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Published Version

Zhang, Y. and Tsang, D. (2023) Knowledge and innovation within Chinese firms in the space sector. Journal of the Knowledge Economy, 14 (3). pp. 2905-2926. ISSN 1868-7865 doi: https://doi.org/10.1007/s13132-022-00935-w Available at https://centaur.reading.ac.uk/104485/

To link to this article DOI: http://dx.doi.org/10.1007/s13132-022-00935-w

Publisher: Springer

Journal of the Knowledge Economy
https://doi.org/10.1007/s13132-022-00935-w

Knowledge and Innovation Within Chinese Firms in the Space Sector

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Received: 25 December 2020 / Accepted: 14 January 2022

Abstract
Chinese firms have made considerable progress in the space industry within recent decades; some larger state entities have joined the Fortune Global 500 list. The market liberalization, since 2014, has further attracted aspiring new entrants. This article develops a conceptual model by synthesizing business process and knowledge management among high-tech employees to understand technological accumulation within the context of the quadruple helix. We examine the case study of Zhuhai Orbita Aerospace Science and Technology in the Southern Guangdong Province of China, based on extensive primary and secondary data collection. The findings in this article suggest that technological accumulation within the firm is linked to cultural mechanisms, and therefore provides a broad perspective on knowledge management. The findings in this article also suggest that global firms that connect with China's past are more likely to motivate talented employees in the industry.

Keywords Knowledge management · Innovation · Space industry · China · Quadruple helix · Zhuhai Orbita Aerospace

Introduction

Space is depicted as the final frontier in the legendary Star Trek media franchise, where the spaceship Enterprise explores the unknown territory where no man has gone before. Knowledge and innovation underlies such grand ambition as in the journey to Mars. Numerous innovations have been associated with space exploration since the end of the Second World War, which includes the USSR's Sputnik, Vostok, and Syouz, and the USA's Apollo, Skylab, and Columbia.

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Published online: 11 March 2022

China, as a later entrant in the global space industry, landed on the far side of the moon in 2019. It focuses on technology-intensive products such as satellites, space stations, spaceships, rockets, and launch vehicles, where knowledge and innovation is of critical importance. China is now being perceived as a potential game changer (David, 2013; Obe, 2019). Established state firms China Aerospace Science and Technology Corporation (CASC) and China Aerospace Science and Industry Corporation (CASIC) are listed in the Fortune Global 500 list, whereas start-ups such as Zhuhai Orbita Aerospace and LinkSure Network have grown since the 2010s. China became the third country to independently undertake manned space missions using the Shenzhou 5 in 2003; its Shenzhou 12 completed the country's longest 90-day mission in space in 2021. Following NASA's Mars exploration program, China has successfully landed a robotic rover in Mars in 2021.

Table 1 provides a snapshot of the country's achievement in 2015, which reflects the progress of an industry that started from scratch in 1956. Different levels of analysis have been used to understand innovation across countries, industries, and firms, involving concepts such as national competitiveness, industrial clusters, and dynamic capabilities. Publications by innovation theorists have distinguished the nature of innovations (e.g., Schumpeter, 1939; Henderson & Clark, 1990; Arthur, 2007; Kaplan & Vakili, 2015; Fu, 2015). Re-combinative innovation could be seen as creating new and improved products by re-combining existing technologies in new ways rather than developing new-to-the-world products using new technologies. Re-combinative innovation "combines components in a new way, or that it consists in carrying out new combinations" (Schumpeter, 1939, p. 88). The Shenzhou spaceship is an example of re-combinative innovation; it was based on the Russian Soyuz but was larger and heavier, with an additional forward system and a different docking system (Harvey, 2004). In this article, we will address the role of innovation in China's catching up. The focus of our research is: How did Chinese firms create technological knowledge and apply it to re-combinative innovation in the space industry? What are the macro- and micro-foundations of knowledge management leading towards their product innovation?

Table 1 Competitive dynamics in the space industry during the mid-2010s

Ranking	Country	Technological capabilities
1	USA	The largest fleet of spacecrafts — space shuttle; numerous communications, electronic intelligence, missile detection, weather, technology, navigation, and surveillance satellites; space station; International Space Station; Mars rover
2	China	The second largest fleet of spacecraft — space shuttle, navigation, remote sensing, communication, and surveillance satellites; space station
3	Russia	The third largest fleet of spacecraft — space shuttle, communication, metrological, and reconnaissance satellites; space station
4	Japan	A fleet of communication meteorological, earth observation, and astronomical observation satellites
5	UK	A large number of communication and earth observation satellites
6	India	Communication, earth observation, navigational, and defense satellites

Source: Aerospace Technology (2015)

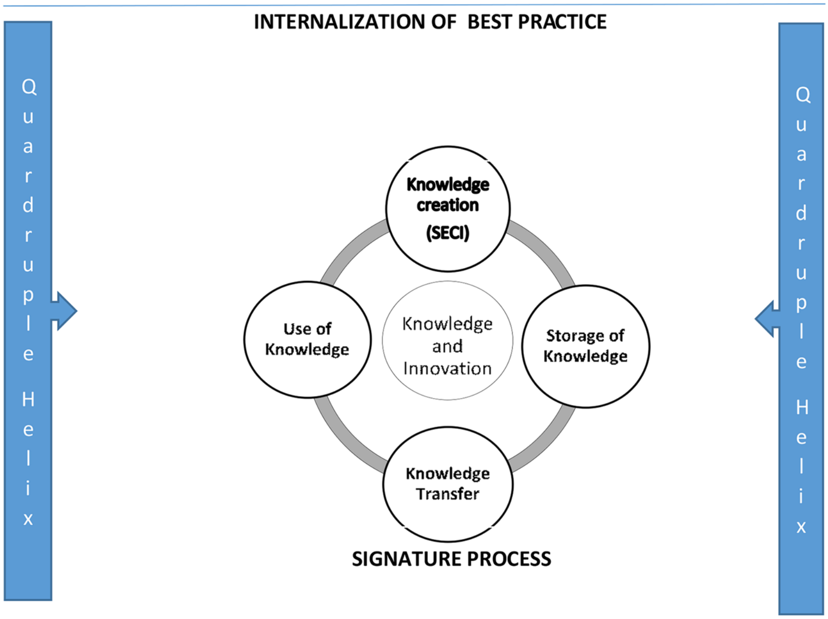
This article presents an original framework to investigate knowledge and innovation in the fast growing Chinese space industry. The underlying influence of the quadruple helix are also highlighted from the macro-perspective and we explain the signature process and best practice that serve as the micro-foundation of knowledge management, which includes creation, storage, transfer, and use. Adding to that, we were able to cooperate with industry professionals and integrated theoretical concepts with business practices in our analysis. This article makes a unique contribution and filled the gap in current literature in an under-researched industry. Contributions were made towards innovation literature and demonstrate the operation of the quadruple helix within a global and local dimension.

This article is structured into the following sections. The next section introduces the concepts and models that underpin our analytical framework. We first discuss the knowledge process within firms and its interaction with internal process and external practice. We also introduce the quadruple helix as the underlying influence of the knowledge process and proceed with the case study methodology, highlighting the selection of a representative firm in Southern China. This is followed by an overview of the space industry in the People's Republic of China. Next, we contextualize our discussion of knowledge and innovation within Zhuhai Orbita Aerospace. Our discussion was supplemented by the analysis of industry and national influences. Then, we draw our conclusion and examine the limitation of our research. Finally, the practical implication of our framework for different stakeholders is examined.

Literature and Analytical Framework

Existing literature has pointed to the implication of knowledge management on innovation (Caloghirou et al., 2004; Cantwell, 2017; Cohen & Levinthal, 1990; Teece, 2007). In particular, the cumulative processes in the development of technology among late entrants were heavily embedded within the literature on political economy and innovation studies (Amsden, 1989; Bell & Figueiredo, 2012; Bell & Pavitt, 1993; Wen & Fortier, 2019). At the country level, technological accumulation could be explained by the knowledge process within the national system of innovation whereas at the industry level ecosystems and clusters enabled us to gain insights into the process (Adner, 2006; Bell & Albu, 1999; Porter, 1998; Stam, 2015). At the firm level, the traditional emphasis of internal R&D has been supplemented by open innovation which highlights the importance of acquiring external knowledge in the development of new ideas and invention of new products (Chandler & Hikino, 1990; Chesbrough, 2003; Huizingh, 2011). Nevertheless, the helices models cut across the macro-, meso-, and micro-components and focus on the functions and relations among government, university, firm, and civic society towards the creation, transfer, and application of knowledge (Etzkowitz & Leydesdorff, 1995; Leydesdorff & Etzkowitz, 1998; Carayannis & Campbell, 2009).

Figure 1 shows the analytical framework that connects the micro- and macro-foundations of knowledge and innovation. The evolving nature of best practice in conjunction with the signature process during technological knowledge process



Source: Authors.

Fig. 1 Analytical framework

could be contrasted with the contingency perspective towards dynamic capability and competitiveness; the core knowledge management activities could be parallel to the lower order sensing and seizing capabilities while the higher order reconfiguring capabilities are embedded within best practice and signature process (Birkinshaw et al., 2016). The underlying influence on innovation within framework is the quadruple helix.

Knowledge Management

Knowledge and innovation within firms can be examined with the process models of knowledge management, comprising of create, store, transfer, and use (Dalkir, 2011; Evans et al., 2014). In particularly, recent literature has looked closely at knowledge creation (Bolade & Sindakis, 2020; Dana et al., 2020; Fachrunnisa et al., 2020; Nonaka, 1991). Bolade and Sindakis (2020) examine individuals creating knowledge through the process in cognition, memory, and psychology. Dana et al. (2020) and Nonaka (1991) focus on the interaction among employees that shape knowledge and innovation in firms. Fachrunnisa et al. (2020) discuss the strategic practices that could shape innovation and propose leadership and management as key factors that generate engaged knowledge employees.

Project teams are the basis for innovation due to the complexity of knowledge in high-technology industry; hence, the social process in conjunction with the creation of knowledge among teamwork as elaborated by Nonaka is important. Nonaka's SECI model states that socialization, externalization, combination, and internalization enable the transfer of both tacit knowledge and explicit knowledge between individuals within firms and between firms and the stakeholders (Nonaka, 1991; Nonaka & Takeuchi, 1995). It has been suggested that technological knowledge could be created passively or deliberately (Hansen & Ockwell, 2014); the former relates to unintentional learning taking place during work activities whereas the latter includes internal activities such as formal training, research, and development or external learning in the form of technical assistance or strategic alliances. In this sense, the SECI model incorporates both the passive and deliberate elements of knowledge accumulation, which can be drawn from distant or similar knowledge.

The SECI model begins with individuals converting tacit knowledge into new tacit knowledge through socialization, and the tacit knowledge will then become explicit knowledge through externalization. The next stage will be individuals integrating different forms of explicit knowledge into some new explicit knowledge and finally the explicit knowledge is internalized and converted into tacit knowledge before the cycle of knowledge re-starts. Socialization occurs as individuals share tacit technological knowledge, whereas externalization occurs as individuals translate tacit technological knowledge into explicit technological knowledge. Combination, on the other hand, relates to how individuals integrate various explicit technological knowledge. Finally, internalization occurs as individuals augment explicit technological knowledge with their own tacit technological knowledge.

Best Practice

Best practice represents the effective and efficient process towards knowledge and innovation within an industry (Spender, 1989). The best practice within the literature has been examined in terms of business process management (Abdulkader et al., 2020; Zott & Amit, 2013) and can be traced to the analysis between value chain and firm competitiveness launched by Porter (1985). Since then, there has been substantial research across the value chain that enables firms to capture the value created. Lombardi et al. (2015) examine the importance of IT within the business process and propose a model to manage the IT process for value creation. Other emerging business processes that include using open innovation within R&D have also become best practice in the technology sectors (Orlando et al., 2020). Examples of management processes within the global space industry PDCA and 6 SIGMA as well as quality standard AS 9000 have been adopted in the Chinese space industry. We have incorporated the best practice within the framework as to illustrate the relevant knowledge management aspect from the industry perspective.

Signature Process

Acquiring best practice and incorporate it into a firm's knowledge and innovation would lead to "a level playing field," firms' capability to maintain competitive advantages therefore require signature processes, and signature process embodies the firms' characters and are idiosyncratic (Gratton & Ghoshal, 2005). The study of dynamic capabilities has argued for the role of strategic processes or messages embedded within firms (Al-Aali & Teece, 2014; Aaker & Aaker, 2016). A signature process relates to the core process that has evolved within the firm, internally, from the values and aspirations of the leaders, which enables the firm to align its culture and people during technological accumulation (Gratton & Ghoshal, 2005). Transformational leaders are key to the signature process (Bass 1985; House & Shamir, 1993; Mumtaz & Rowley, 2020). The signature process is important as it facilitates the sharing of best practice knowledge; in the long run, firms which learn external best practice and embrace their signature processes at the same time are able to generate sustainable capabilities and competitiveness (Forésa & Camisónb, 2016).

The Quadruple Helix

The quadruple helix encompasses the innovation generation process that is based on the interaction among the state, academia, business, and civil society (Carayannis et al., 2012). Universities and businesses undertake research and development whereas the state provides the regulatory framework independently or jointly with research partners. The civil society, comprising of communities and networks, generates knowledge that enhance innovation; users are frequently a key source of ideas within the open innovation model. To a great extent, the civil society draws from the values of the creative class (Florida, 2014) that fosters creativity and innovation. Overall, the four helixes collaborate with one another and are the macro-sources for innovation; the helixes could also substitute one another's function if required. Researchers have examined the quadruple helix at the national (Afonso et al., 2010) and the industry level (Gracia-Teran & Skoglund, 2019); however, research focusing on a holistic understanding of the quadruple helix that integrates innovation at the national, the industry, and the firm level is lacking. The earlier framework in Fig. 1 elaborates the underlying collaborative influence of government, academia, business, and civil society that shape the production of knowledge and innovation.

Overview of China's Space Industry

Foreign trained researchers and scientists from the USA and the Soviet Union were the founders of the Chinese space industry (Bardi, 2016). In addition, China's knowledge transfer agreements with Soviet Union in 1957 as well as in the early stage of Russian economic transition in 1994 were significant. Examples include the design of Dongfeng 1 rocket and Shenzhou spacecraft basing on Soviet R-2 and Soyuz technology (Tsang, 2017). The creation of the Chinese Academy of Sciences served as the first step towards China's ambition in the technology-intensive industry. China's GDP per capita was less than US$500 in its early decades; the development of the space industry utilized finite economic resources that had similarity to the frugal mindsets of Soviet Union scientists. China has continued with such economic approaches to development and only spent US$6,111 million in 2013 despite the economic miracle; the small budget could be contrasted to the US space budget of US$39,332 million in the same year (Luxton, 2016). With further growth in its economy, China allocated US$5.8 billion to space budget in 2018, which was the second highest spending in the world but still substantially lagged behind the US$40.1 billion (CSIC, 2019).

The Chinese state has invested in various institutions in the space industry that could all be traced back to the Fifth Research Academy (headed by Qian Xuesen). The Fifth Research Academy was established under the Ministry of Defence in 1956; it restructured and rebranded itself during politico-economic changes and was successively the Seventh Academy of Machine Building (1964), the Ministry of Astronautics Industry (1982), and the Chinese Aerospace Corporation (1993). In 1999, the Chinese Aerospace Corporation was reorganized into the administrative function, headed by China National Space Administration, and the research, design, and production functions grouped under China Aerospace Science and Technology Corporation (CASC) and China Aerospace Science and Industry Corporation (CASIC). Both CASC and CASIC are independent entities, with some 300,000 total number of employees; the two headquarters could therefore be seen as conglomerates that coordinate large subsidiaries and these large subsidiaries in turn managed operations in China or abroad. Prior to 2014, the two state-owned conglomerates monopolized the industry. Nevertheless, there have been nearly 100 SME new entrants specializing in the niche segment since market liberalization in 2014 (Goh, 2018). These SMEs are founded by individuals with ambitions; some aspire to become equivalent to Elon Musk's SpaceX. Hence, it is not untypical for firms named as One Space, LinkSpace and LandSpace, iSpace, Spacety, MinoSpace, and MXR Space. Some of these start-up firms have grown and attracted funding from investors including Xiaomi and Lenovo, and the more successful ones have obtained funding from investors in the country's stock exchange (Bloomberg, 2018).

We selected a private firm in Southern China that ventured into the space industry using a single case study methodology to illustrate the process of knowledge accumulation and innovation; this case study firm was particularly interesting since the founder was educated in China and had worked in the state sector before accumulating a PhD and industry experience abroad (Cunningham et al., 2017). Additionally, the ownership of the firm involved the equity stakes of local government, which is not untypical within China's state capitalism. To a certain extent, the firm therefore bridges the old and new China within the space industry, which provides unique insight into the development of the Chinese industry. Table 2 shows the key events in the Chinese industry before 2020. Additional key events were the successful landing of the Mars rover Zhurong and the return of Shenzhou 12 that took place in 2021.

Table 2 Development in the Chinese space industry year key event

Year	Event
1956	Establishment of the Fifth Academy research institute as Mao Zedong decided to take China to space
1960	Launch of first rocket, T7
1966–1976	Disruption during the Cultural Revolution
1970	Launch of Dong Fang Hong Satellite, using Long March 1 rocket
1975	Success in satellite return technology, FSW-0
1993	Under Deng Xiaoping, China National Space Administration was established in Beijing after restructuring of state firms
1999	Successful unmanned spacecraft mission
2003	First manned mission with Shenzhou 5 spacecraft
2007	Lunar Exploration Program Chang'e began
2011	Launch of first prototype space station, Tiangong 1
2014	The State Council's market liberation of the space industry and permission of private capital; first private firm LinkSpace was founded in Beijing
2016	The Shenzhou 11 crewed mission, docked in Tiangong 2 space station
2019	Chang'e 4 soft landing on the far side of the moon; release of technology requirement concerning private sector firms involving in small- or medium-sized rockets

Source: Based on Goswami (2018), Beall (2019), and Campbell (2019)

Methodology

Building on the interpretive paradigm (Schwartz-Shea & Yanow, 2012), this article uses a single in-depth case study approach to examine the proposed framework. The qualitative nature of the research provides thick description of knowledge accumulation and their subsequent implications, and is appropriate in understanding the technological significance related to innovation. A case study can be seen as an empirical inquiry that investigates a phenomenon within a specific context; the use of a case study in this article allows an explicit understanding of the individual and collective knowledge that has led to re-combinative innovation in the Chinese aerospace industry. Overall, due to the sensitive nature of information among space firms in the USA, Europe, and China, most space firms were reluctant to cooperate in the research project. We gained access to the case study firm by third-party introduction. Consequently, this article was able to shed light on the private space sector in China.

Extensive collection of documentation in Chinese and English concerning the Chinese space industry and personal interviews with firms were the main sources of data used. Six firms and their contacts were initially identified from news articles in relation to the Chinese space industry in August 2019 and we approached the firms via emails in September. The email highlighted the independent nature of the research, the research ethics, and the potential of international publication. Subsequent telephone calls were made to these firms to follow up the email invitation. Among them, two firms agreed to take part in the in-depth interviews in September 2019 via WeChat. The topics covered revolved around firm specific advantages and knowledge accumulation. Since both firms' knowledge practices were similar to the industry practice, we selected Zhuhai Orbita Aerospace Science and Technology (or Orbita Aerospace) for the single case study in order to examine the framework presented in the preceding section. Orbita Aerospace is located in the Guangdong-Hong Kong-Macau Greater Bay Area, which is the most distant technology cluster from People Republic of China's capital city Beijing. We considered Orbita Aerospace an appropriate firm to examine in the current era of market liberalization; it contrasted with the other firm, which was a division of a leading state owned firm. Two further interviews were conducted with Orbtia Aerospace, both were approximately 30 minutes. The first interview with the senior marketing manager took place in September 2019 whereas the second interview with the senior R&D manager in December 2019. Additionally, we also scrutinized documentations such as annual reports, press releases, shareholders meetings, news reports, research papers, and industry publication concerning the firm since its creation, as to gain further insight of Orbita Aerospace's technological innovation over time. A database with approximately 600 pages was created and was organized into four folders — audio, video, document, and image. For example, the document folder contains the case study protocol, interview guide, interview transcripts, annual reports, relevant research, etc. The use of both primary and secondary data therefore allowed the triangulation of findings which improved the case study design in terms of validity and reliability.

Orbita Aerospace was established in 2000 and currently employs over 1000 staff in multiple sites within China in December 2019. R&D accounts for approximately one-third of its headcount. Orbita Aerospace has been listed in the Shenzhen Stock Exchange since February 2010 (stock code 300053), and its sales revenue has increased from CNY176 million in 2010 to CNY870 million in 2020 (Orbita Aerospace, 2020). It is a provider of aerospace electronics, big data services via satellites in areas such as agriculture, environmental protection, and transportation as well as artificial intelligence. It has, since 2019, operated a constellation of 12 commercial satellites: two were launched in June 2017, five satellites were launched in April 2018, and there was a launch of five satellites in September 2019 (Weitering, 2019). The firm has steadily gained market shares in the commercial low-Earth orbit constellation of satellite services. Its founder Dr. Jun Yan serves as the Chairman of the firm and owns 16% of its equity (Orbita Aerospace, 2018). Orbita Aerospace's business has reached out to both Chinese and overseas customers. The firm has a typical operational structure, culture, and strategy within the industry, and has contributed towards China's emerging position within the industry. Its founder Dr. Yan graduated from the Harbin Institute of Technology and was then allocated centrally to work in the Chinese Aerospace Corporation in 1985; he took part in an exchange program in 1985 to pursue a PhD in Robotics at the University College Dublin, Ireland (funded by the Chinese Scholarship Council). Dr. Yan subsequently gained work experience in the Irish University as a lecturer in the School of Computing. He then left to work in the Canadian industry in 1992 before returning to China in 1998. Dr. Yan started a new firm in Zhuhai (i.e., Orbita Aerospace) specializing in high-performance semiconductors including system-on-chips (SoCs) based on Sun's open-source SPARC processor (Kavanagh, 2017). Due to the rapid pace of technological advance in the space industry, the industry provides an appropriate background to explore technological accumulation and re-combinative innovation. We will discuss the technological accumulation within Orbita Aerospace as the basis to analyze our framework within the following section.

Contextualizing Knowledge and Innovation

We will now examine the analytical framework with the case study firm Orbita Aerospace. The analysis will highlight that the context of knowledge management in the PRC is similar to the process in other knowledge economy; however, the basis of knowledge and innovation is derived from the history and culture of the country.

Knowledge and Innovation

In this sub-section, we will discuss the creation of technological knowledge regarding SECI then we will explore the storage, transfer, and use of technological knowledge in order to illustrate the complete process of technology accumulation.

Knowledge Creation

Using the SECI mentioned in the preceding section, we discuss both internally and externally created knowledge in Orbita Aerospace. As science and engineering degree graduates represent approximately half of the recipients of undergraduate degrees in Chinese universities and the firm is located in an attractive and highly livable location, it has a relatively large pool from which to select the best candidates. It should also be noted that the success of China's space mission further glamorized the industry and turned key figures in the industry into popular idols, which attracts potential candidates. Socialization within Orbita Aerospace enabled the transfer of tacit knowledge from one employee to another through a collaborative meeting every week. Design engineers generated tacit knowledge through direct interaction with other engineers, and this was most useful among the junior employees who were routinely mentored by experienced staff when joining the firm. The transfer of tacit knowledge also occurred when engineers interacted with colleagues who participated in other project teams. Socialization further took place between engineers in commercial satellites and other divisions, between engineers and designers outside the firm and with suppliers, through direct or indirect channels. To a great extent, the process of creating tacit knowledge was driven by the search for new solutions or answers to specific problems; for example, engineers visited or talked to their contacts whenever queries arose.

Externalization, on the other hand, is the process for making tacit technological knowledge explicit. This related to engineers in articulating their knowledge into design and technical solutions during meetings, incorporating inputs from other research institutions or consulting the experts associated with the firm. Discussion and feedback provided opportunities for externalization of knowledge within and beyond the firm boundary, coordinated through scheduled progress meetings and more informal, unscheduled meetings. Scheduled meetings among teams responsible for specific projects adhered to existing timetables and individual project teams could decide the frequency of further meetings. During the scheduled meetings, team members of the projects would discuss their progress, and the meetings provided an open forum for all the members to make valuable comments or to put forward views. Unscheduled meetings involving the project teams would be called whenever issues arose that had to be resolved within a short time span. The unscheduled meetings provided a forum for project teams to meet up and draw on the team's tacit knowledge to tackle immediate issues. Overall, the R&D manager emphasized that the process was "not tightly structured" but "results driven." The conversion of explicit technological knowledge to more complex sets of explicit knowledge could also be identified. Explicit knowledge has historically been transferred among engineers in its explicit form through formal reporting procedures.

The combination process involves combining explicit knowledge in different formats including examples such as publicly available data, internal blue prints, technical specifications, and briefing documents, into organized systems that could be used widely within the firm. Advances in information technology introduced new ways to facilitate the combination of explicit knowledge. Indeed, the digitization of information and knowledge in the past decades has reiterated the new mode of learning and generated substantial opportunities for virtual learning through journal articles published by cutting-edge researchers. A recent review of scientific research and information resources required for innovation activities within the space industry suggested that Chinese engineers used similar core journals to their international counterparts (Du & Song, 2013).

Finally, internalization occurred when engineers absorbed relevant specialist explicit technological knowledge within the firm, transformed it into tacit knowledge through individualized learning, and then applied the knowledge in design, problem solving, and solutions within project work. Orbita Aerospace facilitated the process by organizing formal seminars fortnightly so that engineers could learn from different project teams. Leading industry experts also gave lectures within the firm. It should be noted that the job description for engineering employees in the Chinese space industry are relatively short compared to the USA and the UK since there is high level of trust in these professionals to perform the requirement within their jobs. This process of knowledge creation reinforces the socialization component and forms a self-reinforcing spiral (Fig. 2).

Knowledge Storage

Orbita Aerospace orchestrated a highly structured and secure internal system whereby the confidential database was monitored and safeguarded, which is common among design facilities in global firms. After a project has been completed, all the relevant documents such as paper documentation, pictures, software, and videos

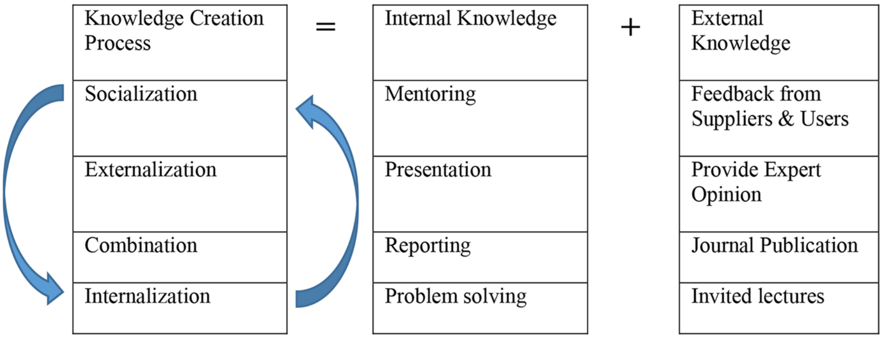


Fig. 2 Knowledge creation process in Orbita Aerospace. *Source*: Based on Nonaka (1991)

were archived. Overall, there was a strong emphasis of the free-flow and exchange of ideas among the team members within the divisions and across the divisions; this was reinforced by the stability of the teams with a below average employee turnover rate that increased shared understanding and trust. The R&D manager mentioned those who left the firm typically relocated to bigger neighboring cities Shenzhen and Guangzhou; their departure therefore reflected individual preferences of mega cities with population of over 10 million. Overall, considerable knowledge was obtained by team members during each project, and they could drew on their tacit knowledge in future projects whenever the needs arose.

Knowledge Transfer

The transfer of technological knowledge related to the dissemination and communication of the knowledge internally and externally. Projects within the company were the foundation for the timing and frequency of knowledge transfer through various coordination mechanisms. The milestones for specific projects enabled the transfer of knowledge among members working towards the same end. It should be added that Orbita Aerospace liaises with industry experts which enabled it to constantly update its knowledge base; Orbita Aerospace has also collaborated with leading Chinese institutions such as Wuhan University, Harbin Institute of Technology, University of Science and Technology of China and Qingdao University of Science and Technology. For example, the satellite Qingkeda 1 which could generate approximately 7000 TB of data annually represents knowledge transfer between the firm and Qingdao University of Science and Technology (City of Zhuhai, 2018).

Use of Knowledge

The decision to apply technological knowledge within projects was driven by a combination of factors, which included the firm's technological capability, the technological trend in the industry, feasibility of the design, market demand, cost, the preliminary research report, and the overall decision of the technological leaders.

The value of applying technological knowledge in terms of engineering design and its subsequent production generated economic value for the company (which it reported in the profit and loss account every 3 months). Though explicit knowledge such as existing patents and blueprints might be employed within new product design, some degree of tacit knowledge would be involved since tacit knowledge was often required in the use of codified knowledge (Dalkir, 2011). The fact that Orbita Aerospace was able to develop four video satellites (OVS1A, OVS1B, OVS2 and OVS3) as well as eight hyperspectral satellites (OHS2 and OHS3 series) in recent years demonstrated its ability to capitalize on its knowledge asset.

Signature Process

The Chinese space industry was created, shaped, and led by returnees from the USA and Europe during the 1950s, who diffused a culture of autonomy within the industry. The research and development activities of the Fifth Research Academy and its subsidiary units, to a great extent, enjoyed a sense of academic freedom in a paradoxically autocratic regime at the time. The culture of the industry, as embodied in the signature processes, remains and is still observable in the wider industry. There was a high level of work autonomy in work scheduling, decision making, and the application of scientific knowledge in engineering design; institutions such as the CASC endorsed engineering employees to be autonomous and avoid being risk-adverse (Liu, 2013). Figure 3 highlights the origins and development of the signature processes. At the country level, the Chinese-Soviet split in 1960 generated a national sense of autonomy since China faced the dire consequence of the sudden withdrawal of Soviet technical assistance (Harvey, 2004); this fostered a sense of urgency among the participants and supporters of the industry to create indigenous technology thorough re-combinative innovation, where autonomy was associated with the long-term development of the strategic industry (Table 3).

It should also be noted that the development of signature processes have been consolidated not only by those who led the industry, but also by intriguing, authentic, and involving signature stories interwoven with the history of the industry. Since the economic reform, the Chinese government has celebrated the achievement of individuals that have contributed significantly towards the

Table 3 Signature process of autonomy within the Chinese space industry

Origin	Sudden withdrawal of Soviet technical assistance
Country factor	Industry pioneers' practice
Industry factor	Organic growth and diffusion
Firm-specific factor	
Development	Nie Rongzhen, Qian Xuesen, Liu Jiyuan
By leadership	Economic reform
By government	
Core values	Obligation and responsibility

Source: Authors

industry, which could be contrasted with the unfortunate purge of intelligentsia (including some aerospace engineers) during the Cultural Revolution. For example, prizes are given to those who made significant contributions at the national, industry, and firm level. The State Council, the Central Committee of the Communist Party, and the Central Military Commission had dedicated a Two Bombs and One Satellite Meritorious Award in 1999 to key scientists and deceased contributors for their distinctive achievements that shaped the country's space development; the Chinese Academy of Sciences has further constructed a Two Bombs and One Satellite Memorial Museum while the history of the project had also been developed into a lecture series disseminated by branch offices within the higher education division of the Chinese Communist Party. Orbita Aerospace's R&D manager elaborated during the interview that there was a strong integration process as driven by customers' needs that bind their different business together. He mentioned that "R&D engineers operate with autonomy in projects directed by the managers… some of these projects last for one year but others might continue for ten or twenty years." Like its Chinese counterparts, the autonomy did not lead to disintegration as there were close relationship among the employees. The R&D employees worked 8 hours a day and enjoyed a 5 day week; they participated in outdoor sports activities with grounds arranged by the firm in Zhuhai in addition to monthly organized leisure activities. As a high proportion of the engineers were from outside Zhuhai, the firm was paternalistic and looked after their well-being.

Best Practice

We will proceed to discuss the best practice within Orbita Aerospace, which has recruited predominantly postgraduate employees with at least 7 years of science and engineering experience in higher education within its project teams. Orbita Aerospace implemented the industry best practice in terms of global technology standard. It obtained the ISO9001 quality system management standards (the 2000 version) in August 2008. It also worked closely with its suppliers to maintain global practice and standard. Its supplier of the clean room facility adopted the industry standard ISO-5. Its aerospace component division utilized a proprietary software tool from the Irish firm OCE Technology to improve its functionality (Kavanagh, 2017). Orbita Aerospace's firm culture could be characterized as collaboration, innovation, respect, and contribution, which were sustained by engineers with autonomy in their work. The founder Dr. Yan's postgraduate education in Ireland and work experience within Ireland and Canada further echoed the overseas experience of the space industry's early returnees. To a great extent, the founder's unique human capital accumulated in the West has enabled him to lead a fast growing firm and cultivate the signature process of autonomy as in the global context. Dr. Yan had publicly acknowledged the importance of the firm's human capital and advocated the role of primary and secondary education in fostering creative individuals and their interests in space technology (Sohu.com, 2019). He was also instrumental in the promotion of recruiting more PhD holders in the city of Zhuhai through the organization of high-level talent association, which highlighted that the cluster of talents would ultimately bring benefit to local firms and the development of the Greater Bay Area in China (jrj.com, 2019) (Table 4).

The Helix Approach

Our discussion in the earlier section has provided useful insight on the interaction within the quadruple helix, which in turn influenced knowledge and innovation in the case of Orbita Aerospace. The earlier Table 3 summarizes the impact of the Fifth Research Institution and the democratic management approach from the relevant government agencies towards the making of signature process within the industry. This signature process has become the norm among firms in the industry including Orbita Aerospace. The best practice as in technological and quality standards established by international institutions were adopted by the government agencies and promoted as a standard within the industry. Furthermore, the best practice was reinforced by Orbtia Aerospace's collaboration with foreign firms. The national academia and the regional culture also played a role towards the knowledge management process. The location of Orbtia Aerospace (close to the high-tech hub Shenzhen and far away from the central administration in Beijing) fuelled the innovative culture essential for creativity. Orbita Aerospace was within the high-tech Greater Bay Area, with leading cities that have led the country's rapid transformation. Shenzhen was the first special economic zone in 1980. China's first McDonald was opened in Shenzhen in 1990. Also in 1990, China's first stock exchange was founded in Shenzhen. The PRC government re-gained the sovereignty of Hong Kong and Macau in 1997 and 1999, and re-integrated the former European colonies using the one country-two system transition. The first overseas Victoria and Albert Museum's Design Gallery opened in Shenzhen in 2017. Burberry established its first Social Retail store for generation-Z customers in Shenzhen in 2020 (Table 5).

Table 4 Knowledge and innovation within Orbita Aerospace

Best practice	Industry knowledge standard
Signature process	Autonomy
Technological knowledge accumulation	
Creation	SECI tacit and explicit knowledge
Storage	Centralized system and within people
Transfer	Project based
Use	Value creation

Source: Authors

Table 5 Interplay between quadruple helix, knowledge, and innovation

Helixes	Signature process	Best practice	Knowledge process
Foreign universities			
Local universities		X	X
International institutions		X	
Home research institutions	X		X
Government agencies	X		
Local authorities			
Foreign firms		X	
Local firms			
Innovative culture			X

Source: Authors

Discussion and Conclusion

This article has built upon the literature from knowledge and innovation and illustrated the wider context of re-combinative innovation. Firm process and practice as embedded in culture serves to explain the accumulation of technological knowledge among space sector employees, which has generated many re-combinative innovations in the Chinese industry. The article has explored the role of critical firm processes that has enabled technological knowledge to be created, stored, transferred, and applied. The findings contradict the notion that Chinese firms exhibited “a greater reluctance to utilize international (i.e., non-domestic) sources of knowledge” (Wibe & Narula, 2002) but support the importance of open innovation as suggested by Chesbrough (2003). The signature process of autonomy in Orbita Aerospace, which mirrored that of firms within the industry (Tsang, 2017), originated from the unique national, industrial, and firm influences and was a product of China’s historical development in the past 50 years. We have incorporated the quadruple helix in our framework and were able to utilize the helix approach within a long-term perspective.

There was a high level of trust among firms in the Chinese space industry despite the first generation of scientists and engineers with prestigious family background or foreign affiliations. The space industry professionals developed a sense of obligation and responsibility that formed the core values of the signature processes; they were dedicated to their work in order to reciprocate the trust and the expectation from the newly founded People’s Republic of China. Interestingly, the founder of Orbita Aerospace stated that the firm felt it had a responsibility towards its shareholders, customers, suppliers, and China’s prosperity (Yan, 2017), which supported the theoretical lens in relation to institution-based advantages deriving from varieties of capitalism proposed by Hall and Soskice (2001). This suggests the variation of knowledge economy in terms of the socio-economic contribution of firms. The results, shown in the previous sections, provide an understanding of the success of Orbita Aerospace within the unique context of economic change. It has built on the signature processes derived from the experience of its founders outside China, who then diffused it to its members by adhering to the best practice in scientific and engineering disciplines from the US and Soviet Union's research and development. Overall, the practitioners in the space industry represented the elites of science and engineering in China and could be compared to the gentlemen-scholars in the Confucian social hierarchy (Liu & Stening, 2016); the reason that autonomy has taken root in the industry could be compared to the Confucian morality among these gentlemen-scholars, who have always been autonomous decision makers in accordance with the proper rites. We have, therefore, provided useful additional insight into the evolution of one specific sector within Chinese management that might be able to be applied across high-tech employees. This is particularly important for the motivation of knowledge employees among foreign investment in China.

It should be noted that the glorification of a Chinese Dream could also be considered as the long-term reinforcement motivating participants in the space industry to excel. But what is the state led version of the Chinese Dream? Perhaps it is about regaining technological influence within the global space development, where China once had unrivalled leadership in gunpowder and primitive rockets. The space industry with artifacts deriving from Chinese legends including Tiangong, Shenzhou, Zhurong, and Chang'e, which has cultural significance, therefore serves as a symbolic vehicle to help China search for its identity in the twenty-first-century global order. The space adventure with its ancient roots and in a modern setting has managed to tap into the intrinsic motivation force despite unprecedented speed of socio-economic changes. To a certain extent, the firm specific advantages of Orbita Aerospace and its counterparts are built upon China's distant past. The finding enriches our understanding of the industry and broadens the scope of research by Zheng (2019) and also supports recent literature on firm level competitive advantage. The recent work of Birkinshaw et al. (2016) has provided an overall framework to de-construct the role of dynamic capabilities, with the combination of the mode of adaptation to the changing business environment and an associated set of capabilities as the key to understanding competitive advantage. Our findings illustrate the simultaneous presence of lower order sensing and seizing capabilities during knowledge management at the project level as well as the higher order capabilities of reconfiguring at the firm level. We have added to the existing literature by specifying the contribution of national heritage in the context of China. In a similar vein, the notion of American exceptionalism might be a heritage that could be tied with the US technological leadership in the space industry. The rise of China in the space industry has illustrated that the country and its indigenous firms are able to create and shape an evolving ecosystem for the needs of re-combinative innovations in the space industry.

Managerial Implication

The proposed framework as shown in Fig. 2 offers an integrated view of re-combinative innovation. The roles of firm level knowledge management as supported by external practice and signature process allow managers to examine the innovation from a wider perspective. Most importantly, innovation takes place within the quadruple helix and that illustrates the location of firms that affect accumulation of knowledge. The quadruple helix highlights the role of knowledge institutions and the civil societies that promote tolerance, pluralism, and diversity, which support creativity and innovation. This therefore suggests that the traditional location factors such as leading research institutions, government policies, and industry clusters could be viewed along contemporary factor of democracy or knowledge democracy. Carayannis and Campbell (2021) propose democracy as an innovation enabler. However, it could also be argued that the Western notion of freedom and democracy could be perceived from a different perspective. The frog at the bottom of the well in the Chinese saying is not free or knowledgeable, but it is the perception (rather than the reality) that counts. As a contrast, a frog in the countryside that does not have the ability to navigate in its surrounding will be confined to a narrow space and a limited perspective like the frog at the bottom of the well. So, locations such as the Greater China Bay Area that are within an autocratic regime but far away from the central administration might provide the incentive for innovation.

Limitation and Future Work

Though this article has provided a unique insight into knowledge management and technology accumulation of a successful firm in the Chinese space industry, it is limited by its single-case prism. Having said that, the selected case did share similarity of typical private start-ups in terms of the founder's human capital and network. Another often cited issue in high-tech sectors such as space is espionage; the leakage of technology from firms such as Grumman could accelerate the technological capability of competitors (FBI, 2020). Throughout the research into the topic of technological accumulation, we have not encountered publication of unethical activities in relation to Chinese space firms. We therefore exclude espionage in our conceptualization of re-combinative innovation in the industry despite investigations involving illicit high-tech component export from the USA (Rohrlich & Frenholz, 2019). Future studies could build on our findings and undertake a wider study to examine the framework with a bigger selection of firms in locations such as Beijing and Guangdong province. The space industry is being privatized and rapidly evolving and it is useful to capture the change at this critical moment. The focus on Guangdong might also highlight the co-evolution of the entrepreneurial micro-electronics cluster in the area that could enable our understanding of firms operating in technological frontiers such as 5G. The focus on Beijing, on the other hand, might shed light on the network relationship firms tend to develop with the established state conglomerates and central government agencies. We might therefore be able to examine the private versus public tension leading to the growth of space firms.

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