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Commercial Space Industry Development from the Perspective of the Triple Helix: Evidence from China and the United States

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Abstract: The university-industry-government triple helix has been an ideal approach to interpret the growth of innovative industries, especially in the context of today's technological leap. This study examines the commercial space sectors in United States and China, the two leading space powers, to analyze how the triple helix structures evolve and synergize to shape their respective industries. It is found that in the United States, the helix is rooted in legislation and procurement support, spurred by a well-developed industrial system, and reinforced by extensive enterprise-university collaboration programs. In contrast, the Chinese triple helix formation trajectory begins with experimental policies and space infrastructure construction, evolves through enterprises' considered positioning in reusable rocket and satellite internet, and is potentially propelled by an expanding scale of talents exiting state-owned space institutions or fostered by emerging academies. After that, a lateral comparison between the two triple-helix models is undertaken to unveil the characteristics, similarities, and disparities within the commercial space industries of these two nations. This paper concludes that, for nations aiming at establishing a commercially sustainable space industry, the essence lies in a fully developed triple helix where efforts of government, industry, and academia can systematically converge without significant lag in any aspect. The paper also mentions the potential benefits of commercial space cooperation between the United States and China.

Keywords: Commercial Space, Triple Helix, University-Industry-Government Relations, China Commercial Space, Industry Development

1. Introduction

The space industry, experiencing a giant shift from state-led initiatives to private entrepreneurship in recent years, has always been the paradigm of complex system engineering. The transition implies a complete redistribution of the elements sustaining the industry's growth, from core-drivers to management methods. This raises the question of how these emerging structures attain equilibrium within China and the United States, shaping their respective environments for space startup growth, and how such equilibrium will sustain over time.

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Previous research on the mechanism of the development of commercial space industry has been constrained by two factors: one is a tendency to focus on single driving force, and the other is a limited spatial perspective examining the industry landscape in a single economy. This paper, adopting the triple helix model of university-industry-government interaction, transcends geographical and institutional constraints to offer a more comprehensive and realistic explanation of the fundamental logic within the commercial space industry in both China and the United States, marking the pioneering application of the triple helix model to study the commercial space industry.

2. The Helical Gradualism of Commercial Space in the United States and China

2.1. Evidence From the United States

The transition of the US space industry from government-led to commercialization in the past decade has been prompted by several key factors. Reflecting on historical developments, it becomes evident that the official impetus from the United States government marked the beginning of this transition.

2.1.1. The Helix's Origin: Public Sector-driven Growth

Continuous Commercial Space Legislation Efforts: The inception of US commercial space policy traces back to 1984 when the Reagan administration enacted the Commercial Space Launch Act, precipitating the swift emergence of commercial space launch companies in the United States [1]. However, hindered by capital barriers and corporate mergers, the development during that period proved to be short-lived. In 2004, the "Commercial Space Launch Amendment Activities" were announced to ensure orderly competition in the commercial space market. This legislation provided more opportunities for small businesses in the space industry and spurred the rise of companies like SpaceX and OSC. Legislative efforts such as the 2015 Commercial Space Launch Competitiveness Act and the subsequent 2018 Second Space Policy Directive significantly clarified and streamlined regulatory frameworks, removing obstacles to commercial space exploration. Notably, in 2023, Florida, a hub for commercial space, introduced the Spaceflight Entity Reliability Bill, further fostering a conducive legal environment for commercial space ventures. The 2024 release of the Department of Defense's Commercial Space Integration Strategy reinforced the supportive policy landscape for emerging private spaceflight enterprises.

Massive Subsidy & Procurement Encouragement: The U.S. government has proactively funded the commercial space sector, encompassing space action agreements, commercial manned space and cargo transportation plans. NASA's Commercial Supply Services (CRS) program for the International Space Station (ISS) has brought SpaceX's of $1.6 billion. Commercial companies have also been welcomed to compete and collaborate in winning national missions' contracts [2]. A very recent example was the successful moon-landing mission "Odysseus" achieved by Falcon rocket from SpaceX and the lander from Intuitive Machines.

Technology Unlocking & Transfer: Advancements have been propelled by extensive technology transfers from NASA [3] and U.S. Air Force to emerging commercial space entities. Leveraging its technological prowess, NASA has provided technical guidance and fostered spin-off commercial applications, exemplified by the utilization of the Merlin engine, originally from the Apollo mission, in contemporary Falcon-9 rockets of SpaceX.

2.1.2. The Helix's Evolution: Powerful Industrial System As the Cornerstone

Technological Disruptive Innovation: SpaceX serves as a paradigm for the entire commercial space industry in the United States [4]. Since its inception in 2002, SpaceX has pioneered numerous disruptive space technologies, including cost-effective and highly reliable rocket reusability and

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vertical recovery methods, advanced design principles for ultra-large-scale low orbit satellites, and streamlined batch manufacturing and launch processes for satellites. These innovations constitute the bedrock of SpaceX's success. Notably, SpaceX's breakthroughs in rocket recovery technology have significantly slashed launch costs, while its ultra-large-scale low orbit satellite technology has propelled the company to profitability. Today, reusable rockets and clustered satellites have become ubiquitous features across the global commercial aerospace landscape.

Eruption of Investment Enthusiasm: Following the enactment of the Commercial Space Launch Competitiveness Act in 2015, the United States witnessed a surge in New Space investment activity in 2016. Subsequently, in 2017, five companies, including Blue Origin and SpaceX, collectively garnered a staggering $2.56 billion in investments solely in rocket manufacturing and launch services. Despite the economic headwinds in the post-pandemic era, the United States maintained its status as the leading market, boasting a commercial space financing volume of $10 billion in 2022.

Inter-industrial Inspiration: American emerging space enterprises have embraced the "fail fast, fail forward" ethos synonymous with Silicon Valley's tech culture, overturning traditional space paradigms of "slow and steady" development. SpaceX notably spearheaded the establishment of large-scale production assembly lines within the rocket industry. The forthcoming fourth test flight of Starship, scheduled for May 2024, showcases a dramatic reduction in turnaround time from 7 months to 2 months. Drawing inspiration from Tesla, many of SpaceX's manufacturing best practices have been adapted from the automotive sector. Additionally, Starship's RAPTOR V2 engine design incorporates AI technology, resulting in a 25% reduction in volume compared to NASA's most advanced RS25 engine, while maintaining equivalent thrust output.

2.1.3. The Helix's Formation: University Researchers As Copilots of Space Companies

American commercial space companies and university research institutions have established multiple collaborations. In 2019, Massachusetts Institute of Technology (MIT) and Blue Origin formalized their collaboration by signing a memorandum to develop multiple lunar payloads for Blue Origin's lunar lander, Blue Moon. In November 2023, the American Institute of Aeronautics and Astronautics (AIAA) Foundation partnered with Blue Origin's non-profit Club for the Future to award an annual $10,000 scholarship to high school seniors interested in pursuing a career in aerospace engineering. Moreover, Intuitive Machines has partnered with Embry-Riddle Aeronautical University to support women in STEM fields.

Furthermore, SpaceX actively engages with academic research institutions by accepting research proposals, offering researchers the opportunity to fly critical science experiments to orbit on the Dragon Spacecraft. Since 2012, Dragon has facilitated the transportation of over 1,000 research experiments to and from low earth orbit (LEO) and the International Space Station (ISS).

2.2. Evidence From China

As a relative newcomer to the market economy, China may never have anticipated the swift transition of its aerospace industry towards commercialization. Despite lagging behind the United States in both technological expertise and market readiness, China, recognizing the potential of commercial space ventures, began encouraging such initiatives a decade ago at a crucial juncture. Driven by its commitment to independence and unwillingness to lag behind, China stands as one of the few economies capable and determined enough to pursue such endeavors.

2.2.1. The Helix's Origin: Experimental Reform and Space Infrastructure Support

Policies as Catalysts of the Space Reform: In China, the policy approach to commercial space has largely been implemented through the issuance of white papers and ministerial plans rather than via

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legislation [5]. In November 2014, Document No. 60 issued by the State Council mentioned "encouraging private capital to participate in the construction of national civilian space infrastructure," signaling China's inaugural national policy initiative to explore commercial space [6]. Influenced by this policy, the first wave of Chinese private space companies, such as Landspace, emerged since 2015. In 2019, the China National Space Administration (CNSA) and the Central Military Commission Equipment Development Department jointly released the "Notice on Promoting the Orderly and Healthy Development of Commercial Launch Vehicles," which specifically underscored the importance of "commercial launch vehicles" for the first time. In 2020, the National Development and Reform Commission (NDRC) announced during a press conference that satellite internet would be included in the New Infrastructure Initiative. In October 2023 and January 2024, respectively, local governments in Shanghai and Beijing each published five-year action plans to encourage the innovative development of commercial space, both highlighting the significance of reusable rockets and large-scale satellite manufacturing. During the Two Sessions in March 2024, the term "commercial space" made its debut in the central government work report, being positioned as a "new growth engine." Despite the absence of substantial related laws, the increasingly frequent, high-profile, and concrete references to commercial space in official settings attest to the Chinese government's ambitions in this domain, especially in rocketry and satellite internet, which private capital keenly recognizes.

Proactive Construction of Commercial Space Infrastructure: With only four launch sites featuring nine launch pads in total, China's facilities must accommodate over 60 launches per year (excluding military missions), presenting a queue challenge for commercial rockets. To address this, the Chinese authorities swiftly constructed the Hainan International Commercial Space Launch Center within less than two years, which is soon to become operational. This move not only resolves the issue of resource allocation for military and national missions competing with commercial space tasks during the launch phase but also provides launch opportunities for enterprises in Southeast Asia and even the Middle East. Additionally, local governments across China are highly proactive in competing for commercial space companies, developing a relatively mature cooperation model. Under the most favorable conditions, local governments are willing to fully finance the construction of base land and factories, saving commercial space enterprises hundreds of millions in capital expenditure. Subsequently, the land and factories would be valued as fixed assets to be converted into equity shares in the commercial space enterprise. In holding shares in these companies, local governments can benefit from long-term dividends, creating a mutually beneficial and win-win situation that fosters healthy and sustainable growth for both parties.

2.2.2. The Helix's Evolution: Strategic Pursuit and Swift Catch-up

Focused Rocket and Satellite Technological Innovation: Chinese commercial space companies have clearly defined business priorities, concentrating on commercial rockets and satellites. In the commercial rocket sector, companies with different technological approaches have achieved success[7]. In 2021, Galactic Energy marked a milestone for China's private sector with consecutive successful launches of low-cost small solid-fueled rockets manufactured in bulk. In December 2023, Landspace successfully orbited the world's first liquid oxygen-methane rocket, "Zhuque-2". Concurrently, i-Space's "SQX-2" became China's first reusable rocket to complete a reflown mission. In the commercial satellite domain, remote sensing satellite company Changguang Satellite's "Jilin-1" constellation broke ground with integrated satellite design and manufacture, along with rapid automated production of remote sensing imagery, deploying 109 satellites in orbit. Geely Auto's subsidiary Geespace innovatively plans to combine its smart vehicle products with a constellation of 240 micro-satellites forming a "Future Mobility Constellation", providing space data link services for

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autonomous driving and logistics, having already developed and launched nine satellites successfully.

Initial Scale in Industry Financing: Chinese commercial space enterprises currently rely primarily on equity/venture capital financing. In 2020, the total amount of financing for Chinese commercial space companies reached approximately CNY 10 billion. Considering China's vast market size, this funding volume represents an initial scale, with a substantial amount of industrial capital still in a wait-and-see mode. A significant reason for this is that many Chinese commercial space enterprises are still in the exploratory phase, lacking strong sustainable business models and clear long-term profit pathways. However, in 2023, China's commercial space industry saw 133 brands and products collectively completed 170 disclosed financing rounds, exceeding CNY 18.5 billion. This indicates that private capital has started to embrace the potential of long-term gains as product outcomes in commercial rocket and satellite sectors continue to materialize.

2.2.3. The Helix's Formation: Space Talent Migration and the Bloom of Space Academies

Outflow of Brains from State-Owned Aerospace Institutes: Due to historical and objective reasons, core technologies and talents in China's aerospace sector have long been concentrated within the so-called "national team", comprising the China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC). However, amid the pressing need for rapid development and the high threshold of aerospace engineering tasks, Chinese private aerospace companies, with their innovative and flexible management mechanisms and attractive remuneration packages not found in state-owned enterprises, have managed to draw in top-tier and experienced backbone talents with relevant backgrounds from within the system. For instance, key members of the i-Space team boast comprehensive experience in the full life cycle development of Long March carrier rockets, with an average tenure of over 12 years in related aerospace institutes. Although the loss of such professionals poses a challenge to state-owned enterprises to a certain extent, this legitimate talent mobility and transfer of intangible assets undeniably contribute to China's space development in the era of commercialization. Moreover, at least five prominent individuals with backgrounds in state-owned aerospace corporations currently serve as provincial governors, exerting a positive influence on regional commercial aerospace activities from a political standpoint.

Rising Demand for Establishing Specialized Aerospace Academies: Chinese private aerospace companies do not solely rely on talents sourced from state-owned enterprises in the short term; they envision the long-term and leverage China's higher education system actively partnering with top-tier domestic and international universities. Through establishing dedicated corporate funds, joint research and development projects, and collaborative laboratories, these companies build and refine their talent pools and intellectual property repositories. In September 2023, Geespace cooperated with Peking University to establish an Advanced Communication Joint Laboratory in the domain of satellite internet. Furthermore, Shandong Province, home to multiple commercial aerospace companies and China's first maritime launch site, plans to build an 'Aerospace Information University. Meanwhile, the leading Shanghai micro-satellite startup SHGS has attracted local top-tier university students in recent recruitment activities, implying the commercial space fever spreading to younger generations.

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3. Lateral Comparison

3.1. The Space Helix of the United States

In the United States, the government plays a catalytic role in the lift-off stage of commercial space industry by orchestrating policies, funding, technology, and procurement orders to create a uniquely advantageous environment conducive to the spontaneous rise of the industry.

Within the dynamic interaction between government and industry, the emergence of disruptive innovations and the gradual clarification of business models have spurred exponential capital accumulation, concurrently triggering inter-industry impacts, exemplified by SpaceX drawing lessons from the Silicon Valley tech industry's developmental path, thus evolving the helix.

The collaboration between enterprises and academic research institutions not only infuses STEM research in academia with practical insights and inspiration from the front lines but also helps businesses transcend their inherent profit-driven frameworks by nurturing their own R&D teams. Academia reciprocates by contributing to the sustainable and healthy development of the U.S. commercial space industry through its reserves of space and business talents, addressing ethical considerations, and maintaining the competitiveness of the U.S. economy by enhancing the employment quality index of graduates.

Over the long-term and through mutual reflection, the organic integration among universities, industry, and government has provided a sustained innovation engine that underpins the U.S. commercial space sector's status as the world's largest and strongest market to date.

3.2. China’s Space Helix

Policy directives signal a absolute green light for capital investment in China. The central government sets the course and provides necessary infrastructure support, while local governments competitively court the commercial space enterprises. As the industry flourishes, local governments grow wealthier and more appealing, and the central government's overall strength increases correspondingly. The government thus acts as the initiator and beneficiary of the helix.

While industrial and private capital may not share the same obsession with aerospace culture as their American counterparts, once they receive realistic signals from policies and inspiring innovation outcomes, they become steadfastly optimistic about the promising prospects of commercial aerospace, sometimes leading to the creation of incredible fusion applications (such as electric smart cars interconnected with satellite internet for data transmission),exhibiting potentials of disruptive innovation [8]. Thus, the helix evolves.

The state-owned aerospace R&D institutions spill over specialized talents and previously closed-off know-how to the commercial space sector, while attempting market-oriented transformations to shed inefficiencies. In this way, their initial boundaries expand. At the same time, the Chinese higher education system forms future-facing industry-university-research alliances with commercial space companies through co-establishment of laboratories and inauguration of new universities. Consequently, the concerted efforts, integration, and transcendence of the government, industry, and research institutions provide an inexhaustible source of impetus for the development of commercial space in China.

3.3. Similarities and Differences

Through the analytical framework above, it is clear that both China and the United States have established robust and synergetic mechanisms for commercial space innovation and development driven by the independent yet integrated roles played by government, industry, and academia,

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reflecting their respective national contexts. There are several commonalities in the models adopted by these two economies:

- A shared starting point of the helix: In both cases, the governments have acted as pioneers, opening up avenues for industrial innovation. Commercial space endeavors embody the entrepreneurial spirit coupled with aerospace engineering prowess, which fundamentally relies on the openness fostered by government legacies from traditional space eras. This commonality is logical given the historical backgrounds and the intrinsic nature of system engineering.
- Similar evolutionary structures of the helix: Industry and academia have sequentially facilitated the current growth and future evolution of commercial space activities. Both countries being the world's largest and second-largest industrial nations, as well as the largest and second-largest markets, respectively, possess strong technological innovation capabilities, supply chain management expertise, and consumer power. Under the tenets of capitalism, when supply and demand capacities align, the ascension of an industry is inevitable, and commercial space follows this pattern. Talent-wise, China boasts a vast population of engineers essential for commercial space development, while the U.S. relies on top-tier universities to attract and cultivate high-quality aerospace talent globally.

At the same time, the model also highlights notable differences that bear significance in predicting future competitive dynamics in the commercial space industry and understanding the development of other industries.

- Divergent modes of government support: The U.S. primarily relies on a continually improving set of mandatory acts, whereas China remains at the exploratory stage with white papers and policies, without enacting commercial-space specialized laws.
- Varied levels of technological and supply-chain maturity: The U.S. commercial space industry is now characterized by leading firms possessing strong cost control ability, closed-loop supply chain capabilities and reliable technology backed by innovative intellectual properties. In contrast, China’s transition from a closed system has been relatively rushed [9], with commercial space companies expected to focus on specific segments of the value chain in the short to medium term.
- Differences in the completion of business models: SpaceX in the U.S. has developed two stable revenue streams – commercial launches and Starlink services - with customers worldwide, exceeding $8.7 billion in revenue by 2023. Its Chinese counterparts, however, largely remain in the non-revenue generating experimental rocket launch phase.
- Distinct efficiencies in research conversion and talent quality: The U.S. boasts deep roots in aerospace education and talent cultivation, allowing for rapid commercialization of research and the delivery of interdisciplinary talent to space companies. By comparison, China's system integrating education and industry is relatively immature, characterized by a large number of engineers with lower degrees of integration and less effective market incentive mechanisms, still reliant on intellectual resources from the old state-owned enterprise system.

Overall, the essence of commercial space innovation lies in systematic innovation. From the Triple Helix perspective, the American system is mature and self-sustaining, while certain constraints affect the innovation helix in the Chinese system due to micro-level weaknesses in its three key entities. Reflecting on history, the U.S. commercial space sector inherits the legacy of past generations and leverages its inherent systemic advantages to maintain leadership. China, as a late-industrializing nation entering the market economy half a century ago, has made significant strides in this field. Looking ahead, the country that ensures healthier interplay and integration among its triple helix entities will likely gain an edge in commercial space innovation. Moreover, technological

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cooperation between the two countries in this domain could elevate the innovation helix to a higher level, unleashing greater energy beneficial to both nations and humanity at large [10].

4. Conclusion

This paper uses the Triple Helix model to perform an development trajectories analysis of the commercial space industries in the United States and China, reflecting the respective roles and mutual interactions of universities, industry, and government in driving this industrial innovation. The findings reveal that the U.S. commercial space industry maintains an absolute lead, benefiting from its highly mature legal framework, formidable capacity for disruptive innovation, and close university-industry-government collaboration. Conversely, although China's commercial space sector embarked later, it is catching up rapidly with frequent achievements in the field of reusable rocket and satellite internet, thanks to timely policy shifts, supplementary build-up of infrastructure, and vibrant dynamism from the private sector.

Despite the divergent paths and characteristics in the development of their commercial space industries, both objects manifest the importance of tripartite interplay within the Triple Helix model. The U.S. evidence underscores the essence of a sophisticated innovation ecosystem for industrial strength, while the rapid progress from China's side demonstrates that emerging economies can also build a robust commercial space industry given a decisive commitment to transformational opportunities, substantial market demand, and diligence in niche sectors.

Looking ahead, China and the United States should cooperate in technological innovation, talent training and market opening, while paying due attention to mutual understanding in fair competition, and should also participate in legislation related to commercial spaceflight to ensure the healthy and sustainable development of the industry. Through these efforts, the global commercial space industry will realize a win-win situation, making significant contributions to human space exploration in the 21st century. This study not only furnishes a fresh perspective on understanding the development of the commercial space industries in the U.S. and China but also serves as a reference for other countries and regions. Future research can delve further into the applicability of the Triple Helix model in diverse nations and regions, exploring how to optimize the model amidst varying cultural and economic contexts to propel collective advancement in the global commercial space industry.

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