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Managing Innovation Paradox in the Sustainable Innovation Ecosystem: A Case Study of Ambidextrous Capability in a Focal Firm

Delin Zeng [1], Jingbo Hu [2,*] and Taohua Ouyang [3]

[1] School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China; dlzeng@bjtu.edu.cn
[2] School of Business Administration, Jiangxi University of Finance and Economics, Nanchang 330013, China
[3] School of Economics and Management, Beihang University, Beijing 100191, China; taohuaouyang@hotmail.com
* Correspondence: jing_bohu@yeah.net

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Abstract: To achieve sustainable development, focal firms should balance two paradoxical kinds of innovation activities: exploitative and exploratory ones. Published works found that ambidexterity is an effective way to resolve paradoxical tensions, but few in-depth studies have been conducted to explore the innovation paradox of focal firms in the innovation ecosystem from an ambidextrous capability perspective. This paper takes China Spacesat Co., Ltd. as the case to study focal firms' management of innovation paradoxes in the sustainable innovation ecosystem and finds that: (1) Sustainable innovation is an ecosystem in which focal firms' internal functional departments, including the product department, technical center, and Makers' groups, cooperate with external organizations, including component suppliers, scientific research institutes, and government departments, closely and complementarily; (2) In the exploitative and exploratory innovations of complex products, focal firms in the sustainable innovation ecosystem mainly confront three paradoxes: profit drive vs. breakthroughs in the strategic intent of sustainable innovation of the profit-driven model, tight vs. loose coupling of sustainable innovation, and sustainable innovation driven by discipline vs. that by passion; (3) Focal firms in the innovation ecosystem resolve these three innovation paradoxes with structural, contextual, and coordinated ambidextrous capabilities, and build innovation paradox management mechanisms with three steps in sequence, namely by establishing dual sustainable strategic innovation units, strengthening sustainable organizational ties between the internal and external, while co-creating and sharing innovation values, and, finally, promoting the formation and development of their sustainable innovation ecosystem. This paper complements and enriches the innovation ecosystem and ambidextrous capability theory, providing significant practical guidance to the sustainable development of aerospace enterprises.

Keywords: sustainable innovation ecosystem; focal firm; innovation paradox; ambidextrous capability

1. Introduction

In the Internet era, sustainable innovation is difficult to achieve within a single organization and, thus, it requires complementary collaboration with other relevant organizations to create valuable products and services for customers continually. Sustainable innovation is not a linear or mechanical process, but an ecosystem formed by continuous interactions between the economy, society, and other aspects [1]. Furthermore, sustainable innovation activities of an organization often reveal innovation paradox in response to different challenges, and the paradox is "not as either/or dilemmas or trade-offs, but as synergistic and interwoven polarities" [2,3]. The sustainable enterprises are intrinsically open

organizations, necessarily engaged in innovation processes [4]. Most industries are adopting an open approach to innovation [5], for the reason that the open innovation can identify future customer needs and scan for disruptions through foresight networks [6]. Taking their cue from the practices of smart phone open innovation systems, such as Boeing, Airbus, and Apple iOS, focal firms in the innovation ecosystem should combine upstream and downstream organizations when using current products to enable exploitative innovation and the development of new opportunities to foster more exploratory innovations. However, as the recognition of managing innovation paradoxes to facilitate the sustainability of focal firms' ecosystems grows, in practice, there are some gaps in the related literature.

The sustainable innovation ecosystem comprises not only the focal firm itself, but also its upstream suppliers, downstream customers, and complementors [7,8]. Although the topic of paradox is a well-researched area across different academic disciplines [9], related research only studies the influence and trigger factors of sustainable innovation paradoxes [10]. Further, most existing theories of managing sustainable innovation paradoxes are for individual organizations rather than the ecosystem context [11]. These gaps reflect the immaturity of the research in this area and a lack of knowledge on the sustainable innovation paradox of focal firms.

It is difficult to probe into focal firms' management of sustainable innovation paradoxes in the ecosystem context without catching the nature of their management processes. More importantly, sustainable innovation paradox management requires inter-organizational cooperation, because innovation relies on a sustainable ecosystem consisting of interactions among organizations, policies, and the environment [12]. This implies that the focal firm plays an important role in managing sustainable innovation paradox effectively [7,13]. Published works found that ambidextrous capability is an effective way of resolving the paradox [14], but few works discussed the sustainable innovation paradox of the focal firm based on it. Therefore, further study is needed in this area. In particular, there is a need for focal firms to establish a management mechanism when mobilizing sustainable ecosystem resources, and then the mechanism will generate different ambidextrous capabilities to resolve exploitative and exploratory innovation paradoxes.

This paper takes Spacesat, a Chinese small satellite company, as a case. Small satellites are less than 1000 kilograms in weight [15]. As the largest small satellite integrated manufacturer in China, Spacesat has independently and sustainably developed more than 40 small satellites. Satellite firms are confronted with an ambidextrous goal of meeting the demand of both national defense and the market, and then this goal often leads to different sustainable innovation tensions [16]. To address the aforementioned theory gaps and the lack of empirical validity in many ways, this research is grounded empirically in a world famous company to refine the management essence of sustainable innovation paradoxes. Furthermore, through an in-depth exploration of the Spacesat case, this research manages to find out how a focal firm develops ambidextrous capabilities to resolve its innovation paradoxes in the sustainable innovation ecosystem context. The research goals in this paper are as follows: first, to identify the features of focal firms' innovation paradoxes and their interrelation; and, second, to investigate how focal firms in a sustainable innovation ecosystem develop ambidextrous capabilities to resolve their innovation paradoxes by constructing paradox management mechanisms.

2. Literature Review

2.1. Sustainable Innovation Ecosystem

With the Japanese economic downturn and the revitalization of the US economy since the 1990s, the US Council on Competitiveness put forward the concept of the sustainable innovation ecosystem clearly with the research report titled "Innovate America: Thriving in a World of Challenge and Change" in 2004 [1]. A sustainable innovation ecosystem includes four entities: the focal firm, upstream component suppliers, downstream customers, and complementors [17]. Moreover, *component* refers to the outputs of upstream suppliers bundled by the focal firm into its products

and *complement* means other offers alongside the focal player's products bundled by downstream customers [18]. For instance, if cars are the core product, then car engines can be referred to as components, and roads and gasoline are complements.

The promise of increased industry competitiveness through innovation has driven interest in innovation by industry managers, policy-makers, and academics [19]. The innovation system has existed for several decades [20,21]. It is just static and stresses external factors of policies and institutions. However, a key difference is that unlike the innovation system, the sustainable innovation ecosystem reflects a paradigmatic changing of innovative research, which is a transition from simply putting elements together to the interplay among elements, the system, and the environment. In the past decade, a growing number of studies on the sustainable innovation ecosystem were conducted, which cover three aspects (see Table 1).

Table 1. Selected studies on the sustainable innovation ecosystem development.

Research Hotspots	Source	Key Arguments
Sustainable Innovation Subject	Adner and Kapoor [7]	The competitive advantages of focal firms are the positive correlation with upstream component challenge and negative correlation with downstream complement challenge.
	Kapoor and Lee [12]	Downstream complementors are beneficial to the competition of focal firms in coordinating the sustainable innovation ecosystem.
	Adner and Kapoor [17]	The pace of technology substitution is influenced by how the sustainable innovation ecosystem responds to challenges and takes advantage of opportunities. The focal firm promotes innovation ecosystems with other organizations.
Sustainable Innovation Process	Carayannis and Campbell [22]	The sustainable innovation ecosystem requires the government, universities, and enterprises to participate in knowledge creation, diffusion, and utilization.
	Wareham et al. [23]	During the process of technology innovation, the ecosystem requires stability in standard components and variability in the market and results in different paradoxes, such as standard vs. variety and control vs. autonomy.
	Hermann and Wigger [8]	The product sustainable innovation ecosystem includes four stages: idea generation, research, development, and commercialization.
Sustainable Innovation Structure and Characteristics	Schwartz and Bar-El [24]	The industrial association plays an important role in the sustainable innovation ecosystem, raising the awareness of all players, assisting firms to develop their innovation capabilities, etc.
	Lauritzen [25]	There are three characteristics in the sustainable innovation ecosystem: value logic, participant symbiosis, and institutional stability.

With the development of science and technology, paradoxical tensions often happen in technology ecosystems that require homogeneity to leverage common investments in standard components and heterogeneity to meet evolving market demands [23]. Additionally, focal firms play a leading role in the ecosystem [26]. However, a review of innovation ecosystem literature (refer to Table 1) reveals a gap in that there has been little research on focal firms managing innovation paradoxes within its sustainable innovation ecosystem. The sustainable innovation ecosystem can be better developed when the focal firm, as a leader, manages innovation paradoxes. To fill the gap, the theory on innovation

paradox is reviewed to provide a management mechanism that serves the focal firm in resolving the existing paradox.

2.2. Innovation Paradox in Sustainability

In order to achieve sustainable development, firms need to innovate through exploiting resources for product improvement and exploring new technologies to develop new products. Therefore, exploitative innovation and exploratory innovation are paradoxical. The innovation paradox often occurs when "the aggressive pursuit of (only) operational excellence and incremental innovation crowds out the possibility of creating ground-breaking innovations (and vice versa)" [27]. Accordingly, a sustainable innovation paradox means that an organization can use existing resources and technologies to achieve exploitative innovation or develop new resources and opportunities to generate more exploratory innovation [3].

Paradoxes in organization studies are often described as conflicting demands, opposing perspectives, or seemingly illogical findings [28]. In the study of innovation paradox, some scholars have discussed the types and factors of innovation paradoxes: the types include profit vs. breakthroughs of the strategic intent, tight vs. loose coupling of the customer orientation, and disciplined vs. passionate personal drivers [2], and the factors consist of plurality, change, and scarcity [29]. Moreover, most scholars focus on ways to resolve innovation paradoxes, such as taking the knowledge exchange strategy and collaboration scheme [30], establishing a hybrid organization [31], and balancing ability and willingness [32].

The studies above have two gaps with respect to the sustainable innovation paradox. First, a significant number of studies devote their attention to the concept and cause of innovation paradoxes and discuss how to manage the paradox within the enterprise. However, most innovations failed in isolation [10]. The effective management of innovation paradoxes should be carried out in their sustainable ecosystems. Second, although ambidexterity is the most useful way of managing paradoxes [9], few works study the implications of ambidextrous capability in resolving innovation paradoxes. Managing innovation paradoxes from an ambidextrous capability perspective can achieve a balance between two paradoxical tasks, such as exploitative and exploratory innovations [33]. Therefore, ambidextrous capability is taken as a theoretical lens to address these two gaps, and this theoretical lens is reviewed below.

2.3. Ambidextrous Capability for Sustainable Innovation

To obtain sustainable innovations, an organization needs to calibrate and effectively manage current business needs and be able to respond adequately to future environmental changes. Ambidexterity of an organization refers to the capability of adopting two different methods to resolve paradoxical tasks in a complex context [34]. The earliest study on ambidextrous capability was in 1996 and had its roots in innovative firm management [35]. Ambidextrous capability is defined as an organization's ability to excel at using current resources to enable exploitative innovation and develop new opportunities to improve exploratory innovation simultaneously [36,37]. Therefore, despite different innovation forms having very large conflicts in behavior patterns and mindsets, organizations need to balance the relationship between exploitative and exploratory sustainable innovations [38].

The ambidextrous capability theory has gained significant achievements in recent years. Earlier research mainly focused on conceptualizing ambidextrous capability, while most current research pays more attention to developing ambidextrous capability and, thus, generates multiple mechanisms, such as differentiation and integration [39]. A review of three typologies of ambidextrous capabilities in existing research is shown in Table 2. There is a structural ambidextrous capability, which divides two paradoxical businesses into different units [2,40]; a contextual ambidextrous capability, which makes individuals gain two behaviors simultaneously in a certain culture [41,42]; and a coordinated ambidextrous capability, which creates an integrated top management team [16,39].

Although each ambidextrous capability has its pros and cons, the integration of the three of them can deal with exploitative and exploratory tasks well [14].

Table 2. Three typologies of ambidextrous capabilities.

Typology	Advantage	Disadvantage	Exemplars
Structural ambidextrous capability	The structural ambidextrous capability distinguishes two different businesses and reduces their conflicts to improve efficiency.	The structural ambidextrous capability may restrain the complementary strengths of these two businesses and increase integration costs.	Andriopoulos and Lewis [2]; Khanagha et al. [40]
Contextual ambidextrous capability	The contextual ambidextrous capability balances two different businesses well in an organization and reduces integration costs.	The contextual ambidextrous capability may result in polarized developments and employees cannot be excellent at two paradoxical businesses.	Gibson and Birkinshaw [41]; Güttel et al. [42]
Coordinated ambidextrous capability	The coordinated ambidextrous capability is beneficial for balancing two different business strategies and reducing conflicts.	The coordinated ambidextrous capability may overlook the balance of operational activities and encourage polarized opinions, because the top management team often has alike mindsets.	Du et al. [39]; Chen et al. [16]

Academia attaches more importance to the ambidextrous capability theory because it can address sustainable innovation paradoxes effectively [43,44]. As many organizations develop increasingly closer cooperation in sustainable product development, product innovation is facing different paradoxical tensions, such as profit and sustainability of the innovation strategic logic. Thus, an important research area for focal firms is the development of ambidextrous capabilities to resolve product innovation paradoxes in the sustainable ecosystem. The authors analyze the Spacesat case based on the ambidextrous capability perspective, and then inductively obtain a process model of how a focal firm manages innovation paradoxes in the sustainable innovation ecosystem to address the research question.

3. Research Method

This paper takes a single exploratory case as the study method to conduct an in-depth analysis on how aerospace companies gain sustainable innovation capabilities. With the aim to find out how focal firms resolve paradoxes with ambidextrous capability to construct sustainable innovation ecosystems, it is suitable to apply the case study method for this research question focusing on dealing with a dynamic process under a single context [45,46]. The selected case follows the principle of representativeness and typicality [47] and reveals the sustainable innovation ecosystem formation process in similar situations and with similar characteristics. Aerospace satellites are related to the security and economic lifeline of a country and Spacesat, with a leading status in the field of small satellite production, has made many sustainable innovation achievements, such as China's first marine satellite.

The data collection and analysis include three phases to ensure reliability and validity (see Figure 1). Phase 1 is the preparation to establish reliability during May and July 2016. Previous interview data were studied and the Spacesat chronological timeline was drawn in May 2016, followed by the initial interviews and the theoretical lens of ambidextrous capability selection. Phase 2 engaged in onsite visits from August to October 2016. The authors interviewed many Spacesat middle and senior team members, refined three different phases, and readjusted the framework. Finally, Phase 3 is the follow-up from November to December 2016. When the interview data were not enough to support theoretical analysis, additional data were collected via phone calls and emails to assure data-theory-model alignment.

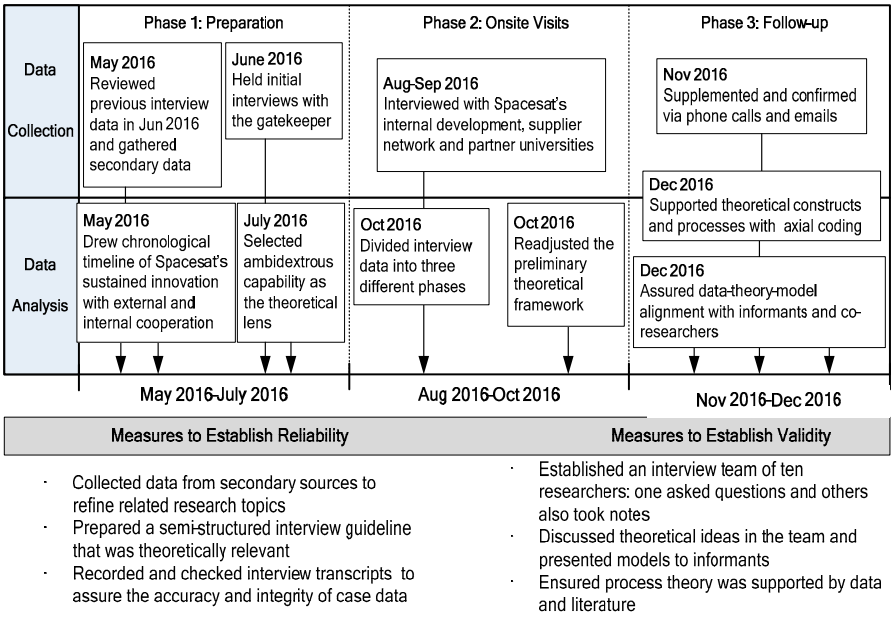


Figure 1. Overview of research methods.

4. Case Description and Analysis

Spacesat, founded in 2001, mainly engages in the design and engineering of satellite systems and applications, as well as foreign exchanges and cooperation of sustainable technological achievements. Small satellites weigh less than 1000 kg. In the past 16 years, Spacesat has developed four types of advanced small satellite platforms at home and abroad and completed the integrated manufacturing of more than 50 small satellites with a success rate of 100%. Spacesat made the first marine satellite in China, the first set of space environment detection satellites, and other great aerospace sustainable innovation achievements. Since its establishment, Spacesat has experienced three developmental stages: start-up, growing, and the advanced stage (see Figure 2). Each stage has different characteristics and the analyses of them are as follows.

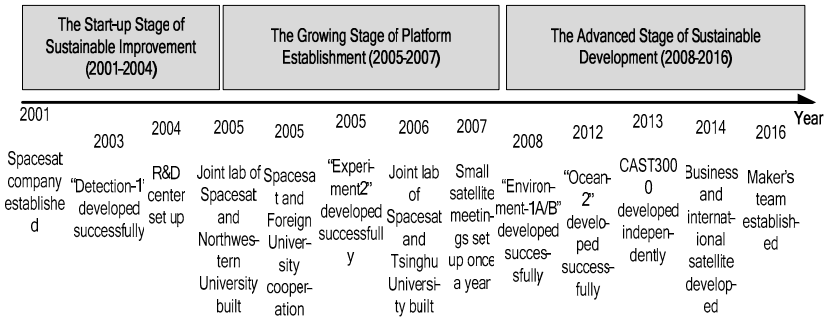


Figure 2. Key events in Spacesat mini-satellite development.

4.1. Phase 1: Establishing Sustainable Innovation Strategic Logic (Paradox A: Profit Strategy and Sustainability Strategy)

Spacesat made small satellites, such as HY-1A and TC-1, rapidly to meet customers' demands based on the improved integration of existing aerospace technologies of China Academy of Space Technology (CAST), Spacesat's holding company. Moreover, Spacesat developed the CAST100 platform by integrating technologies of small satellite platforms CAST968 and CAST2000. In the establishing stage, Spacesat mastered important sustainable small satellite payload technologies, such as charge-coupled device (CCD) transfer and satellite microwave power combiners. With the success of the first export small satellite "VR-1" (the Venezuelan Remote Sensing-One) and the

establishment of the international satellite business unit, Spacesat had entered the international market. By this time, Spacesat had achieved a sustainable breakthrough of satellite technologies, for example, the CAST3000/4000 satellite platform and "GF-1" (Gaofen-One) small satellite. The company conducted short-term technical cooperation projects with Northwestern Polytechnical University (NWPU) and National University of Defense Technology (NUDT) in order to address some technical challenges in the development of components for small satellites, which Spacesat's R&D center encountered when developing products like the CAST100 platform for satellite SY-2, such as structure and thermal control integration and power integration.

It can be seen from the description above that Spacesat faces a sustainable innovation paradox between the exploitation of production and the exploration of development. However, the innovation strategy of the focal firm reflects the balance between the profit leading focus of integrating existing technology and the sustainable leading focus of achieving overall product or platform design [48]. For instance, on one hand, it integrates aerospace satellite technologies of the Fifth Academy of CAST to gain more market share rapidly and, on the other hand, keeps developing high-level technologies, such as the small satellite platform CAST3000, to obtain new international markets and achieve sustainable development.

> *Our company is listed. Product quality should be ensured and production cost should be controlled in the research and development of every satellite. To respond to the market quickly, if a satellite needs to be upgraded or reproduced after its first flight, Spacesat seldom changes the overall design and technologies, including platform technology. This is usually the case at the beginning of Spacesat's development. But to ensure the leading status in the market of small satellites, Spacesat invests about 10% of its income every year into the research and development of new satellite platforms and payload technologies.*
>
> —Director of the Spacesat R&D Center

4.2. Phase 2: Framing the Sustainable Innovation Ways (Paradox B: Tight Coupling and Loose Coupling)

To satisfy the investment demand of stakeholders, the focal firm Spacesat employs methods of single-model manufacturing, such as HY-1/2, in satellite production, enlisting short-term cooperation of technological product breakthroughs and tenders in the component market. This method of loose coupling is beneficial for the enterprise to control production costs, improve efficiency, and ensure a 100% success rate. Spacesat has established an industry-university-institute innovation platform together with R&D institutes and suppliers, including Tsinghua University (THU), Wuhan University (WHU), Technische Universiteit Delft (UTD), and Germany enterprise STI-Studio (STI). It has also set up small satellite meetings and trilateral labs. This method of tight coupling enables the firm to develop world class small satellite products, such as the "VRSS-1" platform, continuously.

The innovation strategic intent of a firm often determines the ways of sustainable innovation cooperation on the operational level [49]. In the paradox of loose vs. tight coupling of complex aerospace product innovations, Spacesat conducts short-term cooperation with external organizations, such as suppliers in single-model product series, such as HJ-1A/B/C, to achieve exploitative innovation. In exploratory innovation, Spacesat develops technologies, including deep space exploration loads and CAST4000, continuously through the intimate industry-university-institute cooperation among CAST and its affiliated organizations, scientific research institutes, and part of its suppliers.

> *Through the intimate cooperation between the internal and external organizations of the firm, we can produce more than 10 small satellites each year and survive in both the domestic and the international markets. This cooperation also pushes forward the continuous development of our sustainable innovation ecology.*
>
> —General Manager of Spacesat

By fully mobilizing the internal and external partners, Spacesat, as the provider and creator of the innovation platform, has, just like its partners, not only benefited from the activities of the innovation ecosystem, but has also found its development direction and an atmosphere of innovation, which has promoted the sustainable development of the innovation ecosystem for small satellites. Its partners include suppliers like Changchun Institute of Optics, Fine Mechanics, and Physics of the Chinese Academy of Sciences (CIOMP), CCD (charge-coupled device) high-resolution imager suppliers, like the Beijing Research Institute of Mechanical and Electrical Technology of the China Institute of Space Technology (Institute 508), and scientific research institutes, like Tsinghua University and Wuhan University.

4.3. Phase 3: Promoting the Sustainable Innovation Drive (Paradox C: Discipline Orientation and Passion Orientation)

In October 2012, Spacesat developed its first small satellite for export, "VR-1" (Venezuelan Remote Sensing Satellite-1), by cooperating with over 10 organizations, including the Fifth Academy of CAST's overall scheme department, control and promotion department, its Xi'an branch, and Institute 508. The production period of this satellite was 12 months shorter than the usual research and production period of a small satellite. At this stage, Spacesat followed a market-oriented method of technology and resource development. For example, with the independent investment of 150 million yuan from the first market financing, ample capital was provided for the exploratory development of the new CAST3000 small satellite platform. Completed in 2012, this new platform was higher-level, more stable, and more accurate. With 200–300 million yuan from the second market financing, Spacesat developed the CAST4000 platform, which represented the international advanced level, in 2016. In addition, Spacesat also developed "Haiyang-2" (HY-2), China's first satellite for marine environmental dynamics detection and "Gaofen-1" (GF-1), the first high-resolution Earth observation system satellite. Most of these products were developed with new principles, methods, materials, and technologies, achieving breakthroughs in function and performance.

An efficient cooperation mechanism is beneficial for the focal firm to produce satellites and respond to customers' demands quickly [50]. For example, Spacesat's state control committee formed by experts will examine and approve the production of satellites of every model on the decision-making level. Spacesat has also set up a chief designer's responsibility system in the production process, with some other departments, such as a Project Office and Engineering Systems Department, working as the support teams of satellite production. Meanwhile, due to the demand of high investment of small satellite R&D and its one-off nature, Spacesat thinks highly of an atmosphere integrated by success and innovation and holds occasional unofficial exchanges, which provides a foundation for external cooperative organizations and suppliers to agree with its values and goal of sustainable innovation ecosystem and provide practical supports.

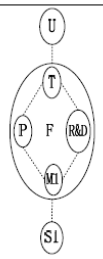
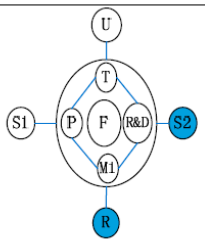
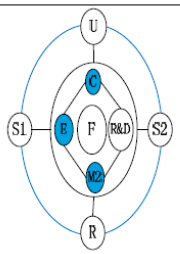
> *Our company requires the R&D and innovation works to "produce technologies and products". That is, a technology is produced only when it has been used in a practical model and a product is produced only when it takes a flight in the aerospace. This changes R&D staffs' mindset. Their technological innovation must be sent into space to become models and their performance determined by success. Therefore, I think Spacesat integrates success with innovation very well and this atmosphere indirectly promotes the idea of innovation in the cooperation between the firm and other organizations. After all, in the field of aerospace, success is everything.*
>
> —Head of Strategic Planning Department

However, in the evolution of the sustainable innovation ecosystem of complex aerospace products, focal firms should coordinate and integrate different subsystems and modules that are in the charge of other involved organizations [51]. Achieving a balance between different coupling methods in the innovation of complex aerospace products still needs appropriate innovation drive. Namely, the paradox of innovation drives of focal firms presents two orientations, that of discipline and passion. In terms of exploitative innovations, Spacesat adopts the matrix system, internally, and efficient

cooperation mechanisms, such as joint efforts in breakthroughs or investment, externally. The exploratory innovation fosters the integration of innovation and success and provides related supports. Accordingly, the interaction between innovation drives and coupling methods is beneficial for firms to conduct different innovation strategic intents [52]. Therefore, the paradox of exploration and exploitation in focal firms' innovations can be reflected in the three tensions at the strategic and operational levels. Additionally, the matching process of different innovation paradoxical tensions can promote the sustainable development of a small satellite product series.

5. Discussion

Organizational ambidextrous capability helps firms to resolve dual paradoxes in multi-organizational cooperative innovations for product development when weighing complex contexts [34]. Aiming at different innovation paradoxes of complex products, focal aerospace firms can select one main ambidextrous capability balancing mode, such as task separation, coordinated ambidexterity, or contextual ambidexterity, to resolve three different innovation paradoxes they, respectively, confront. Accordingly, under different sustainable innovation ecosystem environments, they can gradually establish dual sustainable strategic innovation units, strengthen sustainable organization ties, and then co-create and share the innovation values, so as to build an effective innovation paradox management mechanism in the innovation ecosystem (see Figure 3). Concrete steps of this mechanism are as follows:

Innovation Paradox	**Paradox A:** (Profit vs. Sustainability)	**Paradox B:** (Tight vs. Loose)	**Paradox C:** (Discipline vs. Passion)
Ambidexterity Capabilities of Resolving Sustainable Innovation Paradox	**Structural ambidexterity** (Separating two innovation units for exploitation and exploration in market changes)	**Coordinated ambidexterity** (Flattening the internal organizational structure and creating innovation platforms with external organizations)	**Contextual ambidexterity** (Nurturing innovation culture and self-organizing team)
Mechanism of Managing Innovation Paradox	Step 1: Establishing dual sustainable strategic innovation unit →	Step 2: Strengthening sustainable organization ties →	Step 3: Co-creating and sharing
Context of Sustainable Innovation Ecosystem	 **Distributed innovation ecosystem**	 **Networked innovation**	 **Symbiotic innovation ecosystem**

(Note: The blue dots and lines represent newly-added resources. The meaning of letters in these figures are as follows: F: Focal Firm; R&D: Research and Development; P: Project Office; T: Test Engineering Department; C: Commercial and International Satellite Business Unit; M1: Marketing Department; M2: Maker Team; S1: Suppliers within CAST; U: Universities; R: Research Institutions; and S2: Suppliers without CAST).

Figure 3. A focal firm process model of managing innovation paradoxes with ambidextrous capabilities in the context of the sustainable innovation ecosystem.

5.1. Step 1: Establishing Two Sustainable Strategic Innovation Units

At the beginning of its development, the focal firm Spacesat established two different task units, the Project Office and R&D Center, in its distributed innovation ecosystem to acquire an organizational ambidextrous capability to resolve the profit vs. sustainability strategic innovation paradox. The Project Office is mainly in charge of integrating existing internal and external

technologies to complete the production of more than 10 small satellites each year, as well as the research and development of CAST100 and some other technologies in specific fields. The R&D Center explores internal and external resources to develop small satellite platforms and overall technology. For example, it successfully developed the world-advanced CAST4000 platform and payload technologies, such as uncooled infrared array detectors and static infrared Earth sensors, through international industry-university-institute cooperation.

Therefore, the focal firm Spacesat has acquired an organizational ambidextrous capability mainly by establishing the Project Office and R&D Center for aerospace satellite innovations and separating exploitative and exploratory innovation paradoxes into these two different product innovation business units [2]. This kind of organizational ambidextrous capability reduces conflicts between different innovation strategies by distinguishing the different (behavioral) characteristics of the businesses' organizations [53] and, thus, establishes two different business units with ambidextrous structure.

> *We will let the Project Office and R&D Center take the lead. The Project Office assembles departments such as the Systems Engineering Office for production, aiming to improve and import innovations including optical imaging and nuclear magnetism radar imaging in existing and fixed domains. The R&D Center focuses on exploratory tasks such as space exploration and satellite platform technologies.*
>
> —General Manager Assistant of Spacesat

5.2. Step 2: Strengthening Sustainable Organizational Ties

Although structural separation of the organizational ambidextrous capability can balance different innovation strategies quite well, the complementary sustainable innovation advantages of two different task units cannot be leveraged simultaneously [54]. As the sustainable innovation ecosystem transits from distributed to networked, a technology state control committee (Committee of Science and Technology) formed by chief designers was established at the beginning of Spacesat's development. This committee controls the approval of innovation design projects of model products and designates an expert to take charge of model production, so that HY-1A, HJ-AB, CAST100, and other products suitable for the small satellite market can be developed rapidly. In this way, Spacesat in its growing stage, successfully established a platform for the intimate cooperation between more than 500 Spacesat staff members and over 40 suppliers in a way of "small entities and big virtuality".

In 2013, Spacesat set up the Strategic R&D Management Department and International Satellite Department under the charge of the vice general manager to better coordinate the sustainable innovation platform in the industry-university-institute cooperation among Spacesat, domestic, and international scientific research institutes and suppliers. An innovation platform coordinated by top managers provides participators in the focal firm's ecosystem with cooperation resources and related supporting institutional conditions for technological innovations [55]. It also helps them to achieve overall breakthroughs in technologies for products, including deep space exploration and CAST4000.

> *From the input of creativity to the product end or the output of new technology, small satellite production can be divided into two stages: creative design and model design. The intermediate stage is project approval. Products of every model should be examined and approved by the state control committee. Meanwhile, teams such as the International Satellite Department in the charge of top managers have been built to lead the innovation platforms such as [the] joint lab and industry-university-institute center established by Spacesat and external organizations.*
>
> —Vice General Manager of Spacesat

Therefore, Spacesat has established a top management team to strengthen internal and external organization ties and to gain a coordinated ambidextrous capability [35]. This capability enables the focal firm's two different structural units, that of exploitation and exploration, to complement the advantages of each other and better balance loose and tight coupling innovation methods, so as to maintain the efficiency of cooperation between internal and external organizations.

5.3. Step 3: Co-Creating and Sharing

If the coordinated dualism of organizational capability is in the lack of feedback from the executive level, the polarization of the top management team's ideology is likely to be the result. Thus, an effective organizational context or innovation atmosphere should be established to encourage staff to pursue innovation through the paradoxical conduct of exploitation and exploration simultaneously and promote a sustainable innovation product [56]. The positive culture and climate within a company has a clear connection to improved innovativeness and firm performance [19]. The overall system design, as a significant innovation work for complex aerospace products, highly integrates advanced technologies instead of pursuing one single advanced technology [57].

In the symbiotic innovation ecosystem, Spacesat has established the small satellite meetings, mutually-built labs, and Maker's group to encourage participators in the ecosystem, including scientific research institutes and suppliers, to join in the product design. In this way, these participants can jointly design ground-breaking products, such as the CAST3000/4000 and GF-1, and gradually develop a cultural atmosphere in which sustainable innovation integrates with equal communication about technology. This democratic culture puts the firm's focus on original technology instead of small modifications and improves the innovative atmosphere of the Fifth Academy of CAST in which people consider the enterprise as a family. Meanwhile, Spacesat has established a "special innovation zone" where technologies go first, and management later. In this way, Spacesat can resolve conflicts between production technology and resource management so that resources for small satellite production can be integrated efficiently.

> *"The 'special innovation zone', on one hand, makes production partners stay within the red line of our policies, and on the other hand, opens resources in various aspects and resolves the paradox between technology (such as overall delegation, test prioritizing, and joint development) and management (such as material guarantee and personnel assignment). Overall delegation means that we used to put the overall production solution first and then personnel in engineering and other entities start to develop the product, but now we do these two things at the same time. As for the test, we used to make tests after production is accomplished, but now the testing personnel also engage in product design and development."*
>
> —Top Manager of R&D Center

6. Conclusions

6.1. Theoretical Contributions

This research discusses three paradoxes in complex production innovation of focal firms and how the firms gain organizational ambidextrous capabilities in the form of a management mechanism to resolve innovation paradoxes in different development stages of their sustainable innovation ecosystems. Four main theoretical contributions of this paper are as follows.

First, this research defines the main bodies and types of space focal firms' sustainable innovation ecosystems. Existing studies consider innovation ecosystems as the integration of focal firms and other complementary enterprises like their upstream and downstream suppliers or as three communities—research, development, and application [7,17]. These systems focus on focal firms' overall product development process and provide a macro view of the structure of innovation ecosystems and their interrelation; however, it is difficult for them to highlight the inherent characteristics and nature of themselves in space product innovation in the case of this research. As the major innovation of small satellite development lies in the overall product design, which needs the cooperation of focal firms with scientific research institutes and suppliers, the original innovation capacity is mainly represented by how a focal firm balances users' needs with its basic research and abilities of supply and manufacturing. Therefore, this paper argues that the complementary relation between space focal firms and scientific research institutes and suppliers forms the micro ecosystem

for the catching-up or overtaking innovation in complex product development and has an important impact on the success of the whole product.

Second, this research studies focal firms' mechanisms of resolving innovation paradoxes from the perspective of organizational ambidextrous capability and reveals its processes. Few works have discussed focal firms' management of paradoxes in the sustainable innovation ecosystem from this perspective before [8,52]. For example, Adner and Kapoor claim that focal firms should conduct vertical integration management of key components in interdependent ecosystems and promote technological transformation and substitution [17]. However, they did not discuss the management of multiple innovation paradoxes. Wareham et al. manage paradoxical tensions in science and technology ecosystems through feasible and unfeasible variation mechanisms [23]. However, Andriopoulos and Lewis [2] suggest that the effective manner to manage innovation paradoxes is dualism.

Therefore, this research conducts an in-depth analysis and finds that focal firms gradually construct paradox management mechanisms in the innovation ecosystem by establishing dual sustainable strategic innovation units, strengthening sustainable organization ties, and co-creating and sharing innovation values in sequence. Meanwhile, focal firms use different capabilities simultaneously to resolve exploitative and exploratory innovation paradoxes and promote the development of the innovation ecosystem.

Third, under the context of the sustainable innovation ecosystem, this paper probes into the characteristics and functions of focal firms' innovation paradoxes and enriches the theory of innovation paradox. Existing works put more emphasis on identifying strategic intents, customer orientation, and personal drives and treat innovation paradoxes from a single internal or external angle [25,58]. Wareham et al. conclude the paradoxical tensions, including standard vs. variety of products and services and control vs. autonomy of partners, exist in the product development ecosystem of common scientific and technological products such as the ERP software [23]. However, existing research can hardly reflect the essence of innovative practices' complexity and systematisms. Moreover, under the ecosystem consisting of focal firms, component suppliers, complementors, policy-makers, and other parties, quite a few works conduct in-depth explorations into the innovation paradox characteristics and management mechanisms presented by focal firms internally and externally.

Therefore, this research studies the case of a typical aerospace company. The focal firm should cooperate widely and closely with other firms, institutes, universities, and the government because its production spans the long-term, from pre-research, through project approval, to development. This research concludes three types of focal firms' sustainable innovation paradoxes, profit vs. sustainability in the aspect of strategy, tight vs. loose coupling, and discipline vs. passion in the aspect of operation, and also discusses how different paradoxes affect sustainable innovation ecosystem management in order to construct an effective mechanism to resolve these paradoxes.

Finally, this research analyzes the formation of structural, coordinated, and contextual ambidextrous capabilities more comprehensively, discusses how different ambidextrous capabilities coordinate various paradoxical tensions of exploitation and exploration, and deepens the ties between ambidextrous capabilities and innovation ecology. Existing works study dual management of exploitative and exploratory paradoxes mainly through structure, top managers' cognition, and conceptual research, and thus tend to lack a complete ambidextrous capability analysis framework. This paper explores how focal firms form three ambidextrous capabilities to balance three paradoxical tensions (i.e., strategy, method, and drive), respectively, between exploitative and exploratory innovations. In this way, it studies the case and conducts empirical research to support the judgment of O'Reilly and Tushman regarding the relation between these three organizational ambidextrous capabilities (these three modes are not independent or exclusive) [14], and also provides a novel theoretical perspective for paradox management in the innovation ecosystem.

6.2. Managerial Implication

To construct a sustainable innovation ecosystem, the focal firm Spacesat establishes long-term symbiosis and win-win mechanisms with scientific research institutes and suppliers, new types of joint organizational forms (small satellite meetings, joint labs, trilateral labs, etc.), as well as stable and effective innovation paradox management mechanisms. These help suppliers in key component innovation, scientific research institutes in basic research and efficient transformation, and the focal firm, itself, in predicting future business trends. This research manages to analyze the paradox management process of the sustainable innovation ecosystem from an organizational capability perspective. It helps aerospace firms and the government to further identify operational rules of the aerospace satellite innovation ecosystem and establish a set of organizational system structures and operational modes for sustainable product innovation.

6.3. Limitations and Future Research

This paper only takes aerospace satellite manufacturing as a case to discuss focal firms' management of innovation paradoxes in the sustainable innovation ecosystem. However, it does not mention how focal firms interact with other types of manufacturers in their innovation ecosystems to manage paradoxes using organizational ambidexterity. In subsequent research studies, the team will use the main civil aerospace satellite manufacturer and service industries as cases [59], and will explore innovation paradox management of focal firms in the sustainable innovation ecosystem from a more macroscopic perspective. Meanwhile, this exploratory research aims at revealing the paradox management process mechanisms of focal firms in the sustainable innovation ecosystem. Future research can consider using quantitative analysis for statistics and confirmation so that the model of focal firms' paradox management processes in the sustainable innovation ecosystem can be improved with its restrictive conditions identified.

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