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Exploring the Key Driving Forces of the Sustainable Intergenerational Evolution of the Industrial Alliance Innovation Ecosystem: Evidence from a Case Study of China's TDIA

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Abstract: Why does an industrial alliance upgrade sometimes quickly and sometimes very slowly? The answer to this question can scientifically reveal the key driving forces of the sustainable intergenerational evolution of industrial alliance innovation ecosystems. From the perspective of structural evolution, we analyzed and compared the key driving forces using a longitudinal case study from the 2G to 3G, and then to the 4G innovation ecosystems of China's Time Division Industrial Alliance (TDIA). The findings showed that the internal key driving forces influencing the intergenerational evolution of the industrial alliance innovation ecosystem include the superiority of the new innovation ecosystem, the sustainability of the old ecosystem, and inheritance between the new and old ecosystems. Market demand and government policy indirectly affect the intergenerational evolution by shaping the environment in which the innovation ecosystems are embedded. This research will support industrial alliances and core members in making strategic innovation ecosystem decisions and support governments in designing related policies with scientific theoretical guidance and decision-making references. In particular, this study aimed to offer inspiration for the promotion of the successful sustainable evolution of China's TDIA towards 5G.

Keywords: intergenerational evolution; innovation ecosystem; key driving force; industrial alliance; sustainability; case study

1. Introduction

With the drastic changes emerging in global industries and technologies, international industrial competition is increasingly dependent on innovation. An industrial technology innovation strategic alliance (industrial alliance for short) is an organizational form of alliance of high-end innovation subjects in industry that aims to conquer industrial key and generic technologies, establish global industrial standards, and improve core industry competitiveness. Since the 1980s, America, Europe, Japan, and other developed countries have formed a large number of alliances to seize command of the economy and of science and technology. For example, Sematech (Semiconductor Manufacturing Technology) in America and VLSI (Very Large Scale Integration) in Japan have improved the international competitiveness of their domestic industries.

Enterprises from late-development countries need to achieve knowledge transformation and coordinate the interests of stakeholders by building an alliance [1]. According to the connection mode between the alliance actors, an industrial alliance can be classified as equity-based or contract-based [2]. In the Chinese context, most industrial alliances, such as the Time Division Industrial Alliance (TDIA), are contract-based. Industrial alliances in China construct and operate based on alliance contracts with equality and mutual benefit. Meanwhile, considering the functions of industrial alliances, i.e., quickly conquering key common technology innovation, building whole industrial chains, etc., such alliances are supported by the Chinese government. For example, Made in China 2025 and the 13th Five-year Development Program for National Strategic Emerging Industries both proposed to encourage the establishment of innovation alliances and introduce the cooperative advantages of CEEUSRO (Cooperation Education of Enterprise, University and Scientific Research Organization). In 2007, six ministries and commissions in China jointly held the "Signing and Pilot Kick-off Meeting of Industrial Technology Innovation Strategy Alliances", which formally began the pilot work of industrial alliances. By the end of June 2019, China had 146 national pilot industrial alliances, and more than 1000 industrial and regional-level industrial alliances had been established. These alliances play a positive role in the upgrading of key industries and the growth of emerging industries. With the rapid increase in the number of industrial alliances, problems such as loose organization, slow follow-up development, and the weak driving force of industrial innovation have become increasingly prominent. It is important to rapidly promote these industrial alliance transformations and upgrade them from quantity to quality to realize their sustainable development and their role in driving related industries in China.

Marked by the great success of Apple and the continual leadership of Silicon Valley, the innovation paradigm has changed and upgraded from an engineering and mechanical innovation system to an ecological and organic innovation ecosystem [3,4]. The essence of the innovation ecosystem is that innovation activities and their laws are scientifically examined in the context of technology–economic–social systems [5]. Its theoretical aspects have been widely addressed by scholars and practitioners, and related research and applications have been conducted at the micro, medium, and macro levels. Thus, the innovation ecosystem provides new requirements and highlights new directions for the sustainable development of China's industrial alliances by accelerating the transition and upgrading of industrial alliance innovation ecosystems. However, in reality, there is always the question of why an industrial alliance sometimes transforms and upgrades very quickly, while this process is sometimes very slow or even fails. From the perspective of innovation ecosystems, the differences and effects of internal and external dynamic factors influence an industrial alliance in building a new innovation ecosystem and replacing the previous one to realize sustainable intergenerational evolution.

TDIA is the earliest and most successful industry alliance in China. The standardization process of 3G and 4G, led by TDIA, is also a process of the establishment, development, and upgrading of its innovation ecosystem, which follows the laws governing the development and upgrading of innovation ecosystems of industry alliances in the context of China. Therefore, this study aimed to explore the key driving forces of the sustainable intergenerational evolution of industrial alliance innovation ecosystems by considering the long-term evolution of TDIA as a typical case. We believe that this research will be helpful for guiding TDIA to successfully evolve towards a 5G and higher level innovation ecosystem, and will offer a reference for the sustainable upgrading of other industry alliances.

The remainder of the paper is arranged as follows. First, we reviewed the relevant literature on research issues and proposed a research framework. We then proposed a research design, including research methods, research objects, and data collection and analysis. Third, we obtained and discussed the research findings from a case study. Finally, we present the conclusions, implications, limitations, and future research prospects.

2. Literature Review and Research Framework

2.1. Theoretical Concept of the Innovation Ecosystem

An ecosystem is a metaphor for close collaboration among enterprises that can be traced to Moore's "business ecosystem" in 1993 [6]. To further highlight co-innovation in the era of knowledge economy, the concept of the "innovation ecosystem" was proposed by Adner [7] and Fransman [8]. The core theoretical aspects of innovation ecosystems can be summarized as follows.

- All actors in the innovation ecosystem should have a common value proposition [7,9]. These stakeholders and their activities of value creation, distribution, and transmission to realize this common proposition constitute the value system of the innovation ecosystem.
- Innovation success lies in the close dependence between innovation subjects. It depends not only on core technology breakthroughs but also on the technical completeness of components and complements. All of these form a relatively complete technology system.
- The innovation ecosystem has a layered structure [10]. The overall performance of an innovation ecosystem is decided by both the efficiency of a value system with a common value proposition and the performance of an interdependent technology system.
- Innovation ecosystems exist in broader social–technical environments [11]. Pioneering value innovation activities challenge the existing mainstream social–technical regime.

2.2. Sustainability and Intergenerational Evolution of Industrial Alliance Innovation Ecosystem

The terms sustainable development and sustainability are used in studies concerning enterprise innovation, strategies, and related policies. The concept of corporate sustainability and its multiple dimensions are affected by multiple factors [12,13]. First, corporate sustainability represents a high level of innovation quality, and innovation plays an important role in achieving sustainability [14]. The concept of "experimentation" for sustainability transitions is designed to promote system innovation [15]. Successor knowledge and succession willingness greatly influence corporate sustainable innovation [16]. Second, value creation represents business sustainability [17]. An enterprise's sustainability depends on small businesses and their surroundings to co-create value for customers [18]. Firms acting in environmentally sensitive industries with sustainability reporting have higher market valuations [19]. Third, policy and public support are needed for sustainability transitions [20]. Different categories of network management strategies (policy mix) could be deployed to advance collaboration among actors [21].

Innovation ecosystem sustainability is accompanied by its transformation and reconfiguration. Focal enterprises advance by transforming their ecosystem from a single hub to a multi-hub and by helping their complementors co-evolve along with the developing ecosystem [22]. Sustainability transitions require actors to reconfigure their incumbent innovation ecosystems and related regimes [23]. This type of evolution involves two mechanisms, i.e., variation and selective retention [24]. The sustainable development of an innovation ecosystem requires a different mentality than that of the traditional innovation system [25]. The manner of innovation ecosystem reconfiguration likely depends on the design attributes of the product and the type of disruption experienced [26].

New entrants tend to ally with core enterprises that have more alliance partners to dynamically renew their alliance networks [3]. It is beneficial for technology to gain global recognition and realize the sustainable evolution of the alliance by opening to foreign enterprises and continuing to absorb foreign enterprises [1]. The community consists of interdependent enterprises from different levels that co-evolve and update in a continuous cycle [27,28]. As a high-end innovation alliance, the industrial alliance is committed to technology co-innovation and value co-creation to realize the common value proposition that all members should promote their sustainable innovation and development and related industries. Updating and transforming an industrial alliance is the essence of its intergenerational evolution innovation ecosystem.

The sustainable intergenerational evolution of an industrial alliance innovation ecosystem is a sustainable intergenerational upgrading process in which a new innovation ecosystem replaces the old system within the industrial alliance. This process has the dual characteristics of competitiveness and inheritance. First, similarly to competition among other types of innovation ecosystems, this process replaces the old innovation ecosystem with a new innovation ecosystem, followed by the competitive replacement process of "survival of the fittest" between their value proposition efficiency and technical system performance. Second, this process guides and absorbs more members to join the new innovation ecosystem from the old innovation ecosystem, and there is usually a certain degree of "continuity" between the ecosystems.

2.3. Key Forces Driving the Sustainable Intergenerational Evolution of Innovation Ecosystems

The structural concepts of innovation ecosystems represent a logical starting point for the exploration of the internal drivers of the evolution of innovation ecosystems [7,9]. First, the structure, position, diversity, and relationship of the main players affect the development of innovation ecosystems [29–32]. Second, the complementary assets and complementary platforms drive the synergistic evolution of innovation ecosystems [33–35]. However, these factors, which have been explored in the existing literature, are linked to the innovation ecosystem's evolution more than to its sustainable intergenerational evolution.

The sustainable evolution of innovation ecosystems is driven by multiple factors. The success of India's renewable energy innovation ecosystem benefits from supporting infrastructure construction mechanisms at the national level and enterprise entrepreneurship mechanisms at the micro level [36]. The sustainable evolution of China's new energy vehicle industry innovation ecosystem is driven by both internal and external driving forces [37]. The key forces driving the sustainable intergenerational evolution of the industrial alliance innovation ecosystem should also be explored from both inside and outside perspectives.

2.3.1. Internal Key Driving Forces

Knowledge recombination is the foundational process of most innovation [38]. As an important form, intergenerational recombination in innovation ecosystems refers to focal enterprises forming a new technology paradigm by combining old-generation technical knowledge and potential alternative technology knowledge accompanied by cooperation and competition [39]. The intergenerational evolution of innovation ecosystems is accompanied by a technology cycle that reshapes new and old technology systems and the competitive landscape of incumbent enterprises [40]. Therefore, the intergenerational evolution of industrial alliance innovation ecosystems is a cycle from one generation to another, within which a new innovation ecosystem replaces the old ecosystem. Competitiveness and inheritance between the new and old innovation ecosystems are internal key factors.

Competitiveness. A comprehensive analysis of the empirical literature indicates that research on alliance evolution has ignored the research and development of technology and the measurement of the technological lifecycle [41]. The substitution of technological innovation is restricted by the embedded innovation ecosystem [42]. Competition between old technology and substitutable technology leads to the unstable development of the current innovation ecosystem [12,43]. Both the challenges faced by emerging technologies and the opportunities for old technologies codetermine the pace of technological substitution [44]. Similarly to the competition among other types of innovation ecosystems, the intergenerational evolution of industrial alliance innovation ecosystems means that a new innovation ecosystem replaces the old ecosystem. This competitive substitution process is "survival of the fittest" between both the value proposition efficiency and the technology system performance of the two innovation ecosystems. Thus, the old value proposition efficiency and technology system performance both have the potential for further exploration, while the superiority of the new value proposition and technology system is continuously improved. These two situations form competitive driving forces between new and old innovation ecosystems within an industrial alliance.

Inheritance. Inheritance theory can explain the diffusion and persistence of innovation and is a key practice used to identify and halt detrimental aspects to form a new source and to better understand innovation [45]. Thus, some characteristics of a new technology system are inherited from the old system [46]. The continuous development of innovation ecosystems requires evolution and reconstruction [47]. The intergenerational evolution of industrial alliance innovation ecosystems is a process of absorbing more alliance members from the old innovation ecosystem to the new ecosystem. There is usually some inheritance of value systems and technology systems from an old innovation ecosystem to a new one. Thus, greater internal consistency of the value system and the technical system between the two innovation ecosystems can accelerate intergenerational evolution.

2.3.2. External Key Forces Driving

The evolution of the innovation ecosystem is also affected by the broader external environment [48]. Development opportunities, competition levels, and demand preferences has resulted in different evolution processes of the iPhone application ecosystem and led to market differences between gaming and non-gaming categories [49]. The external driving forces of the sustainable evolution of the new energy vehicle industry innovation ecosystem were mainly the market demand pulling force and the government policy guiding force [37], which is consistent with the classification of external driving forces proposed by Nemet [50].

Market Demand. Consumers' preferences vacillate between old and new technology, and focal enterprises will extend the performance of an old technology system to compete with the new technology system [51]. The layer-by-layer value adoption chain consists of value creation, distribution, and transmission to customers in relation to the interdependence among the innovation subjects, reflecting the willingness and enthusiasm of the innovation ecosystem to provide customers with comprehensive innovation solutions [7,44,52,53]. As an innovation ecosystem is differentiated from a traditional innovation system, the realizability of innovation value should always be considered [3,54]. The satisfaction of market demand with the value created and transmitted by innovation ecosystems determines the formation, development, and transformation of value adoption chains [37].

Government Policy. Alexander et al. [55] found that highly formalized legal procedures to ensure contract execution lead to high-level innovation of technology alliances. The social regime in which the innovation ecosystem is located is mainly a policy environment created by the government's macro-management [56,57]. Policies aim to guide linking activities among the three stages of research, technology transformation, and system development [58,59]. The innovation subjects (or communities) in the innovation ecosystem need to align their innovation strategies with government policies to achieve innovation success [60,61]. Policies that promote innovation ecosystems to accumulate technology and learn interactively are also included [2,11]. NASA's innovation policies have shifted from classic supply-side oriented research and development investment to policy coordination and combination. Its function has also shifted from NASA-directed development in low-Earth orbit (LEO) to the establishment of an innovation ecosystem composed of private, nonprofit, and public organizations [62,63]. Non-market, state-supported manufacturing intermediaries should focus on the cooperation of the innovation supply side and single enterprise [64]. However, when a strategy is formulated against the background of dynamic system innovation, shaping complementary and alternative exclusive regimes becomes the central point [65,66].

2.4. Research Framework

The existing literature on the connotations, structure, and evolution of the innovation ecosystem has laid a theoretical foundation to explore the possible main factors driving the sustainable intergenerational evolution of the industrial alliance innovation ecosystem. However, there is still a lack of research on these driving factors, and we need to answer this research question from the perspective of innovation ecosystem: Why does an industrial alliance sometimes upgrade quickly, and sometimes upgrade very slowly or even fail?

2.4.1. Intergenerational Evolution Situations of Industrial Alliance Innovation Ecosystems

As shown in Figure 1, assuming that the horizontal axis represents the time dimension, the vertical axis represents the performance dimension, and the performance variation of the industrial alliance innovation ecosystem follows the lifecycle S-curve, the intergenerational evolution has four situations, as follows.

- **Situation A**. The intergenerational evolution of the industrial alliance innovation ecosystem is a process in which the performance curve of the new innovation ecosystem (S_1) replaces the old one (S_0), and the performance surpasses and completes the substitution at time point T_A. This represents the substitution of the new and old innovation systems in the normal sense.
- **Situation B**. The old innovation ecosystem performance can be further explored, and its performance curve is improved from S_0 to S_0'. The substitution time point is delayed from T_A to T_B; as a result, the intergenerational evolution of the industrial alliance innovation ecosystem is delayed.
- **Situation C**. Compared with the old innovation ecosystem, the performance improvement of the new innovation ecosystem faces more challenges, and the performance curve of the new innovation ecosystem translates from S_1 to S_1'. The time point when new innovation ecosystem performance surpasses the old system is also postponed from T_A to T_c, and the intergenerational evolution will slow.
- **Situation D**. When the old innovation ecosystem's performance is continuously explored and the new innovation ecosystem's performance advantage is insufficient, the substitution time point is delayed from T_A to T_D, and the intergenerational evolution is the most difficult.

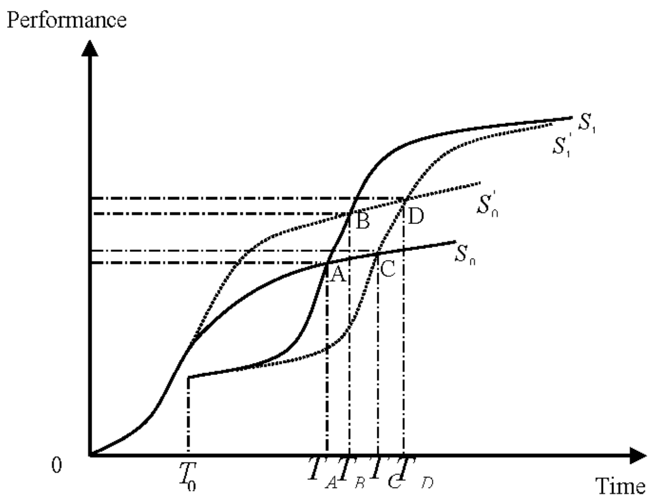

Figure 1. The schematic diagram of intergenerational evolution situations of an industrial alliance innovation ecosystem (Data source: drawn by authors based on the literature [44].

In summary, V_i is used to express the intergenerational evolution pace, and the evolution pace of the above four situations is V_A>V_B, V_C>V_D. The order of V_B and V_C depends on the performance comparison between the new and old innovation ecosystems.

2.4.2. Research Framework for the Key Driving Forces of the Intergenerational Evolution of Industrial Alliance Innovation Ecosystems

Studies have noted that the dynamic adaptation of enterprises to their alliance networks (e.g., the formation of relationships beyond the scope of enterprises) has a positive impact on innovation performance [41]. The sustainable evolution of innovation ecosystems should be driven by internal and external factors together. Based on the previous literature review, analysis of key driving forces and depicture of intergenerational evolution situation, we propose a research framework for the dynamic factors of the sustainable intergenerational evolution of industrial alliance innovation ecosystems (see Figure 2).

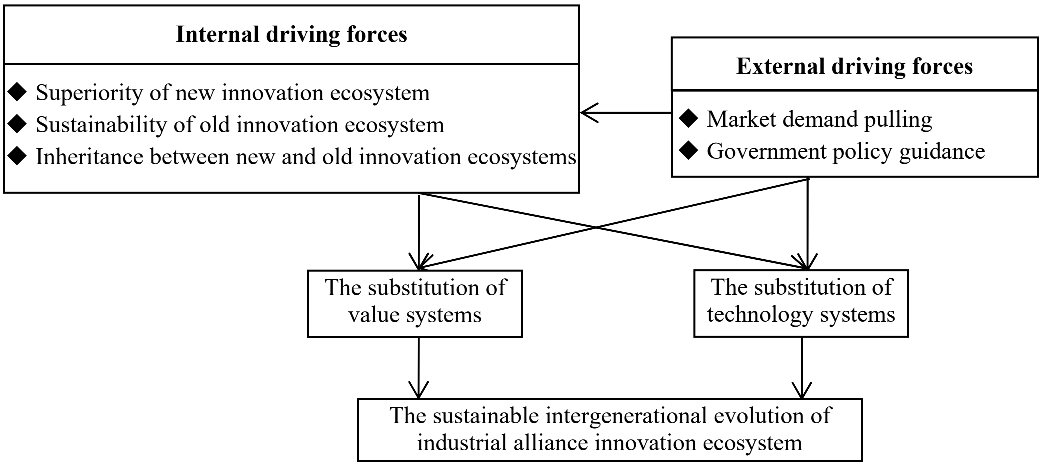

Figure 2. Research framework for key driving forces of sustainable intergenerational evolution of industrial alliance innovation systems.

The key driving forces include internal and external forces. The internal driving factors reflect the competitiveness and inheritance between the new and old innovation ecosystems within the industrial alliance, and specifically include the advantages of the new innovation ecosystem, the sustainability of the old innovation ecosystem, and the inheritance between the new and old systems. The external driving factors mainly include the market demand pulling force and the government policy guiding force. The internal and external dynamic factors affect the sustainable intergenerational evolution of the industrial alliance by shaping the different substitution situations of the value system and the technology system between the new and old innovation ecosystems.

3. Methods and Materials

3.1. Research Methods and Research Objects

3.1.1. Research Methods

The key forces and the influencing mechanism driving the sustainable intergenerational evolution of industrial alliance innovation ecosystems can be covered by a typical "why" research question. It has situational, dynamic, and complex characteristics and meets the relevant requirements for a case study [67]. In particular, a longitudinal case study can show in detail the intergenerational evolution process, the driving factors, and their complex interactions with the industrial alliance innovation ecosystem to obtain theoretical explanations. In addition, we attempted to apply the innovation ecosystem theory to explore the transformation and upgrading of industrial alliances to expand the theory through the case study.

3.1.2. The Research Target

Case objects are selected by theoretical sampling instead of probabilistic sampling [67]; that is, the selected case should be typical and unique. There were three reasons for choosing TDIA as a case study target. First, TDIA is a successful example in China with a long time span and frequent technological substitution, which meets the research need for sustainable intergenerational evolution of the industrial alliance innovation ecosystem. Second, TDIA is a successful industrial alliance innovation ecosystem attempt in China that is devoted to occupying innovation commanding points in the global communication field. It can help to show the driving mechanism of the industrial alliance to realize sustainable development via the continuous substitution of innovation ecosystems in the context of China. This analysis can also provide a decision-making reference for upgrading the industrial alliances in later-development countries. Finally, TDIA has attracted increasing attention from academia, industry, government departments, and relevant media since its establishment and has relatively abundant case materials. Therefore, we attempted to reveal the key driving forces and interactive relationship of the sustainable intergenerational evolution of the industrial alliance innovation ecosystem through an overall investigation of the evolutionary history of TDIA's innovation and development, along with a multi-stage and multi-factor analysis and comparison.

3.2. Case Data Collection and Analysis

3.2.1. Obtaining First-Hand Data through In-Depth Interviews

We proposed the research draft based on the research theme and then formulated interview outlines. The main questions used in the in-depth interviews are provided in Appendix A. We interviewed executives of TDIA, government officials, and experts in the communication industry from 2018 to 2019 (see Table A1). To conduct the interviews, we formed specific interview groups. Each interview was conducted with two to three people and lasted for 45–100 min, and the generated interview records included approximately 100,000 words.

3.2.2. Collecting Second-Hand Data through Multiple Channels

We searched for data through the official websites of China's government departments, including the State Council of China (http://www.gov.cn), Ministry of Industry and Information Technology of China (www.miit.gov.cn), Ministry of Science and Technology of China (http://www.most.gov.cn), and National Development and Reform Commission of China (https://www.ndrc.gov.cn). We searched papers, industry statistical reports, and other data related to TDIA through CNKI (https://www.cnki.net). The Baidu (https://www.baidu.com) search engine was used to look for all news reports about the innovation and development of TDIA. We also collected relevant dynamic information through the TDIA portal website (http://www.tdia.cn).

3.2.3. Verifying the Case Data by Triangulation

To resolve description bias in case data and contradictions among the data, the data collected through multiple channels were verified by triangulation to improve their reliability. We adopted triangulation to provide a chain of evidence and strengthen the argument in our study [67,68]. First, the research draft and interview outline were sent to the interviewees in advance, and face-to-face, in-depth interviews were then conducted to obtain first-hand data. Second, when selecting the interviewees, we attempted to include different but key participants to eliminate bias from the responses of specific interviewees. Furthermore, all vital information was confirmed based on other data to minimize the impact due to the information providers' subjective bias.

Lastly, the data were arranged according to the time sequence [69], and the key driving forces of the sustainable intergenerational evolution of the TDIA innovation ecosystem were then investigated based on "condition–action–result".

4. Case Study: China's TDIA

4.1. Overview of the Evolution Situation of the TDIA Innovation Ecosystem

The development history of TDIA is a process of sustainable development accompanied by continuous upgrading and changing of communication technologies. Generally, it underwent a 2G stage in which its core members participated before the establishment of TDIA, and 3G (TD-SCDMA) and 4G (TD-LTE) stages since its establishment (the 5G stage is still not clear in either the technology or the market and has not replaced 4G). Therefore, TDIA has conducted two upgrades (from 2G to 3G and from 3G to 4G). Although the three stages coexisted at the same time points, the value proposition and technology system had different emphases in the different stages. Key events in the different stages of the development process of China's TDIA are shown in Figure 3.

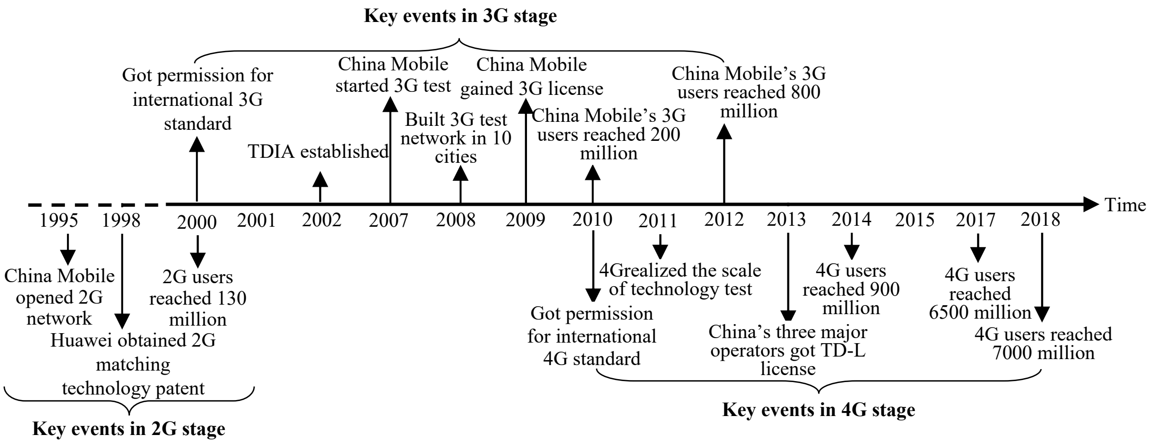

Figure 3. Key events during China's Time Division Industrial Alliance (TDIA) development.

4.1.1. 2G Innovation Ecosystem Participation by Core Members of TDIA

In 1995, China Mobile officially launched GSM digital telephone network technology (called "2G"). With the continuous decline of telephone charges and mobile phone prices, the number of users grew rapidly. By 2001, the number of 2G mobile terminal users in China had reached 130 million, and the number of users continued increase at a rate of 5 million per month. Although 2G is a technology system dominated by developed countries, at the beginning of its establishment in China, major members of TDIA, such as Huawei, ZTE, Putian, Waveguide, and China Mobile, participated in the promotion and application of 2G and developed low-cost alternative 2G technologies. With the rapid expansion of China's market, domestic telecom equipment manufacturers, mobile operators, and mobile phone manufacturers all made substantial profits.

Through further exploration of the transmission potential of the GSM network, mobile terminal equipment achieved higher speed and more functions (called "2.5G"). Some value-added services, such as web browsing and wireless data transmission, also appeared, which better met the diversified needs of consumers and expanded the profit space of Chinese enterprises participating in the GSM network.

4.1.2. 3G Innovation Ecosystem

The term 3G refers to third-generation mobile communication technologies that support high-speed data transmission. In 2000, the TD-SCDMA technical standard proposed by Datang was approved as the international 3G standard. To promote the development and industrialization of TD-SCDMA, eight enterprises, including Datang and Huawei, set up TDIA in 2002.

Based on the introduction of Siemens TDD technology, Datang developed code division multiple access (CDMA) technologies with other alliance members and built the core technological platform of 3G. At the same time, TCL, Lenovo, ZCTT and other enterprises joined in the development of supporting technologies, such as 3G mobile terminals, test instruments, wireless networks, UIM cards, and network compatibility, to gradually promote a perfect 3G technology system.

The number of members of TDIA has continuously increased, reaching 39 in 2008. TD-SCDMA pilot networks were established in 10 cities, including Beijing, and Shanghai. In 2009, China Mobile officially obtained a commercial license for 3G. The 3G system is devoted to value-added services such as browsing web pages, sending and receiving emails, video calls, and watching live broadcasts. Content suppliers also launched various value-added services based on the 3G network, which became key supplements to link the 3G technology system with consumers.

It took 9 years for the 3G led by TDIA to be formally commercialized from the establishment of technical standards in 2000 to 2009 (at least 7 years since the formal establishment of TDIA in 2002). However, the market adoption of 3G was lower than expected, with only 80 million users in 2012.

4.1.3. 4G Innovation System

TD-LTE-Advanced, proposed by TDIA, was proven to be the international 4G standard in 2010. To promote the smooth evolution from TD-SCDMA to TD-LTE, Datang united with Ericsson to conquer the core technologies of orthogonal frequency division multiplexing (OFDM). Huawei and TD Tech developed the broadband multimedia digital cluster solution. China Mobile developed 4G data cards and other terminal products with Huawei and Shanghai Bell. Other alliance members have also developed cross-domain integration technologies based on 4G and finance, transportation, big data, and cloud computing.

The number of TDIA members continued to increase, attracting foreign companies such as Ericsson and SK Telecom to join in the 4G phase. In 2010, the number of members reached 78. In 2011, TD-LTE scale technology experiments were conducted in six cities, including Guangzhou and Shanghai. In 2013, 4G commercial licenses were officially issued. Based on its faster transmission speed, 4G not only greatly improved the quality of all types of mobile interconnection services in the 3G period but also realized "cross-boundary connection" through strong technological penetration. It attracted enterprises in fields such as big data, wearable devices, and the Internet of Things to pursue value-added service innovation.

It took 3 years for TDIA to lead 4G to be formally commercialized from the establishment of international standards in 2010 to 2013. The number of China Mobile's 4G users reached 90 million in 2014 and topped 700 million in 2018, and the number of alliance members reached 107.

The number of TDIA members has continued to increase yearly (see Figure 4), and the layer structure and main members in the three stages of the innovation ecosystem are becoming increasingly abundant (see Figure 5).

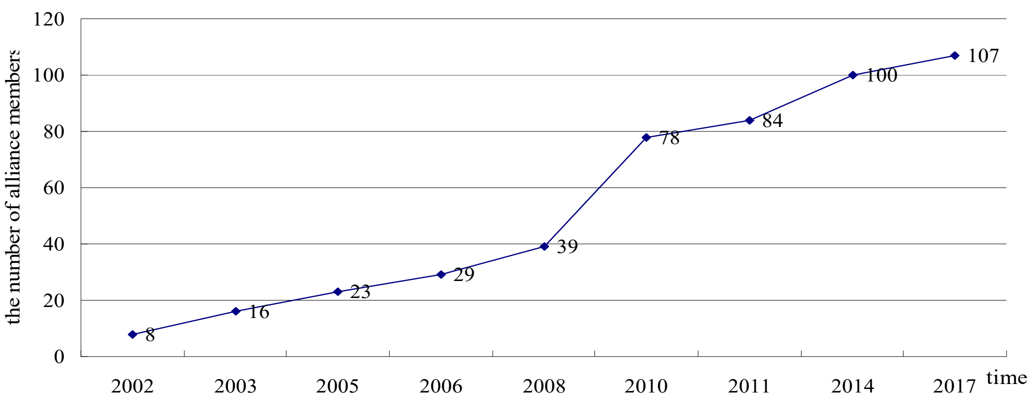

Figure 4. Variation in the number of TDIA members.

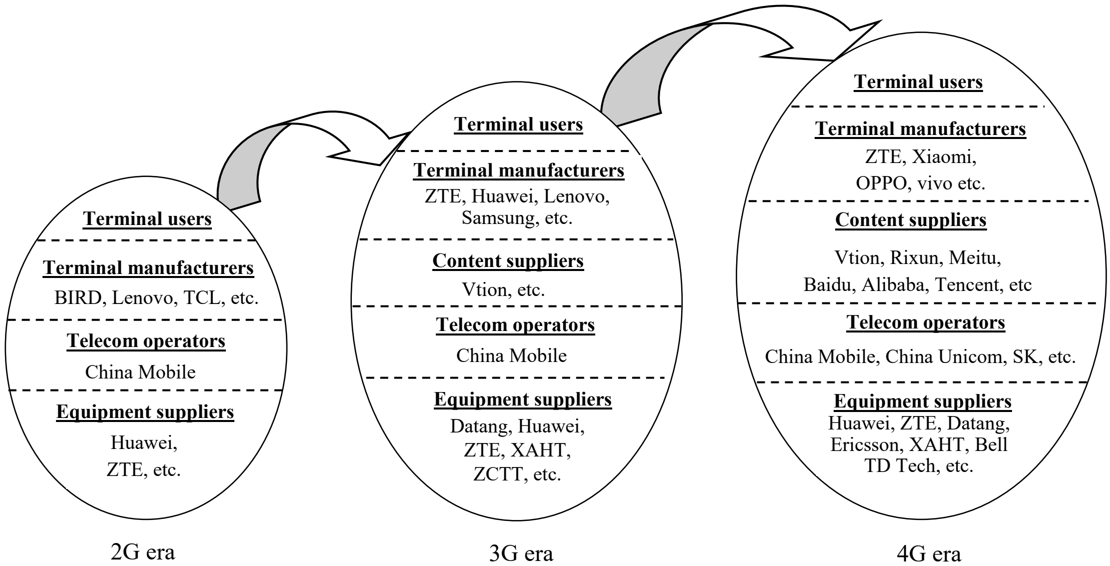

Figure 5. Layer structure and main members of the TDIA innovation ecosystem in its three stages (Figure 5 is drawn according to Fransman's layer structure of innovation ecosystem [10], in which only different layers and their representative members in the TDIA innovation ecosystem are given).

4.2. The Superiority of the New Innovation Ecosystem of TDIA

4.2.1. New Value Proposition Attraction

Compared with the old innovation ecosystem, the value proposition attraction of the new innovation ecosystem of the industrial alliance is reflected in three aspects: value creation potential, value transfer efficiency, and value distribution rules. Members of the industrial alliance innovation ecosystem participate in three value activities. The other entities in the environment of the innovation ecosystem, including experts, news media, the government, and cross-industry enterprises, can also exaggerate or suppress new value proposition attraction [46]. The strong attraction of new value proposition has increased the enthusiasm of alliance members to join the new innovation ecosystem to realize value creation and capture [52]. Heterogeneous external members are also attracted to join the alliance. Thus, strong new value proposition attraction promotes the establishment of a new innovation ecosystem and the replacement of an old innovation ecosystem in an industry alliance.

Before the establishment of TDIA, the majority of experts, scholars, and industry players generally believed that 3G had high value creation potential, which became the key driving force that attracted Datang, Huawei, ZTE, and other early alliance members to join. However, the 3G innovation ecosystem faced difficulty in transferring more value to customers. One year after the issuance of the 3G license (in 2010), Tencent, China's largest and most-used Internet portal, reported that as many as 60% of respondents thought that the 3G tariff was high coupled with the high cost of 3G mobile terminals, and they held a wait-and-see attitude towards the 3G network. Compared with 2G, the 3G innovation ecosystem value distribution involved a wide range of stakeholders. Data flow, web browsing, videophone, and other emerging business and service modes have led more members and even organizations outside the alliance to participate in the value distribution. This change also led to China Mobile no longer occupying a monopoly position in the 2G innovation ecosystem in China's market. Huawei and ZTE also wanted to remain in the GSM network to mine profits. Although the 3G innovation ecosystem had high expected potential for value creation, it inhibited the enthusiasm of the alliance members who were in a monopoly position in the 2G business to join in the development of 3G. Thus, the attraction of new value proposition depends on three aspects, value creation, transmission, and distribution, and a weakness in any one of these will lead to a lack of attraction of new value propositions.

Compared with 3G, the value proposition of the 4G innovation ecosystem was more attractive to the core alliance actors. As early as 2011, a group of telecom operators from India and Europe made it clear that they would buy China's 4G networks. At that time, it was predicted that the number of 4G users in the world would reach 90 million in 2015. In fact, the number of China Mobile's 4G users reached 90 million in 2014 and grew to 310 million in 2015. Furthermore, 4G value creation forms were diversified, and value transmission was more efficient. In 2010, an article published in PC World predicted that a 4G network would deeply penetrate medical, live broadcast, gaming, cloud computing, and navigation fields to form "killer applications" able to better meet the personalized needs of customers and deliver more value to them. With the increase in the user base and the sustainable innovation of mobile value-added services, more alliance members were attracted to participate in the 4G innovation ecosystem to create and capture rich value.

4.2.2. The Maturity and Completeness of the New Technology System

The emergence of a new innovation ecosystem depends on core technology change [70,71]. If the core members of the industrial alliance have strong independent innovation capability and master mature core technologies, this will contribute to the rapid formation of the "niche" of a new innovation ecosystem. With breakthroughs in a series of related core technology modules, the mature core technology platform is gradually improved [72], which promotes the development and expansion of the new innovation ecosystem. Members and even organizations outside the alliance actively conduct matching technology co-innovation based on the new core technology platform [73], not only to guarantee the effective performance of the core technology of the new innovation ecosystem but also to promote the diversified development and industrialization of new products, new techniques, and new services. A complete application environment for the core technology quickly forms to accelerate the establishment and growth of a new innovation ecosystem of industrial alliance.

The 3G system was initially faced with the problem of a lack of core technologies with independent intellectual property rights. Datang, ZTE, and other core members of the alliance had to develop smart antennas and synchronous CDMA based on the introduction of Siemens' TDD technologies. The slow development and low maturity of core technologies repeatedly delayed the launch of the 3G service. In terms of matching technologies, China Mobile's 3G network construction also encountered a drop-off phenomenon caused by the high difficulty of network optimization and low coverage. Network congestion caused slow speeds for data download and web browsing, and the incomplete matching technologies presented another obstacle for 3G's commercialization. In addition, many immature 3G matching applications, such as wireless Internet access, video voice, mobile TV, and other hardware and software technologies, slowed the technology system's change from 2G to 3G.

In the evolution from 3G to 4G, the core members of TDIA concentrated their advantageous innovation resources to improve the feasibility of 4G core technology. In a short time, core technology modules including multipoint transmission, enhanced carriers, hotspot enhancement, and timeslot configuration were developed to promote the rapid formation of R10, R11, R12, R13, and beyond for 4G technical standards. A mature 4G core technology platform was built in a short time. Complete matching technologies were also the key to improving the advantages of 4G innovation ecosystem. For example, Huawei and ZTE were able to rapidly launch 4G-oriented mobile terminals. China Mobile also actively conducted cross-border technology integration with financial, medical, and other types of institutions and absorbed innovative subjects in the fields of cloud computing, wearable devices, and the Internet of Things to join in the development of a diversified "mobile Internet" application environment based on the strong penetration of 4G technology. Compared with 3G, the 4G technology system became mature and complete in a short time, which accelerated the replacement of the 3G technology system.

As shown in Table 1, the superiorities of the 3G and 4G innovation ecosystems of TDIA differed, which resulted in differences in their intergenerational evolution. Specifically, the 3G innovation ecosystem's low value proposition attraction and low maturity and completeness of the new technology system weakened its superiority as a new innovation ecosystem and eventually prolonged the intergenerational evolution of TDIA from 2G to 3G. In contrast, the 4G innovation ecosystem exhibited high superiority as a new ecosystem and accelerated the intergenerational evolution from 3G to 4G.

Table 1. Vertical comparison of superiorities of new innovation ecosystems of TDIA.

New Innovation Ecosystem	New Value Proposition Attraction	Maturity and Completeness of New Technology System	Effect of Superiority of New Innovation Ecosystem on Intergenerational Evolution
3G innovation ecosystem during the evolution from 2G to 3G	• **Value creation**. The high expectation of value creation potential attracted early alliance members to join. • **Value transfer**. Low value delivered to 3G customers led to more potential users holding a wait-and-see attitude. • **Value distribution**. The rules of multi-subject participation in value distribution were not clear, which reduced the enthusiasm of members to join in 3G development and application.	• **Core technology**. The core technologies of 3G were deficient and immature, and follow-up smart antenna technologies and synchronous CDMA technologies were developed slowly. • **Matching technology**. The matching technologies supporting various value-added services such as data downloading, wireless Internet, and video call were not complete.	• Low efficiency of value transfer and distribution made it difficult to attract more members to join in the 3G new innovation ecosystem. • 3G technology system was immature and incomplete, which prolonged the time to surpass performance of the mature 2G technology system.
4G innovation ecosystem during the evolution from 3G to 4G	• **Value creation**. The value creation potential expected was huge to attract more alliance members to join in 4G. • **Value transfer**. Diversified, cross-domain business met personalized demands and delivered more value to 4G users. • **Value distribution**. More members participated in value distribution and capture due to the increase in the user base and the sustainable innovation of mobile value-added services.	• **Core technology**. Core technology modules including multi-point transmission, enhanced carrier, and hotspot enhancement were developed, and a mature 4G core technology platform was built rapidly. • **Matching technology**. Complete 4G-oriented mobile terminals, cross-border matching technologies, and application environment of "mobile Internet" quickly formed.	• 4G value proposition was more attractive, and helped to encourage more alliance members turn to 4G value creation from the 3G value system. • 4G technology system became rapidly mature and complete to accelerate the replacement of 3G technology system.

4.3. The Sustainability of the Old Innovation Ecosystem of TDIA

4.3.1. The Sustainability of the Old Value Proposition.

The sustainability of an old value proposition includes value creation, distribution, and transmission sustainability. The value proposition of an old innovation ecosystem with strong sustainability can produce a value "lock-in effect" and keep alliance members and even users in the old innovation ecosystem for a long time.

In the face of the 3G substitution threat, the value proposition of the 2G innovation ecosystem had strong sustainability. In 2001, the number of 2G mobile terminal users in China reached 130 million, with a high growth rate of 5 million per month. This presented great potential for value creation. With the increase of users and the decrease of telephone fees, the 2G innovation ecosystem transferred more value to users. In fact, in the process of 3G research and developmen and industrialization, some core members of TDIA (such as Huawei, ZTE, and China Mobile) still made huge profits by actively promoting 2G technologies, products, and services in the domestic market. With the upgrade from 2G to 2.5G, some value-added services, such as web browsing and wireless data transmission, were launched. The incremental innovation attracted alliance members and potential 3G users to stay in the 2G innovation ecosystem for a long time.

However, in the face of 4G replacement pressures, the 3G innovation ecosystem's significant services, such as data flow, video, and other value-added services, were insufficient. The number of China Mobile's 3G users grew slowly. From 2009 to the end of 2011, the total number was only 50 million. The small user base and insufficient scale effect led to little value being delivered to customers. In terms of value distribution, the equipment manufacturers, operators, content providers, mobile terminal providers, and other innovation subjects who constituted the 3G innovation ecosystem expected to obtain more innovation value. However, the total value creation was too small and the distribution rules were not clear, both of which reduced the enthusiasm of relevant subjects to participate in the follow-up innovation of 3G technologies. Most of them hoped to turn to 4G as soon as possible to capture more value.

4.3.2. The Extensibility of the Old Technology System

Alliance members mine the performance of the existing technology system, which can improve the threshold of its replacement. In particular, the improvement of existing core technology performance depends on the "ecosystem" composed of relevant components and complementary technologies [44]. Therefore, based on the co-innovation of industrial alliance members, the service life of the old technology system is delayed, and the time required for the performance of the new technology system to overcome the old one is prolonged.

In the upgrading from 2G to 3G, 2G core technology had good extensibility. Based on the existing GSM technology architecture, wireless packet data transmission technology was added to expand 2G core technologies to the 2.5G level. This supported the launch of Internet access, WAP, and other wireless data services in the 2.5G mobile network environment and improved the threshold of 3G core technology performance beyond 2G. The expansion of 2G core technologies to 2.5G also depended on the extension of related matching technologies to some extent. On the one hand, a new hardware unit was added to the original base station subsystem (BSS) of 2G to greatly improve the transmission speed and realize the functions of call connection and wireless channel management in the mobile network. On the other hand, matching technologies, such as wireless multimedia, e-mail, and Bluetooth, were developed or integrated based on the 2.5G technology platform to support the introduction of some value-added services. Therefore, both the core technology performance mining of GSM and the diversified innovation of related 2.5G matching technologies presented higher requirements for the overall performance of the 3G technology system and delayed the intergenerational evolution from 2G to 3G. Although the 2G core technology had good extensibility, it had inherent technical limitations that were unable to support these non-traditional value-added services with high data transmission efficiency. Therefore, in the face of market demand, 2.5G still needed to upgrade to 3G.

In the intergenerational evolution from 3G to 4G, through the establishment of a 3G test network on a large scale, alliance members Huawei, ZTE, and others found that 3G had technical problems, such as unstable data transmission, poor signal coverage, hidden risks in network security, and vulnerable authentication protocols. These core members had to constantly perfect 3G core technologies, so 3G core technologies were in the stage of experimentation and technical repair for a long time and could not address performance expansion. The 3G innovation ecosystem was committed to the in-depth exploration of non-traditional value-added services and cross-border development and application. However, relevant matching technologies continued to improve slowly. For example, content suppliers, as important adopters of 3G technology, did not actively produce content aimed at 3G mobile terminals. Even China Mobile did not launch more matching technologies to support value-added services. There were few cross-border integration technologies, which limited the performance expansion of 3G core technologies. Due to the lack of extensibility of the 3G technology system, alliance members and other related matching enterprises hoped to turn to the development and application of 4G technologies as soon as possible.

Therefore, as shown in Table 2, both strong value proposition sustainability and strong technology system extensibility determined the 2G innovation ecosystem's strong sustainability, which hindered the intergenerational evolution of TDIA from 2G to 3G. In comparison, the weak sustainability of the 3G innovation ecosystem accelerated the intergenerational evolution from 3G to 4G.

Table 2. Vertical comparison of sustainability of old innovation ecosystems of TDIA.

Old Innovation Ecosystem	Value Proposition Sustainability	Technology System Extensibility	Effect of Sustainability of Old Innovation Ecosystem on Intergenerational Evolution
2G innovation ecosystem during the evolution from 2G to 3G	• **Value creation.** The high expectation of value creation potential attracted early alliance members to join. • **Value transfer.** Low value delivered to 3G customers led to more potential users to hold a wait-and-see attitude. • **Value distribution.** The rules of multi-subject participation in value distribution were not clear, which reduced the enthusiasm of more members to join in 3G development and application.	• **Core technology.** The core technologies of 3G were deficient and immature, and follow-up smart antenna technologies and synchronous CDMA technologies were developed slowly. • **Matching technology.** The matching technologies supporting various value-added services such as data downloading, wireless Internet, and video call were not complete.	• Low efficiency of value transfer and distribution made it difficult to attract more members to join in the 3G new innovation ecosystem. • 3G technology system was immature and incomplete, and prolonged the time to surpass performance of the mature 2G technology system.

Table 2. *Cont.*

Old Innovation Ecosystem	Value Proposition Sustainability	Technology System Extensibility	Effect of Sustainability of Old Innovation Ecosystem on Intergenerational Evolution
3G innovation ecosystem during the evolution from 3G to 4G	• **Value creation.** Data flow, video, etc. were insufficiently value-added, and 3G users grew slowly. • **Value transfer.** The price of 3G tariff and mobile phone remained high, and little value was transferred to users. • **Value distribution.** Unclear distribution rules led to little value acquisition for alliance members.	• **Core technology.** 3G core technologies were in the stage of experiment and technical repair for a long time, let alone performance expansion. • **Matching technology.** Content production for 3G mobile terminals, matching technologies to support 3G value-added services and 3G cross-border integration technologies were deficient.	• It became difficult to improve the efficiency of 3G value creation, transmission, and distribution, and majority of alliance members hoped to turn to 4G as soon as possible. • The 3G technology system was of less extensibility and of easier replacement from the 4G technology system.

4.4. Inheritance between the New and Old Innovation Ecosystems of TDIA

4.4.1. Inheritance between Value Propositions.

If the logic and rules of the value creation, transmission, and distribution of the new and old innovation ecosystems are consistent or change continuously, the inheritance between the new and old value propositions is good. Strong inheritance makes the implementation of the new value proposition less threatening to the alliance members who are embedded in the old innovation ecosystem to create and obtain value. Good inheritance strongly attracts and stimulates more members of the old value system to join a new value system.

First, the 3G innovation ecosystem was mainly based on mobile Internet services to achieve value creation, while 2G mainly relied on SMS and voice services. The value source of the 3G innovation ecosystem was very different from 2G, and the inheritance of value creation between them was weak. Second, according to the "China Mobile Internet and 3G User Survey Report" in 2009, 80% of 2G or 2.5G users were unwilling to transfer to the 3G network in a short time, and only 20% of them would consider using 3G. The 3G innovation ecosystem had no more value than 2G transferred to users. Finally, in the 2G innovation ecosystem, operators played a leading role in the value distribution, while in 3G, due to the diversification of value-added business subjects, Internet enterprises, and content providers had to participate in the value distribution, which reduced the enthusiasm of China Mobile to rapidly promote 3G.

Compared with the lack of inheritance between the 2G and 3G value propositions, 4G had a better inheritance of the 3G value proposition. In terms of value creation, 3G was dedicated to non-traditional value-added services, including data traffic, Internet access, and visualization, but 4G's network speed was faster and its scope of business integration was wider. Therefore, 4G better inherited the value creation mode of operators and content providers in the 3G period. In terms of value delivery, the "Economic Operation of Communication Industry" released on the official website of the Ministry of Industry and Information Technology in 2017 showed that 3G users were rapidly converting to 4G, and the value demands of 3G users' mobile Internet were effectively met in the 4G innovation ecosystem. In terms of value distribution, from the diversification of value distribution subjects to forcing operators to abandon monopoly profits in the 3G innovation ecosystem to continue to promote the diversification of subjects to distribute value according to their contribution in the 4G innovation ecosystem, 4G carried on the inheritance of 3G value distribution.

4.4.2. Inheritance between Technology Systems.

Inheritance can shorten the time required for an industrial alliance to quickly build a new core technology platform so that the alliance can use some of the core technologies from its old innovation ecosystem or integrate existing core technologies from outside organizations. It can also attract more organizations to join the new innovation ecosystem together with these technologies. Similarly, if new core technologies that are promoted and applied are easily connected with the matching technology in the old innovation ecosystem, this can provide a "plug and play" application environment for the new core technologies and reduce the time required for alliance members to develop extra components or complements technologies.

TD-SCDMA core technologies and GSM network technologies dominated by foreign countries belonged to different technology systems, which made the inheritance between 3G core technology and 2G poor. It took longer for TDIA to build a new 3G core technology platform. The 2G network was mainly used to realize voice calls, SMS, and other relatively simple services, while the 3G network focused on value-added services such as multimedia and wireless Internet. Thus, matching technologies to support 3G network facilities, mobile terminals, and content production were almost nonexistent in the 2G period, let alone inherited.

In contrast, the core technology of 4G TD-LTE was the continuous smooth evolution of 3G TD-SCDMA. The main feature of TD-LTE technologies was that they retained the core technology Smart Antenna (SA) in the 3G period. Therefore, the core members Huawei, ZTE, and Datang developed SA + MIMO technologies on the basis of SA and quickly built a 4G core technology platform. Datang proposed a smooth evolution scheme based on 3G to 4G that highlighted the upgrading and downward compatibility of the network. The SA matching system of the 3G network was transplanted into the TD-LTE network. Better inheritance of matching technologies reduced the 4G network construction cost and its commercialization time. In addition, 3G content production, apps, and other technological environments could be updated to be compatible with 4G core technologies.

Table 3 shows that the inheritance between the new and old innovation ecosystems also affected the sustainable intergenerational evolution of the innovation ecosystem of TDIA. There was low inheritance between 2G and 3G in terms of the two dimensions of value propositions and technology systems. Their low inheritance delayed the intergenerational evolution of the TDIA innovation ecosystem from 2G to 3G. In contrast, there was high inheritance between 3G and 4G, which advanced the intergenerational evolution from the 3G to 4G innovation ecosystems.

Table 3. Vertical comparison on inheritance between the new and old innovation ecosystems of TDIA.

Inheritance between Innovation Ecosystems	Inheritance between Value Propositions	Inheritance between Technology Systems	Effect of Inheritance between Innovation Ecosystems on Intergenerational Evolution
Inheritance between 3G and 2G innovation ecosystems	• **Value creation**. 3G was devoted to value-added services of mobile Internet, while 2G was devoted to short message and voice services. They had different value sources. • **Value transfer**. There were significant differences in the value delivered to customers. • **Value distribution**. Content providers, Internet enterprises, etc. participated in 3G value distribution, while operators occupied a monopoly position in 2G value distribution.	• **Core technology**. 2G and 3G belonged to different technology systems, and the members of TDIA were lack of core technologies of 3G independent intellectual properties. • **Matching technology**. The 3G network facilities, mobile terminals, content delivery, and other matching technologies did not exist in 2G.	• Compared with 2G, 3G value creation, transmission and distribution threatened the vested interests of some core alliance members. The users' conversion cost from 2G to 3G was higher. • It took a long time for TDIA to develop a new 3G technology system.
Inheritance between 4G and 3G innovation ecosystems	• **Value creation**. Both 3G and 4G were dedicated to non-traditional value-added services, but 4G's network speed was faster and its scope of business integration was wider. • **Value transfer**. 3G users' differential value demands were better satisfied in 4G. • **Value distribution**. Both 3G and 4G broke the unique value distribution pattern of operators in 2G era, and 4G continued to promote more alliance members to participate the value distribution.	• **Core technology**. TD-LTE of 4G was a smooth evolution from 3G. 4G inherited and upgraded the core technology SA of 3G. • **Matching technology**. 4G was downward compatible with 3G. SA supporting technologies and application environment of 3G could be upgraded and transplanted to 4G technology system.	• The value proposition of 4G was continuously expanded from 3G. Alliance members and users in 3G innovation ecosystem gained more value in 4G. • Effective connection between 3G and 4G technology systems and inheritance of "plug and play" application environment shortened the development time of 4G technology system.

4.5. Market Demand Pulling

4.5.1. New Potential Market Demand Pulling

The technological innovation of intergenerational evolution has the characteristics of discontinuity and unpredictability. It makes future market demand uncertain, potential, and wait-and-see. Some demands need to be mined and created through radical innovation. Of course, this type of potential market demand has a positive driving effect on the intergenerational evolution of innovation ecosystems. First, when market demand becomes increasingly difficult to meet through the existing innovation ecosystem, it will continue to breed new potential demand and require the emergence of a new innovation ecosystem. Second, market demand in the fuzzy state is particularly attractive to core alliance members who are eager to obtain future competition initiatives, even by exaggerating the future market demand potential [46], to stimulate more members to join the new innovation ecosystem to develop new key core technologies [74].

As early as 2003, when the 3G World Summit 2003 of the China Global Summit was held in Beijing, experts from the Telecommunications Research Institute of the Ministry of Information Industry noted that after the introduction and growth periods, the number of 3G users in China was expected to reach 198–266 million, accounting for 36%–40% of mobile users. Its operating income would reach 1 trillion, equipment income would reach 600 billion, and terminal market income would reach 400 billion. Haiping Che, the vice president of Huawei's wireless products department, also predicted that 3G would become an alternative to the 2G network after 2010. It became the consensus of the TDIA members at that time that 3G could produce huge market demand. This optimistic prediction promoted the rapid establishment of a 3G innovation ecosystem and especially accelerated the development of key core technologies.

As early as 2010, PC World announced that 4G networks promoted "killer" applications in five technological areas, including mobile video live streaming, mobile/portable games, and applications based on cloud computing, "augmented reality" navigation, emergency response, and telemedicine. Optimistic forecasts of potential demand also accelerated the evolution to 4G. At the Mobile World Congress in 2011, the main mobile operators from India and Europe announced that they would adopt the 4G standard led by China to build commercial networks. According to predictions at that time, the number of global 4G users was expected to exceed 90 million by 2015.

4.5.2. Explicit Market Demand Pulling

This forms a "lock-in effect" of the market in which the old innovation ecosystem satisfies the existing explicit demand. With the prototype formation of the new innovation ecosystem, especially the breakthrough of core technologies, the potential market characteristics (such as scale and structure) gradually become clear, which in turn leads to the perfection of the new innovation ecosystem.

From new potential market demand to explicit demand, the new innovation ecosystem of the industrial alliance is required to provide a comprehensive customer solution. It not only requires the continuous improvement of the new core technology performance but also the co-innovation of new peripheral matching technologies [51]. Diversified final products and services are developed and delivered to encourage the industrial alliance innovation ecosystem to realize intergenerational evolution.

Specifically, when the 3G innovation ecosystem of TDIA was established, customers' explicit demand for rich video, data flow, and other services gradually emerged to pull the rapid maturity of the 3G innovation ecosystem. This not only required the continuous improvement of the 3G industry's core technology platform but also promoted the development of smart phones by Huawei and ZTE. China Mobile also actively deployed networks and introduced new services. By the end of 2011, the number of TD-SCDMA base stations had reached 220,000, and the number of end users had reached 51.21 million. An innovation ecosystem to address users' comprehensive innovation solutions had been established.

With the proposal of the "Internet +" strategy in China, user demand for the "mobile Internet" made it clear that the 4G innovation ecosystem of TDIA was intended to meet the new needs of users, including broadband wireless communication, high-level intelligent terminals and cloud application platforms, and a large data system. These new needs pulled the 4G innovation ecosystem to develop in scale, diversification, cross-domain aspects, and globalization. By the end of 2015, the number of TD-LTE base stations had reached 1.3 million, accounting for 43% of the total LTE, and the users accounted for 45% of the total in the world. In addition, the market demand in cross-border areas such as transportation, education, medical care, and national defense continuously expanded the boundaries of the 4G innovation ecosystem of the TDIA.

Generally, the new potential market demand pulled the new core technologies of the 3G and 4G co-innovation separately. Explicit market demand also pulled their new matching technologies.

China's large market demand encouraged the TDIA innovation ecosystem to realize intergenerational evolution. However, there were more difficulties in the transmission from the potential demand to explicit demand of 3G than 4G. Therefore, the quicker intergenerational evolution from 3G to 4G benefited from more the market demand pulling force.

4.6. Government Policy Guidance

4.6.1. Innovative Supply-Side Policy Guidance.

In an industrial alliance's upgrading process, its mission focuses on the innovation and industrialization of emerging technologies Therefore, innovative supply-side policy guidance is the key driving force. The establishment and replacement of the innovation ecosystem of industrial alliance aim to conquer key common and core technologies by absorbing core members and integrating advantageous innovation resources. The government increases innovation investment to make up for the lack of investment in the industrial alliance, and helps to break the bottleneck of key common technologies and core technologies of the industrial alliance and lay the foundation for the replacement of the industrial alliance innovation ecosystem.

With the establishment of the 3G innovation ecosystem of TDIA and the intergenerational evolution from 3G to 4G, innovative supply-side policy played a leading role in strategic layout and guidance, as shown in Table 4.

Table 4. Typical innovative supply-side policies for TDIA and their guiding effects.

Intergenerational Evolution	Typical Policy and Its Promulgation Time	Key Contents of the Policy	Guiding Effects of Typical Policies on Intergenerational Evolution
Intergenerational evolution from 2G to 3G	Datang Telecom was approved as "863 industrialization base" in 2000.	Datang Telecom became the base to develop core technologies of TD-SCDMA (3G) standard.	Key technologies of 3G innovation ecosystem of TDIA were promoted for research and development, and construction of relevant R&D facilities increased.
	3G was listed in the National 10th Five-Year Plan in 2000.	The Ministry of Information Industry took 3G as the focus of the National 10th Five-Year Plan, and 3G was also one of the "Twelve High-Tech Projects" determined by the State Planning Commission.	Key position of 3G was highlighted in the work of China's government, and continuous investment from government was ensured to develop 3G.
	China's government increased R&D funding support for TD-SCDMA in 2003.	The government granted local manufacturers no less than 600 million RMB per year to support the R&D of 3G.	Financial support for the R&D of 3G core technologies was provided to guide multinationals to participate in the innovation ecosystem.

Table 4. *Cont.*

Intergenerational Evolution	Typical Policy and Its Promulgation Time	Key Contents of the Policy	Guiding Effects of Typical Policies on Intergenerational Evolution
Intergenerational evolution from 3G to 4G	The R & D of 4G was listed in the 10th Five-Year 863 Plan in 2002.	Core technologies of 4G became the Focus in the 863 Plan.	Core technologies of 4G innovation ecosystem of TDIA were conquered to push the evolution from 3G to 4G.
	Shanghai Research Center of Wireless Communication was established in 2003.	This center focused on the research of 4G key technologies and promoted their standardization.	The investment of 4G innovative talents increased, and innovation of 4G core technologies were strengthened.
	4G was included in the National 11th Five-Year Plan in 2006.	The wireless bandwidth of communication in the Plan was emphasized to strengthen the R&D of 4G.	Advantageous innovation resources were guided to invest in the core technology R&D of 4G innovation ecosystem.
	The Ministry of Information Industry established the 4G Promotion Group in 2007.	4G Promotion Group was devoted to the smooth evolution from 3G to 4G and the 4G standardization.	The international R&D level of core technologies of 4G innovation ecosystem was improved.

4.6.2. Innovative Demand-Side Policy Guidance.

During the process of replacing the old innovation ecosystem with the new innovation ecosystem of an industrial alliance, the guiding force of innovative demand-side policy is also very important. These policy instruments, such as specific pilot industrialization, industrial infrastructure support, government procurement, and trade regulation, stimulate potential demand and guide consumption. Notably, unlike general demand-side policy, innovation demand-side policy promotes matching subjects downstream to adopt the core technology module or architecture upstream. Through this layer-by-layer adoption, matching technologies are improved to promote the rapid growth of the new innovation ecosystem of the industrial alliance.

The focus of government policy shifted to the innovative demand side to play an implementation and adjustment role in the process of the gradual maturity of the 3G and 4G innovation ecosystems, as shown in Table 5.

Overall, China's innovative supply-side and demand-side policies both had effects on guiding the common and core technologies used to separately support the construction of the 3G and 4G innovation ecosystems. However, more innovative supply-side policies emphasized the smooth evolution from 3G to 4G than from 2G to 3G. The innovative demand-side policies for 4G covered more extensive application fields through the national strategies of "Belt and Road" and "Internet +" Action" than for 3G. Thus, China's 4G policies better accelerated the intergenerational evolution from 3G to 4G innovation ecosystems.

Table 5. Typical innovative demand-side policies for TDIA and their guiding effects.

Intergenerational Evolution	Typical Policy and Its Promulgation Time	Key Contents of the Policy	Guiding Effects of Typical Policies on Intergenerational Evolution
Intergenerational evolution from 2G to 3G	TD-SCDMA network was used in the Beijing Olympic Games in 2008.	TD-SCDMA network was constructed in eight cities including Beijing, Shanghai, which covered the majority of Olympic host and co-host cities.	Market demand for 3G innovation ecosystem of TDIA was guided to expand through application demonstration.
	3G commercial license was issued in 2009.	A TD-SCDMA commercial license was issued to China Mobile, which is the most competitive operator in China.	The industrial admittance ensured the demand scale of TD-SCDMA, and shaped a favorable innovation demand pattern.
	3G was included in government procurement in 2009.	Related products of TD-SCDMA were listed in the "Catalogue of Independent Innovation Products Purchased by the Government".	Government procurement created the stable market demand of TD-SCDMA and helped to realize the innovation value of 3G innovation ecosystem.
	"Several Policies to Encourage the Development of Software Industry and Integrated Circuit Industry" were promulgated in 2009.	It was emphasized that enterprises which were engaged in the development of communication matching software such as TD-SCDMA could enjoy the policy of "two exemptions and three reductions in half".	Supporting technologies were guided to be developed to build 3G innovation ecosystem and carry out low-cost industrialization.
Intergenerational evolution from 3G to 4G	4G license was issued in 2013 and 2015.	TD-LTE license was issued to China Mobile, China Telecom, and China Unicom in 2013, and FDD license was issued to China Telecom and China Unicom in 2015.	The industrial admittance institution ensured the demand scale of TD-LTE and created a favorable innovation demand pattern.
	Jining government and China Mobile built the information consumption pilot of 4G together in 2014.	4G network was promoted for use in 16 fields including intelligent medical care, education, transportation, etc.	Market demand for 4G innovation ecosystem was expanded by building "information consumption" demonstration city.
	FDD cooperated with TDD in the "Belt and Road" strategy in 2014.	Related cooperation of TDD through interaction between politicians was promoted, for example by signing TDD/4G contracts and giving TDD mobile phones as gifts.	Overseas market demand of 4G innovation ecosystem of TDIA was actively expanded.
	The State Council Issued "Guidance on Actively Promoting "Internet +" Action" in 2015.	Industrial foundation, strategic reserve of intellectual property, and the construction of laws and regulations were strengthened.	Industrialization process of 4G innovation ecosystem of TDIA was accelerated and applied in multiple industries.

5. Discussion

5.1. Competition and Inheritance Coexist in the Sustainable Intergenerational Evolution of the Industrial Alliance Innovation Ecosystem

The intergenerational evolution of industrial alliance innovation ecosystems involves competitive replacement between new and old innovation ecosystems. The competition is not limited to performance competition between the technology systems [44], but extends to the "technology–economy" system [10]. It also highlights the efficiency of value creation and transmission between the two value systems. The intergenerational evolution of the innovation ecosystem of industrial alliances originates from the change of key core technologies. However, to complete competitive replacement, it also depends on the completeness of related matching technologies in the process of the diffusion and adoption of new key technologies and the value realization of stakeholders [75,76]. The intergenerational evolution of the innovation ecosystem of an industrial alliance is determined by both the superiority of the new innovation ecosystem and the sustainability of the old innovation ecosystem. The advantages of the new innovation ecosystem are mainly reflected in the extensive new attraction of the new value proposition and the mature completeness of the new technology system. A new value proposition with strong attraction improves the enthusiasm of alliance members to join the new innovation ecosystem to conduct innovation. Mature core technologies and complete matching technologies improve the overall performance of the new technology system [77], and thus accelerate the replacement of the old innovation ecosystem. Similarly, the sustainability of the old innovation ecosystem of the industrial alliance is determined by the sustainability of its value proposition and the extension of the technology system. The continuous improvement of value creation, transmission, and distribution efficiency attracts alliance members and users to remain in the old innovation ecosystem. The continuous extension of incumbent core technologies and related matching technologies improves the overall technology threshold for the industrial alliance to build new innovation ecosystem. For example, the emergence of 2.5G based on GSM deep mining delayed the evolution of the TDIA innovation ecosystem from 2G to 3G.

In contrast to the general innovation ecosystem succession [35], replacement [44], and reconstruction [37], the intergenerational evolution of the innovation ecosystem of industrial alliances has the characteristic of self-upgrading. It shows the inherited replacement between the new and old innovation ecosystems. The inheritance between the two value propositions can ensure that alliance members have the motivation to develop and adopt high-performance new technology systems; otherwise, they will maintain their vested interests. Similarly, the internal consistency of new and old core technologies reduces the difficulty of new technology breakthrough, and the inheritance of related matching technologies determines whether the new core technologies can achieve a "plug-and-play" effect based on the existing matching technologies. The weak inheritance of value propositions and technology systems between 2G and 3G delayed the establishment of the 3G innovation ecosystem to some extent. In contrast, 4G was a better inheritor and was substituted for 3G more quickly.

5.2. Market Demand Ambidexterity to Promote the Sustainable Intergenerational Evolution of Industrial Alliance Innovation Ecosystems

In the context of the sustainable and high-speed economic growth of emerging markets represented by China, the sustainable intergenerational evolution of industrial alliance innovation ecosystem can be promoted by huge market potential and real purchasing power. However, the market demand also presents an "ambidexterity" feature in which both demand scale and quality increase at the same time. The growth of demand scale causes the current innovation ecosystem to have a certain sustainable profit potential and rapidly reduces the cost of adoption. This makes the alliance members and customers remain in the existing innovation ecosystem for a longer time. For example, in the continuous demand scale of China's 2G market, it was difficult for the TDIA to establish a 3G innovation ecosystem. The upgrading of consumer demand quality leads to the rapid growth of potential demand for new innovation ecosystem, and this emerging demand tends to be an optimistic estimation [46], which encourages the industrial alliance to construct a new innovation ecosystem. The recognition of market demand for the new innovation ecosystem is a gradual process. The new potential market demand pulls the core members of the alliance to accept new value propositions and devote themselves to the development of new key technologies, and it promotes the formation of the prototype of a new innovation ecosystem. The new increasing explicit market demand pulls more alliance members to the new innovation ecosystem to accelerate the intergenerational evolution.

5.3. Public Goods Attributes and Effect Differences of Innovation Policy in Encouraging the Sustainable Intergenerational Evolution of Industrial Alliance Innovation Ecosystems

The industrial alliance aims to achieve the key common core technology breakthroughs, competitive global technology standards and the improvement of the independent innovation ability of the industry. First, innovation policy that encourages the sustainable intergenerational evolution of industrial alliance innovation ecosystem is of a public goods nature [78]. The government tends to invest in technology development before competition, and it transforms scientific and technological achievements and supports and protects infant industries to play the role of industrial alliances in promoting innovation radiation in the industry [79]. This is also an important reason for China's government to issue a large number of policies to guide the development of TDIA.

Second, there are differences in the impact of different types of innovation policies. Innovative supply-side policy encourages and guides members and their innovation activities to complete the upgrading of the innovation ecosystem. However, given the uncertainty and lag of the innovation process itself [80], the innovative supply-side policy tends to perform strategic layout in advance. The innovative demand-side policy is more likely to achieve value transfer by stimulating consumers' purchase power. Due to the high market sensitivity, this type of policy tends to adjust over time. The differences can be seen in the two types of policies to guide the 3G and 4G of TDIA shown in Tables 4 and 5.

5.4. The Synergy of Driving Factors for the Sustainable Intergenerational Evolution of Industrial Alliance Innovation Ecosystem

The sustainable intergenerational evolution of an industrial alliance innovation ecosystem depends on the synergetic effect of all of the key driving forces. First, the intergenerational evolution of industrial alliance innovation ecosystem depends on the consistency of internal driving factors. It not only requires the superiority of new innovation ecosystem compared with the old innovation ecosystem, but also highlights the high inheritance between them. Second, the sustainable evolution of an industrial alliance innovation ecosystem also depends on the innovative ecological environment. Market demand needs to transform from new potential to explicit demand, and government policy needs to highlight the layout of innovation supply in advance and the adjustment of innovation demand over time.

Finally, internal driving factors are the root of sustainable intergenerational evolution, while external dynamic factors play a driving role by influencing the competitive landscape and inheritance between the new and old innovation ecosystems. Any weakness in these factors will delay the intergenerational evolution of the innovation ecosystem of industrial alliance or even cause it to fail. It also fully reflects the complex technology–economy–society system that is the essence of the industrial alliance innovation ecosystem and the high dependence on the environment.

The effects intensions of the key forces driving on the intergenerational evolution of the innovation ecosystem of TDAI are summarized as in Table 6. Combined with the specific intergenerational evolution situation (see Figure 1), the strong sustainability of the 2G innovation ecosystem improved its performance curve from S_0 to S_0', while the low superiority of the 3G innovation ecosystem shifted its performance curve from S_1 to S_1'. Furthermore, the poor inheritance between 2G and 3G and both the weak market demand pulling and government policy guidance made it more difficult for 3G (S_1') to replace 2G (S'_0). Therefore, the synergetic effects of five key driving forces delayed the intergenerational evolution from 2G to 3G, i.e., the substitution time point was delayed from T_A to T_D.

Table 6. The effects intensions of key driving forces on the sustainable intergenerational evolution of innovation ecosystems of TDIA.

Key Driving Forces	Effects on Intergenerational Evolution from 2G to 3G	Effects on Intergenerational Evolution from 3G to 4G
Superiority of new innovation ecosystem	Low	High
Sustainability of old innovation ecosystem	Strong	Weak
Inheritance between innovation ecosystems	Poor	Good
Market demand pulling	Weak	Strong
Government policy guidance	Weak	Strong
Results of the synergetic effects	Delayed the evolution	Accelerated the evolution

In contrast, the 4G innovation ecosystem had high superiority, while the sustainability of 3G was weak. Furthermore, the inheritance between 3G and 4G was good, and both the market demand pull and government policy guidance were strong for the evolution from 3G to 4G. Therefore, the synergetic effects accelerated the intergenerational evolution, and the corresponding substitution time point was T_A.

The dynamic relationship model of the key forces driving the sustainable intergenerational evolution of the industrial alliance innovation ecosystem is shown in Figure 6.

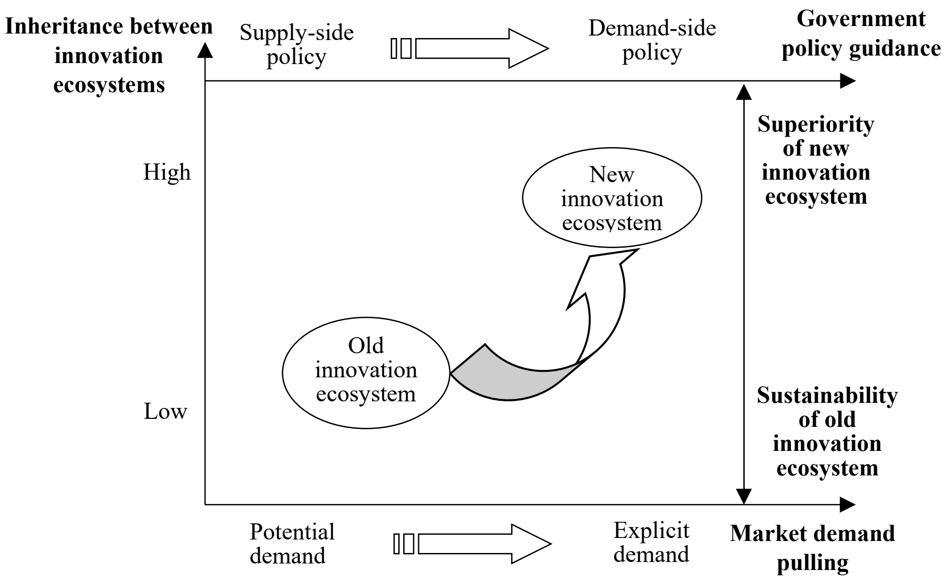

Figure 6. The dynamic relationship model of the key forces driving the sustainable intergenerational evolution of the industrial alliance innovation ecosystem.

6. Conclusions and Prospects

6.1. Conclusions

The key driving forces are the key control points for the sustainable intergenerational evolution of the industrial alliance innovation ecosystem. From the perspective of the structural evolution of innovation ecosystem, the following conclusions are drawn based on the case description, analysis, and discussion of China's TDIA.

The internal forces driving the intergenerational evolution of an industrial alliance innovation ecosystem are the superiority of the new innovation ecosystem, the sustainability of the old innovation ecosystem, and the inheritance between these ecosystems. Specifically, the strong superiority of the new innovation ecosystem accelerates the intergenerational evolution of the industrial alliance innovation ecosystem, and the strong sustainability of the old innovation ecosystem delays it, while strong inheritance between the new and old innovation ecosystems accelerates it.

The external driving forces of the intergenerational evolution of the industrial alliance innovation ecosystem highlight two aspects, i.e., market demand pulling and government policy guidance. In terms of market demand, the new potential market demand encourages the core alliance members to propose a new value proposition and devote effort to the development of new key technologies to set up a new innovation ecosystem. When the new potential demand becomes explicit, more alliance members are encouraged to join the new innovation ecosystem to replace the old ecosystem. Innovative supply-side policy, emphasizing the smooth evolution, and demand-side policy, covering more extensive application fields, can accelerate and help to drive the intergenerational evolution.

The intergenerational evolution of the industrial alliance innovation ecosystem depends on the synergetic effects of internal and external key driving forces. The internal driving factors reflect the competitiveness and inheritance during the process of replacement between the new and old innovation ecosystems within an industrial alliance, which depends on the internal consistency of the value proposition and technology dependence of the innovation ecosystem. External dynamic factors play an indirect role by shaping the environment of the embedded industrial alliance innovation ecosystem to drive the intergenerational evolution.

Unlike previous studies that focused on the evolution of the life cycle of industrial alliances and innovation ecosystems, we focused on the intergenerational evolution of the industrial alliance innovation ecosystem and demonstrated the key forces and their effect mechanisms that drive the substitution between new and old innovation ecosystems through the vertical case study of TDIA. This research helps to enrich related theories concerning innovation ecosystem and industrial alliance evolution.

6.2. Implications

This research can provide theoretical guidance for the transformation and upgrading management of industrial alliance, the strategic selection of innovation ecosystems for alliance members, and related policy making for government departments. In particular, it offers decision support for both the TDIA and the government to promote the sustainable evolution of the innovation ecosystem from 4G to 5G and even beyond.

China has taken the lead in 5G technology development and commercialization in the world with the power of TDIA. However, it is still uncertain whether TDIA can realize the smooth evolution from a 4G to a 5G innovation ecosystem [81].

It will be key for TDIA to improve the superiority of 5G innovation ecosystem. The 5G smooth evolution process includes a non-standalone (NSA) stage and a standalone (SA) stage. The former focuses on the core technologies to accelerate network speed. The latter is devoted to the core technologies needed to build the actual 5G technology system which is independent of 4G. For example, edge computing belongs to SA, which is the focus of 5G core technology R&D in the future. Supporting technologies also delay 5G performance. It is also necessary to strengthen development of various kinds of mobile intelligent terminals (such as smart wear, furniture terminals, etc.) besides smart phones, as well as the killer applications covering driverless cars, virtual reality, etc. In terms of 5G value proposition attraction, it is convenient for users to transfer networks by carrying their current phone number, whereas the high price of 5G packages and mobile phones will leave consumers in the wait-and-see stage for a long time. The value proposition attraction needs to be improved for members of TDIA to transfer from 4G to 5G; in particular, it can attract more heterogeneous innovative subjects join the 5G innovation ecosystem to participate proactively in cross-domain co-innovation.

With the issuance of the 5G commercial license on 6 June 2019, the government policy should expand from the innovation supply side to the demand side. On the one hand, China's government should increase development support for SA core and supporting technologies. On the other hand, more demand-side policies need to be issued to stimulate the 5G market need from being potential to being explicit. In South Korea, for instance, the government is offering consumers subsidies to buy 5G mobile phones to popularize the 5G network.

In spite of an inevitable trend towards 5G systems replacing 4G, it will be helpful to accelerate the smooth evolution between them by examining the dilemma from the perspective of sustainable intergenerational evolution of the industrial alliance innovation ecosystem.

6.3. Research Limitations and Prospects

There were two limitations to this paper. First, it mainly explored the key driving forces of the intergenerational evolution of the innovation ecosystem of the industry alliance through the single case of China's TDIA. Although the TDIA is representative, it is necessary to conduct comparative multi-case studies and empirical studies based on large-sample questionnaire surveys to further improve the universality of the theoretical framework proposed in this study. Second, we mainly identified the key driving forces based on a case study, but we did not consider the accurate measurement of both the pace of intergenerational evolution and the degree of influence of these factors. In the future, related quantitative measurement models need to be strengthened; specifically, the multiplier effect model could be introduced to measure the scale of the effects on the intergenerational evolution of innovation ecosystems.

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Appendix A

The main questions for managers were as follows:

1. When did your firm join the TDIA? When and how did your firm start 2G, 3G, or 4G businesses? When and what did your firm extend to other related business segments during its development?
2. When did your firm make greater achievements in terms of technological innovation or value-added services and what were they? What were the key forces that drove your firm to transfer to new business?
3. Which types of organization were your firm's main cooperative partners within TDIA? How did your firm and its partners start new business together?
4. How did your firm balance its interests with its cooperative partners to satisfy the consumers?
5. What were the main challenges your firm faced during the process from one business to another? How did your firm meet these challenges?
6. What types of government policy helped your firm to rapidly upgrade the main business? What did not? Why?
7. What opportunities or challenges do the emergence of the "Internet plus" or "Belt and Road" strategies bring to your firm? How does your firm prepare to deal with this trend in the future?

Main questions for officials and experts are as follows:

1. When and why did China decide to build TDIA to develop 3G, 4G, and beyond? What phases did China's TDIA undergo?
2. What achievements did TDIA make in technological innovation and market scale during its development?

3. What strategies did TDIA use to conquer the technological bottlenecks during its development? What was the specific interdependence among these technologies?
4. How did the main members in the TDIA cooperate and balance their interests to offer different consumers with attractive total innovation solutions?
5. How did the government policy to promote or hinder TDIA to develop 3G, 4G and beyond?
6. What are the advantages of China's 3G, 4G, and beyond compared with other countries'?
7. How do current "Internet plus" technologies and "Belt and Road" strategy affect TDIA upgrading towards 5G and beyond?

Appendix B

Table A1. List of interviewees.

Type	Number of Interviewees	Location
Executives from the members of TDIA	20	Beijing, Shanghai, Guangzhou, Hangzhou, Shenzhen, and Harbin, China
Officials from central and local governments	7	Beijing, Shenzhen, and Harbin, China
Experts from information and communication field	6	Beijing and Harbin, China

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