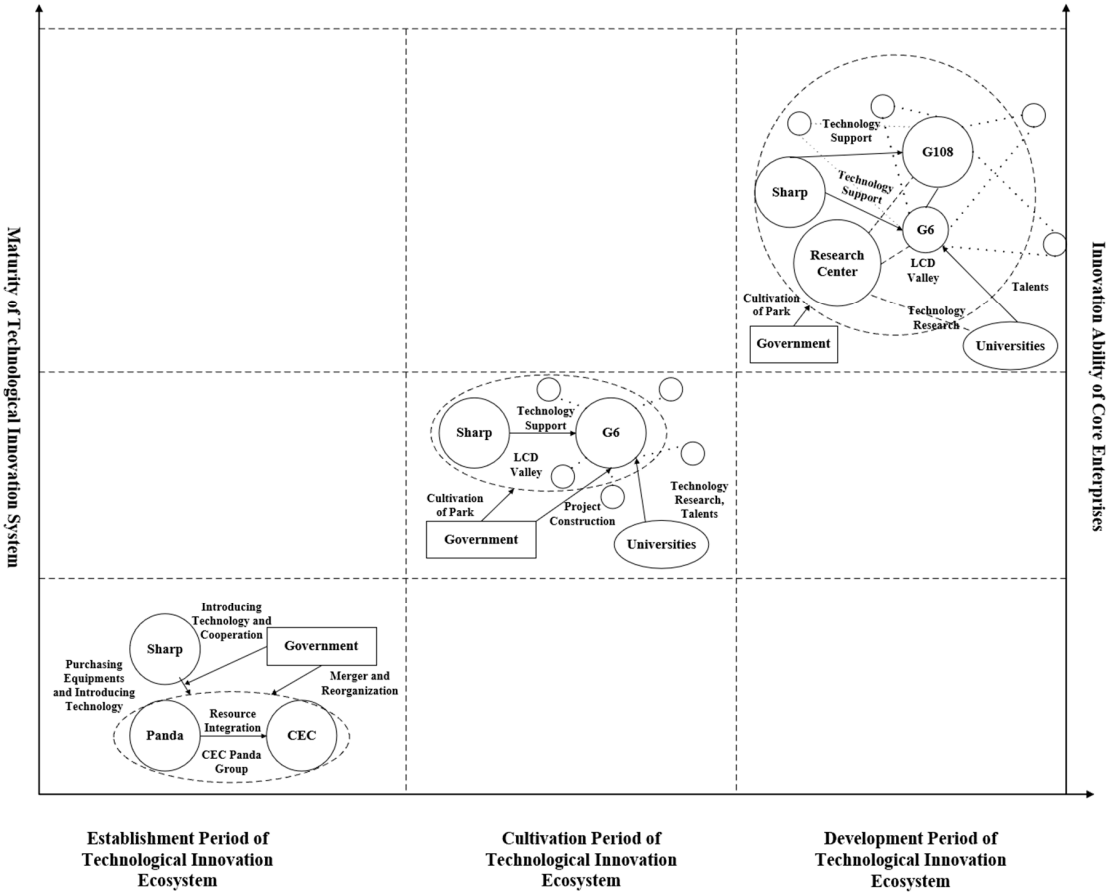

Figure 2. The Development of the LCD Technological Innovation Ecosystem of CEC Panda Group (Note: Small circles connected with core enterprises through dotted lines represent related enterprises in the technical cooperation network.).

The cooperation network of the LCD technological innovation ecosystem of the CEC Panda Group in three stages is composed of different innovation subjects, and its network structure has transformed from simplicity to complexity.

1) Formation period. In the first stage, the Nanjing municipal government promoted the resource integration of the CEC Panda Group and it played an important role in the formation of the innovation network of the technological innovation ecosystem. The CEC Panda Group horizontally cooperated with Sharp Company regarding technological cooperation network. The CEC Panda Group imported Sharp's equipment and technologies to form a one-way technological cooperation network to absorb technology and knowledge from Sharp Company.

2) Incubation period. At this stage, Nanjing Municipal Government promoted the construction of the G6 project of the CEC Panda LCD Company and actively advocated for the construction and cultivation of the LCD Valley Science and Technology Park. Regarding the development of technology learning, aside from continuing the horizontal cooperation with Sharp Company and acquiring technical support, the CEC Panda Group also established agreements with Southeast University, Nanjing University of Science and Technology, and Fudan University to promote its own technological innovation. However, the full technical support provided by Sharp Company encompassed production to management due to CEC Panda LCD Company still being at the stage of learning new equipment and technologies. As for the industrial chain, the CEC Panda Group established long-term cooperation agreements with leading enterprises of raw materials in the upstream of the industrial chain, such as Japan Toppan and Dainippon Printing Co., Ltd.. to form vertical technical cooperation in order to build a sound supply system. Uniform standards on product specifications were also established with

Guanjie Science and Technology, TCL, Skyworth, and Konka, among others, in the downstream of the industrial chain to ensure the production and sales of products.

3) Development period. Based on the technological cooperation network of the G6 project, the CEC Panda Group established a dual-core technological innovation network that was composed of the G6 project and the G108 project. A flat panel display engineering technology research and development center was established to serve as platform for new technology development, debugging, and production-university-research cooperation in order to further improve its innovation level and reduce the failure cost of innovation. The CEC Panda Group established long-term vertical cooperative relations with domestic companies, such as Hefei Rainbow, Beijing Youyan, Lida Optoelectronics, and Colid to reduce the dependence on the technology and products of foreign enterprises and to vigorously promote the localization of key materials for the G6 and G108 projects. At this stage, the Nanjing Municipal Government transformed from being a direct participant and promoter of technological innovation cooperation network into becoming the service provider of technological innovation ecology that delivers good ecological environment. In the future, CEC Panda Group will lay out a more advanced LCD production line in LCD Valley, will continue to improve the relevant supporting industry chain, and will form a three-core driven technological innovation ecosystem. With the network structure of technological innovation network becoming increasingly complex, the stability of the system and the innovation level of core enterprises will continue to become higher and higher.

5.5. Evolutionary Driving Mechanism of Technological Innovation Ecosystem

The internal driving factors in the evolution of the technological innovation ecosystem come from the technological demands and innovative willingness of the innovation subjects, which are dominated by core enterprises. The external driving factors emanate from the external innovation environment of the technological innovation ecosystem, which includes pressure driving factors and support driving factors. Pressure driving factors mainly originate from the market environment, technology environment, and resource environment. The pressure driving factors of the market environment refer to the market share and market demand pressure. The pressure driving factors of the technology environment refer to the level and status of technology in the industry within the ecosystem. The pressure driving factors of the resource environment is the availability and free utilization of innovation resources. Support driving factors arise from the policy and legal environment, cultural environment, financial environment, and infrastructure environment. Figure 3 summarizes the driving modes of the three stages of the technological innovation ecosystem evolution of the CEC Panda Group.

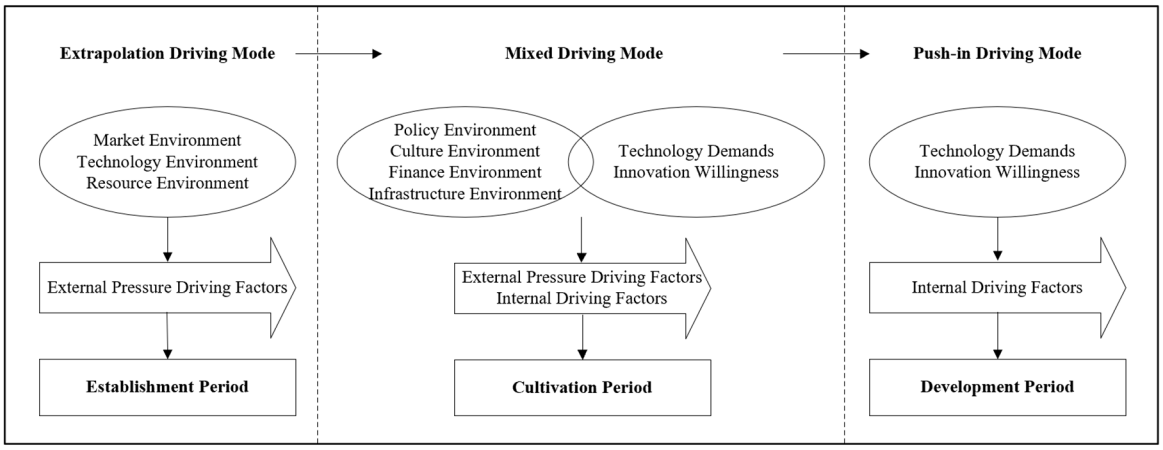

Figure 3. Evolution of Technological Innovation Ecosystem and Change of Driving Mode.

The three stages of the LCD technology innovation ecosystem of CEC Panda Group are in different innovation environments. The continuous interaction between innovation subjects and the innovation environment drives the continuous growth of the technological innovation ecosystem. Its driving mode has evolved from extrapolation-driven, to mixed-driven, and into push-in-driven.

(1) The development period of the technological innovation ecosystem—extrapolation driving mode. During this period, China's LCD technology was at a backward level. The core technology was basically in the hands of foreign enterprises. Almost all of the LCD panels required for domestic production had to be imported every year. The domestic LCD industry was in a disadvantageous market, resource, and marginalized technology environment. A series of encouraging and guiding policies had to be issued at the national level to create a good industrial policy environment in order to encourage the development of LCD technology. Coupled with its own urban development needs, the Nanjing Municipal Government seized this opportunity, promoted the restructuring of the CEC Group's resources for Panda Electronics, and actively promoted the technological cooperation between CEC Panda Group and Sharp company. The goal was to revitalize the "Panda" brand and build a leading domestic and world-class LCD industry chain. In such a culture environment, the Nanjing Municipal Government directly participated in the establishment of a technological innovation ecosystem with the G6 project as core, and established a conducive finance and infrastructure environment for resource reorganization and technology importation.

Among the various environmental factors, the pressures from the market, resource, and technology environment became the primary external driving factor for the government to promote industrial development and consequently led to the establishment of an LCD panel technology innovation ecosystem by the CEC Panda Group. During this period, although core enterprises had their own internal motivations for development, their development goals were still mainly limited, which were mainly geared towards getting out of fiscal deficit and following the development of advanced technology.

(2) The incubation period of the technological innovation ecosystem-mixed driving mode. During this period, the market environment of LCD TV became fierce. The policy environment at the national level transitioned from guidance to promotion in order to speed the development of the LCD industry. The Nanjing Municipal Government actively advocated for the development of the "LCD Valley" Science and Technology Park and focused on promoting the G6 project construction of CEC Panda Group to create a good technological ecology environment required for the development of core enterprises. The Nanjing Municipal Government and CEC Group listed the construction of the 6th Generation Line as "No.1 Project", and all government departments in Nanjing contributed in creating the suitable conditions for the infrastructure environment construction of the G6 project and ensured that the project can be completed quickly and immediately become operational. The Nanjing Municipal Government issued preferential tax and other supporting policies to attract related enterprises for the LCD Valley, form industrial clusters, and improve the vitality and maturity of the ecosystem in order to better cultivate the technological innovation ecosystem with the G6 project as core. The CEC Panda Group was able to learn from previous failures in enterprise development. When establishing the G6 project, the development idea of "cultivating talents, innovating, and developing" was always front and center. In this period, driven by the joint efforts of the government and enterprises, the LCD technology level of CEC Panda LCD Company had rapidly upgraded, approaching the global competitiveness level.

During this period, with the support from the government, a favorable policy, finance, culture, and infrastructure environment had been formed. Supported by these four external support driving factors, coupled with the foundation of the core enterprises' development in the previous stage, the technology level gradually reached the international advanced level. Its technological innovation network changed from being simple to complex, and the pressure driving force gradually reduced, while the technological demands and innovative willingness of the innovation subjects, which was

dominated by core enterprises, gradually increased. Thus, the external and the internal driving factors both promoted the evolution of the technological innovation ecosystem.

(3) The development period of the technological innovation ecosystem—push-in driving mode. During this period, the domestic LCD industry was no longer in a backward and marginalized state The focus of development of the LCD industry was no longer simply to pursue the most advanced technology, but to pursue a healthy development of technological innovation ecosystem, in order to improve the level of technological innovation and reduce the dependency on raw materials and other resources upstream of the industrial chain. During this period, the country promoted the "localization" of the development of the LCD industry by raising tariffs on some key materials in the upstream of the LCD industry. The Nanjing Municipal Government also transformed its role in the technological innovation ecosystem from being a direct participant during the formation, into becoming the service provider of the ecosystem's outer circle. In the aspect of industrial planning and guidance, its primary duty had shifted from introducing talents to instituting good policy and developing an infrastructure environment. However, during this period, the production of the 6th generation line could not meet market demand. The CEC Panda Group launched the G108 project and the flat panel display engineering technology R&D center, which formed a technological innovation ecosystem driven by both the G6 and G108 project in order to realize the vision of becoming a first-class new display industry base and leading R&D platform. In terms of the technology environment, the IGZO technology that was used in the G108 project was able to reach the first-class level globally. In terms of resource environment, the CEC Panda Group actively promoted the localization of raw materials under the guidance of national policies, which consequently led to some core raw materials being fully localized.

During the development period of the technological innovation ecosystem, the policy, culture, finance, and infrastructure environments gradually matured, which significantly improved the development speed of LCD panel technology. The technological level of core enterprises gradually reached leader status in the industry. Given the constant technological change and increasing market competition, the innovation subjects that were dominated by core enterprises showed strong innovation willingness, which then became the main driving force promoting the further evolution and development of the technological innovation ecosystem.

6. Conclusions and Discussion

6.1. Research Conclusion

This paper constructed a framework of the technological innovation ecosystem, including innovation subjects and innovation environment, based on the innovation network theory and industrial cluster theory. The evolution process and driving mechanism of the technological innovation ecosystem were analyzed while using the CEC Panda Group as a case study. The study found that the development of the technological innovation ecosystem has undergone three stages of evolution: the formation period, the incubation period, and the development period. The innovation environment of the ecosystem has been the external driving factor, while the innovation subject has been the internal driving factor. These two factors have mutually contributed to the development of the technological innovation ecosystem.

During the formation period of technological innovation ecosystem, the market environment, the technological environment, and the resource environment are the main external pressure-driven forces. Government departments are geared towards forming external support-driven forces at the level of policy environment, legal environment, culture environment and finance environment, and promoting enterprises that would develop to meet the market and technological demands and participate in the construction of technology network of core enterprises. The necessary members and environmental factors in the system have not yet formed in the early stages of establishing the technological innovation ecosystem, and the technological status and capability level of the core enterprises are weak. The direct guidance and participation of government can accelerate the formation

of the technological innovation ecosystem. When the necessary members of the system are connected and formed and the necessary environmental factors (e.g., infrastructure and finance environment) are present, the technological innovation ecosystem will enter the incubation period. During the incubation period, the maturity of the newly formed technological innovation ecosystem is insufficient, and the degree of connection between the core enterprises and the innovation subjects is low. The government, as the main driver, has to continue in promoting the core enterprises towards a higher level of technology by supporting the policy, finance, and infrastructure environment. At the same time, the government needs to stand at a higher strategic level to create a high-objective culture environment for the technological innovation ecosystem. With the technological development of core enterprises, their position in the technological environment can gradually improve. Enterprises become more active and initiate the construction of technological innovation networks by themselves. With the completion and stability of the technological innovation network centered on core enterprises, the technological innovation ecosystem enters the development period. During this period, the culture environment, which is created by the internal innovation and development demands of core enterprises, becomes the main driving force for the growth of the technological innovation ecosystem. The government is no longer required to directly participate in the construction of technology network within the system, and it shifts towards improving the ecological environment and guiding the healthy development of industries through policy and legal environment. This paper has contributed to the construction of a technological innovation ecosystem that is based on core enterprises and towards understanding on how to accelerate the development of the technological innovation ecosystem.

6.2. Discussion

Chinese enterprises always have "innovation inertia", especially in technology-intensive manufacturing enterprises. Most enterprises are always passively following in technology for the sake of stability in development because of the high innovation cost and long R & D cycle of manufacturing industries. This leads to the widening gap between the technological level of enterprises and the technological level abroad, and the increasing dependence of enterprises on external technological resources. As Neslen (2015) pointed out, enterprise transformation is a "top-down" painful process. LCD screen is a high-tech and high-investment industry [24]. For most companies, even if they know that their technology is backward, they are unwilling to invest money towards improving their technical level due to excessive investment and risk. For example, in the early days of Panda Electronics, they were willing to give up their original LCD screen business and switch to other low-cost electronics industries, rather than investing more in their own technology. In this context, the direction and support from the government become particularly important. The government's direct guidance and assistance through policies, economic incentives, and infrastructure development can significantly promote innovation and development in enterprises and reduce existing concerns regarding innovation costs. Another example is BOE Technology Group, the company that has developed well in China's LCD industry. This company currently has a world-class AMOLED panel production line. The company received substantial government funding between 2009 and 2012, with total funding exceeding the total profit. In the early stages of BOE's development, government subsidies became the main source of its performance and management surplus. Subsequently, BOE's operating capacity and profitability gradually increased. After which, the proportion of government subsidies gradually declined and settled below 50% [44]. The self-employment ability of enterprises has been significantly improved.

Enterprises should be mindful with regards to the process of innovation development. Constructing an innovation ecosystem with itself as the core can improve the innovation vitality of enterprises and mobilize more resources to support innovation activities. One example is the BOE Technology Group, which in the 1980s did not even enter the emerging CRT technology field. In the early 1990s, under a government-sponsored shareholding system reform, CRT and related technologies were introduced in a joint venture with Asahi Glass Co., Ltd., and the technology was completely dependent on the technology's home country. The raw materials were almost all exclusively

from Japan. In order to have its own core technology, in 2001, BOE acquired the TFT-LCD 2nd, 3rd, and 3.5th generation production lines of Hyundai Display Technology Co., Ltd. and established its 5th generation TFT-LCD production line in Beijing. It steadily cooperated with domestic companies in terms of raw materials, and began to build good ecological interaction with research institutes, industry associations, and financial institutions. By 2011, the BOE Technology Group gradually shifted its strategic focus from manufacturing into combined R&D and manufacturing [45]. Like the CEC Panda, BOE Technology Group also built a technology research and development center. The construction of the sixth-generation AMOLED production line in Chongqing in 2018 heralded the formation of the BOE Technology Group's polycentric innovation ecosystem.

The structure of the technological innovation ecosystem of core enterprises is not permanent. Its growth evolves along with the technological development of enterprises and changes in the cooperative network structure. The interaction between the innovation subject and innovation environment dominated by core enterprises is the fundamental driving force thrusting the evolution of the technological innovation ecosystem. The government needs to stand in a higher direction. Enterprises are required to have long-term development vision, make good use of their own and surrounding innovation resources, and build a technological innovation ecosystem that is suitable for their own development. Enterprises fully mobilize the internal innovation power of innovation subjects, being driven by the external pressure innovation environment and supported by the external support innovation environment, and realize the sustainable evolution of technological innovation ecosystem with the concept of innovation development and sharing.

6.3. Theoretical Significance and Research Prospect

This paper has the following theoretical significance:

1) We analyzed how Chinese manufacturing enterprises can achieve technological catch-up by means of technological innovation ecosystem. We examined the bottlenecks that need to be addressed and the conditions that they require for leaping-frogging technological growth, which would contribute to enriching the discussions on technology catch-up theory for late-developing enterprises with open innovation. For industries with substantial investment and high technology content, realizing technology investment by solely relying on funds and the will of the company itself would be difficult. Government guidance and support are of particular importance. With government assistance, enterprises can increase their technical investment without considering short-term gains. Although the company's development at the early stages is highly dependent on foreign technology, as the demand for innovation increases, an ecosystem, with itself as the core, is eventually formed through cooperation with enterprises, universities, and other organizations, will gradually improve its own research and development level, and will finally get rid of technological dependence.
2) We discussed the evolution mechanism of the technological innovation ecosystem for Chinese manufacturing enterprises and the interactive driving modes of the internal and external environment. This would help to explain the inherent law of technological innovation ecosystem evolution, particularly for technology-intensive enterprises. Different drivers at different stages propel the evolution of the technology innovation ecosystem that is built by core enterprises. The driving forces at the earliest (formation) stage of the technological innovation ecosystem were driven by pressures from the external market environment, technical environment, and resource environment. At the second (incubation) stage, the driving forces are primarily directed by four external factors (i.e., policy environment, cultural environment, financial environment, and infrastructure environment), the internal technological demand, and the innovation willingness of enterprises. At the third (development) stage, technological demand and the innovation willingness of enterprises mainly drives the progress in the technology innovation ecosystem.

3) Previous studies have mainly focused on the cooperative relationship among enterprises and universities, but less on the role of government departments. Here, we discussed the role of government in technological innovation in detail. In the context of external system and policy support, government support includes the creation of cooperative innovation relationships through policy guidance, and influencing the track of technological growth of enterprises. We found that early government guidance can solve the problem of "innovation inertia". With the development and expansion of enterprises, the direct guidance of government gradually transitions into indirect supervision, leading enterprises to become more independent and paving the way for a more conducive innovation environment.

The findings in this study provide some insights for promoting technological catch-up, particularly for late-developing enterprises: (1) The technological growth process of late-developing enterprises has the characteristics of leapfrogging periods. At different stages, enterprises face unique growth bottlenecks, which makes it necessary to consider the external environment factors, the current technological upgrading needs, and the internal capabilities and resources. Enterprises should formulate targeted innovation strategies and ensure suitable matching and synergy between the external environment and the innovation subject in order to break through these bottlenecks. (2) In the construction of technological innovation ecosystem, late-developing enterprises should pay attention to the gradual transformation from initial "contract coordination" to "strategic coordination". This would promote the sustainable development of technological innovation ecosystem, strengthen technological learning based on external cooperative innovation network relationship, overcome technological barriers, gradually accumulate technological advantages, and foster strong independent innovation ability through technology absorption, application, and transformation. (3) Government departments should promote the technological catch-up of late-developing enterprises, especially technology-intensive manufacturing enterprises, by strengthening organizational leadership and guidance in industrial planning, training and introducing talents, actively broadening financing channels, and creating an industrial development environment.

More case studies would have to be undertaken to verify the conclusions of this study in order to overcome the constraints of analyzing a single particular case. Additionally, while this study examined the construction and evolution of innovation cooperation networks, there is still a significant shortage of discussion regarding network structure characteristics and innovation ecosystem construction. In the future, social network analysis (SNA) and multi-agent system modeling methods will have to be introduced in the conversation to strengthen the quantitative analysis of related issues and expand existing research on innovation cooperation network theory.

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Appendix A

Table A1. Innovation Environment in the Formation Period of Technological Innovation.

Innovation Environment		Typical Examples	Keywords	Coding Result	References
Market Environment		In the second quarter of 2005, Sharp's global LCD TV sales reached 750,000 units, and its annual sales are expected to exceed 300 units. The combined sales of LCD TV in all domestic enterprises are less than half of its total.	Sales volume, market share	The market environment is under great pressure.	[46]
Technology Environment		1. The investment of a 4th generation line of LCD panel is 7.5 billion yuan, the fifth generation line is 10 billion yuan, and the sixth generation line is 20 billion yuan. Excessive capital and technical barriers make it difficult for domestic enterprises to enter this industry. 2. The lack of core manufacturing industry makes Chinese color TV companies lose their voice in the competition of LCD era and become a "marginalized" group.	Technical barriers, technology marginalization	The technical environment is not friendly and the technical level is low.	[47]
Resources Environment		At present, China produces and sells hundreds of millions of color TV sets annually, 80% of which are flat panel TV. But almost all the LCD panels needed for TV production depend on imports, with an annual import of nearly US$40 billion, making it the fourth largest single import commodity after oil, iron ore and chips.	LCD panel depends on import	Resources depend on imports and are subject to constraints	[48]
Policy Environment	**National**	1."Outline of National Medium and Long Term Science and Technology Development Planning (2006–2020)", 2."Special Project for Specialization of Flat Panel Display Devices", 3. "Notice on Continuing to Organize and Implement Special Issues Concerning Industrialization of New Flat Panel Display Devices", 4."Notice on Several Policies to Encourage the Development of Digital Television Industry", 5."Eleventh Five-Year Plan for Informatization of National Economic and Social Development", 6."Planning for the Adjustment and Revitalization of Electronic Information Industry", 7. "Notice on Preferential Policies for Import Tax to Support the Development of New Display Industry"	Priority development, promotion of union, expansion of scale and cultivation of independent innovation ability	Promoting the development of flat panel industry in policy environment	1. [49] 2. [50] 3. [51] 4. [52] 5. [53] 6. [54] 7. [55]
	Local	1."Nanjing Ten Industrial Chains Development Action Program", 2."Software Industry Revitalization Plan and Electronic Industry Rejuvenation Plan", 3."Some Policy Opinions on Accelerating the Development of New Display Industry in Nanjing"	Focus on supporting, promoting technological innovation and creating a good policy environment	Strongly support the development of flat panel industry in policy	1. [56] 2. [57] 3. [58]
Culture Environment		Make "CEC Panda" a first-class electronic high-tech enterprise with international influence and vigorously revitalize the brand of "Panda"	Create a first-class brand	To become the first-class goal at home and abroad	[59]
Finance Environment		1.Nanjing SASAC, CEC Group, Jiangsu Guoxin Asset Management Company and other companies restructure and invest resources in China Electric Panda. 2.In the form of loan discount, the central government has allocated 20 billion yuan of special funds for technological renovation, giving priority support to six aspects, such as new display and transformation of color TV industry.	Resource restructuring, capital investment, loan discount	Good financial environment and sufficient funds for restructuring	1. [60] 2. [61]
Infrastructure Environment		The LCD Valley of the 6th Generation Line Project is located in the economic and technological development zone of Qixia District, Nanjing, adjacent to Xianlin university town, which has a good geographical environment advantage.	Construction location has geographical environment advantage	Good infrastructure environment	[62]

Table A2. Innovation Environment in the Incubation Period of Technological Innovation Ecosystem.

Innovation Environment		Typical Examples	Keywords	Coding Result	References
Market Environment		The advanced technology, excellent product performance indicators and complete downstream industry chain of CEC Group, the 6th generation project market is fully guaranteed.	Market guarantee	Low market pressure	[41]
Technology Environment		The introduction of new technology has made this line the most advanced 6th generation line in the world, and its main performance indicators can reach the optimal level among domestic and foreign counterparts.	Close to the world's leading level	Reduction of technology environment pressure	[39]
Resources Environment		A large number of contacts and cooperation agreements have been signed with the core suppliers of LCD panel raw materials.	Suppliers of LCD panel raw materials, cooperation agreements	Develop cooperation to reduce resource constraints	Retrieve from interview records.
Policy Environment	National	1."Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries", 2."Investment in Technology Progress and Technology Transformation of Equipment Manufacturing Industry (2010)", 3."Currently Prioritized Guidelines for Key Areas of High-Tech Industrialization (2011)", 4."Industrial Transformation and Upgrading Plan 2011–2015", 5. "Guide Catalogue for Major Innovations in Major Technical Equipment", 6."Twelfth Five-Year Development Plan for Electronic Information Manufacturing Industry", 7."Electronic Special Equipment 12th Five-Year Plan", 8. "The 12th Five-Year National Strategic Emerging Industry Development Plan", 9."The New 12th Five-Year Plan for Display Technology Development"	Overall planning, rational layout, and vital support	Rational construction of the industrial chain	1. [63] 2. [64] 3. [65] 4. [66] 5. [66] 6. [67] 7. [68] 8. [69] 9. [70]
	Local	1."Nanjing LCD Valley Industry Development Plan (2010–2015)", 2."Notice of the Municipal Government on Promulgating the Top 50 Industrial Enterprises (Groups) and the List of 50 Key Investment Projects of Industrial Upgrades in 2012", 3. "Notice of the Municipal Government Establishes the Leading Group for the Promotion of Nanjing LCD Panel Projects"	Pushing forward and supporting vigorously	Promoting the construction of flat industry chain based on LCD valley	1. [71] 2. [72] 3. [73]
Culture Environment		For the 6th generation line construction, two mandatory guarantees are required. First, to ensure the construction period. It is necessary to achieve the goal of not returning, the standard is not falling, and the time is unchanged. Second, to ensure the level, we must ensure that the 6th generation line will produce products with the 8th generation line or even 10th generation line level and build the world's best 6th generation line, reflecting the technical competitiveness of Nanjing 6th generation line.	Speeding up construction, leading quality standards in the world, guaranteeing project progress and introducing high-end technology	Promoting the rapid and sound construction of the 6th generation line	[40]
Finance Environment		Through preferential policies and taxes, Nanjing has provided a suitable environment for the further development of the flat panel display industry. It has attracted many flat-panel display companies and has driven a large number of supporting projects to follow up quickly. Currently, an industrial cluster represented by TFT-LCD has been formed.	Preferential tax policy	Good finance environment	[74]
Infrastructure Environment		In order to create a suitable infrastructure environment for the future development of the 6th generation line, in the case of the fire protection design of the 6th generation line giant factory, there is no ready-made standard in the country, the provincial and municipal fire departments help them to design a reasonable plan; With the help of the gas and other departments, the power supply and gas supply facilities of the 6th generation line were built and used in the fastest time.	Creating a good technology environment	Building a sound infrastructure environment	[39]

Table A3. Innovation Environment in the Development Period of Technological Innovation.

Innovation Environment		Typical Examples	Keywords	Coding Result	References
Market Environment		The excellent characteristics of the 6th generation line products are far from meeting the market demand.	Excellent characteristics of products, far from meeting the market demand, polycentric processes, creative innovation	Low sales pressure, high market demand	Retrieve from interview records.
Technology Environment		The operation of the G108 project marks that China has broken through a key process technology in the field of new flat panel display, filling the gap in IGZO mass production technology.	Breaking through key technologies, filling gaps in technology	Technology is first-class in thecountry, leading the world	[75]
Resources Environment		Localization of core materials such as glass, target, special gas, chemical liquid crystal, and polarizer materials	Gradually realize localization	Innovative resources to realize localization, reducing resource dependence	Retrieve from interview records.
Policy Environment	**National**	1.Encourage Imported Technologies and Product Catalogue (2014), 2. 2014–2016 New Display Industry Innovation and Development Action Plan	Raw materials, increase tariffs	Guiding enterprises to develop to localization and reducing resource dependence	1. [76] 2. [77]
	Local	1."Opinions of the Provincial Government on Further Strengthening the Promotion and Application of New Technologies and New Products", 2."The Outline of the Thirteenth Five-Year Plan for National Economic and Social Development of Nanjing", 3. "Made in China 2025 Nanjing Implementation Plan (2015—2017)", 4."Notice of the Government on the Key Investment Projects for Industrial Upgrading in Nanjing in 2014"	Planning and Guiding, promoting independent innovation, accelerating the training and introduction of talents and creating a suitable industrial development environment	Focus on Creating Innovation Environment	1. [78] 2. [79] 3. [80] 4. [81]
Culture Environment		Through five years of development, achieving the goal of the first domestic industrial scale and the first independent innovation capability in the flat panel display industry. Through ten years of effort, becoming the strategic goal of the world-class flat panel display integrated manufacturer.	Domestic industry scale first, international first-class level	Pursuing development goals of innovation and leading	"Feasibility study report of CEC Panda Group"
Finance Environment		1. In January 2014, Huadong Science and Technology, a listed company of China Electronics, announced a non-public issuance plan, intending to raise more than 10 billion yuan to invest in the CEC Panda 8.5 generation line, leveraging the capital market to promote the growth of the panel business. 2. As the lead bank of syndicated loans, CCB (China Construction Bank) will continue to increase its support for CEC Panda, accelerate the development of enterprises by providing better financial services, and achieve mutual benefit and win-win between banks and enterprises.	Financing, mutual benefit and win-win between banks and enterprises	Adequate funds for technology research and development	1. [82] 2. [83]
Infrastructure Environment		Nanjing LCD Valley takes planning as the guide, takes advanced generation LCD panel project as the core, introduces upstream and downstream supporting projects, and constructs LCD industrial clusters with perfect industrial support, a high degree of industrial cluster, strong innovation ability, proprietary intellectual property rights, domestic and international orientation.	Introducing supporting projects, Improving the industrial chain, LCD industry cluster	Improvement of industrial chain	[84]

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