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Master's degree in engineering and management

Master's Degree Thesis

A comparative study of public-private relationship in new space economy, including United Status, Europe and China.

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Abstract

The new space economy era has come with the private sector development. Yet in space industry public sector is important with the accumulated knowledge and responsibility of governance. The study of public-private relationship in space economy could bring better understanding on dynamic situation. Europe, United Status and China is on different situation of space economy, which is the result of internal factors; The comparative study could see what factors influence the public-private relationship in space economy, also finding the effect of these factors in Europe, United Status and China could lead to a better understanding of public-private relationship. The thesis combined the study of public-private relationship and comparative study in space sector.

Acknowledgements

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Abbreviations and acronyms

ASD	Aerospace and Defence Industries Association of Europe
ASI	Agenzia Spaziale Italiana
AST	The Office of Commercial Space Transportation
ATV	Automated Transfer Vehicle
BEA	Bureau of Economic Analysis (United Status)
BEMA	Bigelow Expandable Activity Module
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science and Industry Corporation
CASSINI	Competitive Space Start-ups for Innovation Initiative (European Union)
CCTI	Commercial Cargo Transportation Initiative
CMC	Central Military Commission Government agency (China)
CNES	Centre national d'études spatiales
CNSA	China national space administration
COTS	Commercial Orbital Transportation Services
CPA	The statistical classification of products by activity (European Union)
CSDA	Commercial Satellite Data Acquisition (United Status)
DARPA	Defense Advanced Research Projects Agency (United Status)
DOD	Department of Defense (United Status)
DOT	Department of Transportation (United Status)
D&D	Design and development
EAR	Export Administration Regulations (United Status)
ELDO	European Launcher Development Organization
ELV	Expendable launch system
EPO	European Patent Office
ESA	European Space Agency
ESMD	Exploration Systems Mission Directorate (United Status)
ESRO	European Space Research Organisation
ESPI	European Space Policy Institute
EU	European Union
FAA	Federal Aviation Administration (United Status)
GNSS	Global navigation satellite system
GPS	Global positioning system
GVA	Gross value added
IAI	Istituto Affari Internazionali
ISS	International Space Station
ITAR	International Traffic in Arms Regulations (United Status)
JUICE	Jupiter Icy Moons Explorer
LEO	Low earth orbit
L3S	Launceur a Trois Etages de Substitution

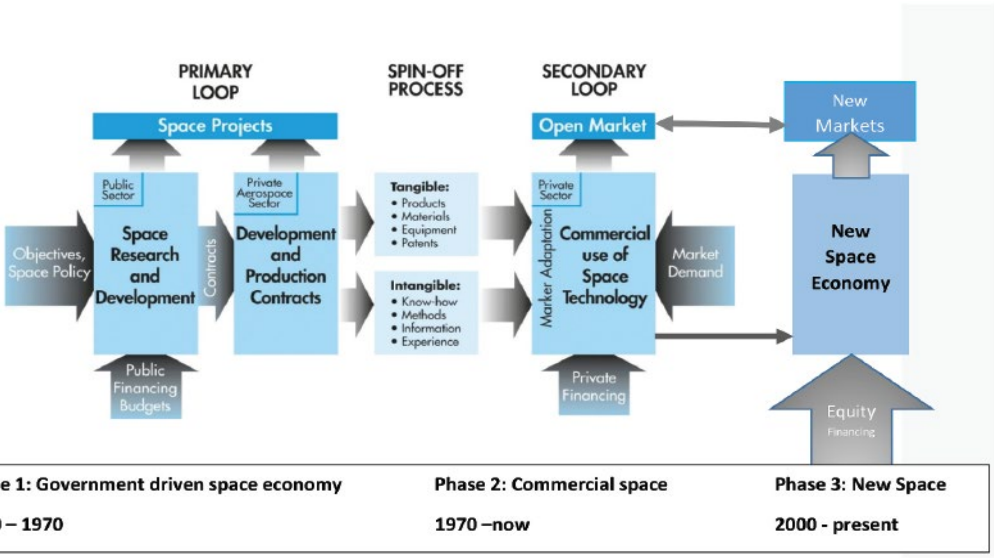
Ocon	Operation Concession
OECD	Organisation for Economic Cooperation and Development
PF-FDO	Partially Finance and Fully Design-Develop-Own-Operate
PFD	Partially Finance-Design-Develop
PFD-FO	Partially Finance-Design-Develop and Fully Own-Operate
PNT	Positioning, Navigation, and Timing
PPP	Public-Private partnership
R&D	Research and development
RLV	Reusable Launch Vehicle
ROI	Return on investment
SASTIND	State Administration of Science, Technology and Industry for National Defense (China)
SCaN	Space Communications and Navigation (United Status)
SLI	Space Launch Initiative (United Status)
SME	Small and medium enterprise
SSO	Sun-synchronous orbit
TTCS	Technological transfers and commercialization
U.S.	United Status
VSE	The Vision for Space Exploration (United Status)

Chapter 1 Introduction

1.1 The new space economy

Over the past few decades public sectors around the world tend to seize initiative on space related activities and industry while providing the majority of fund and demand. The private sector was involved as contractor who provides the hardware and services that public project requires. However, “The digitalisation of society and rising geopolitical tensions worldwide highlight the importance of space infrastructure, including space-based systems and their supporting ground segments“ [1], with the technology development, the demand for space service from multiple industries like remote sensing and cloud computing are booming; at the same time the cost of space activities and launching -related hardware development is reduced, two trends emerge and create the flourishing of space industry, which we called as “New Space Economy”.

Figure 1 Three phases of space economy



Source: Evolution of the Space Economy: Government Space to Commercial Space and New Space [2]

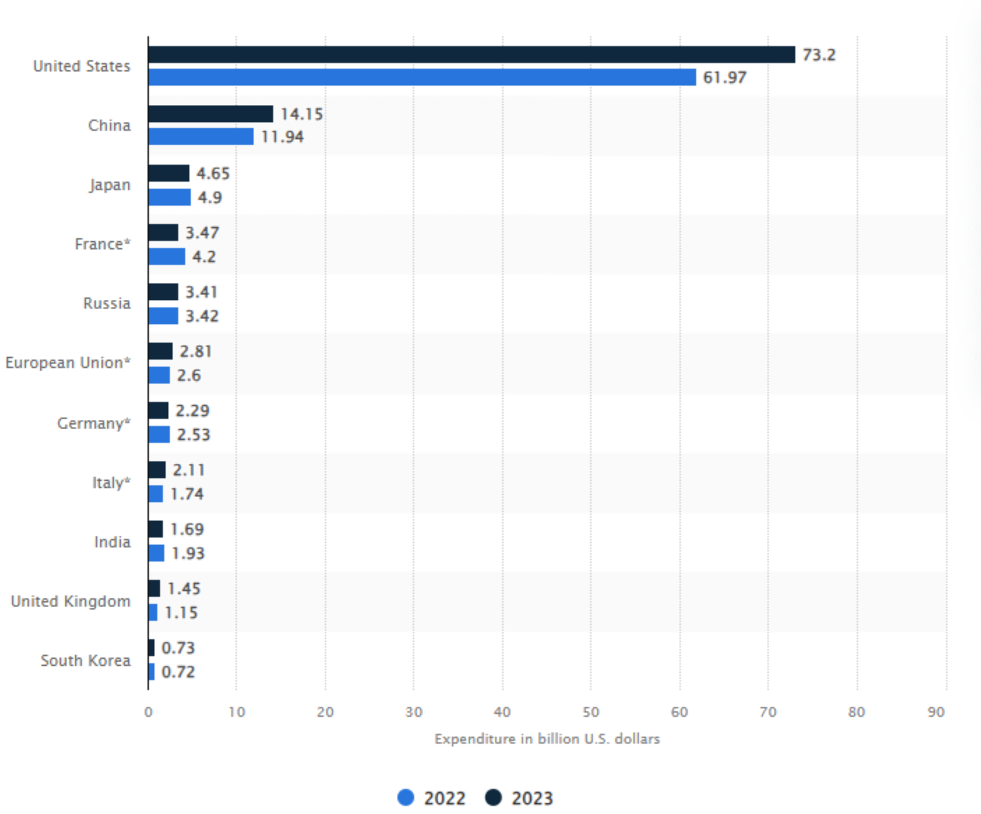
1.2 Public private relationship is important in space economy

Both public and private sector has strong impact on domestic space industry. During time private sector is evolving from being exclusively a contractor to sharing more of the development costs and taking on more financial risk and responsibilities in selected joint space projects. [3] while public sector shift the role to beneficiaries and provide necessary supervision and management. The reason behind is that private sector can provide better cost efficiency and ROI on space program [3] However, the importance of public sector in space economy cannot be neglected: from governance perspective, the government decides how private sector participate in new space economy by approving licenses, enforcing laws and policy; from economic perspective, governments help creating both economic value and working opportunities; from national defense perspective, space security is always an important subject, especially with the participation of private sector; from international perspective, the competitiveness of domestic companies is vital. Needless to say that without the permission from government in the first place, there is no private sector in space industry. Public sector also provide demand, funds, infrastructures like spaceport, acting as procure party. In the new space economy, public sector and private sector are both vital for domestic space industry, they are interdependent, and the nature of space industry makes them strongly and continuously interact. To best utilize the competence and advantage of public and private sectors in space economy, the appropriate public-private relationship should be formed.

1.3 Research and study

To study the public-private relationship in new space economy, the following research question raises: What are the factors that influence public-private relationship in new space economy? To have a comprehensive perspective, a comparative study will be conducted. For study object, United Status, Europe and China are selected. The governance of industry and public-private relationship of these three regions are representative; The governments are willing to invest considerable portion of GDP in space industry, and the scale of aggregated European funds from both European level and major countries (such as Italy, Germany and France) is in top three position in the world as the figure 2 shows. With the emphasis on space industry, the political system, history of space industry, national program, private sector competence, space industry markets are both quiet different, making the three regions ideal choice for the comparative study. The study will focus on the upper space manufacturing industry: launch vehicle and satellite manufacturing industry, that target low earth orbit (LEO) due to the fact that being the most popular object for space industry in new space economy.

Figure 2 Government expenditure on space programs



Source: https://www.statista.com/statistics/745717/global-governmental-spending-on-space-programs-leading-countries/

For studying the question, in chapter 2 the literature related to public-private relationship in space economy and in general situation will be mentioned, along with the comparative study between United Status, Europe and China. In chapter 3, certain hypothesis that try to answer the research question will be proposed. In chapter 4 the study methodology and data collection as well as choice will be illustrated. In chapter 5 the qualitative study will be conducted, ending with the conclusion in Chapter 6. By doing this research, the goal is answering the research question, along with the comprehensive review of United Status, Europe and China space public-private relationship, and see the difference between them as well as the cause.

1.4 Contextual notes

In general, the term "public sector" includes government and space agency, and the term "private sector" includes space industry private companies. In Chinese case, however, the public sector also includes university and academic institution, due to the reason that all the space-related universities and institutions are public in China.

Chapter 2 Literature Review

Space economy is a classic and popular topic in Europe, United Status and China, there are substantial related literatures available. For this thesis, the literature review includes three themes: Public-Private relationship, comparative study in space economy, and history of space economy in Europe, United Status and China. Based on the current literature, the comparative study on public-private relationship in space economy does not exist.

2.1 Public-Private Relationship

2.1.1 General Public-Private Relationship

In general public-private relationship study, the literatures are written in multiple perspectives: economic, political economic, innovation and industry. Government-business Relations: Summary of Theories and Construction of Prototype has studied different patterns of public-private relationship [4]: Masahi ko Aoki adopts a comparative institutional approach, where he groups the government into four types from two dimensions. [5] American scholar John Zysman, divides the industrial changes into three patterns: state-leading, business-leading, and third parties-negotiating, [6] Richard Rainwater, a politics professor of Rutgers from State University of New Jersey thinks that GBR that are independent with the nations, who compares the related systems and practice in America, England, Germany, Japan and EU, assorting the patterns of GBR into three types: corporate domination, pluralism, market capitalism and stakeholders. [7] From political economy perspective, Government and Business: American Political Economy in Comparative Perspective studies corporate activities and government policies. [8] Governments, Markets and Growth conduct a comprehensive view on Finance and politics of Industry. [9] Revisiting the government's role in catalysing modern innovation shows the different government roles such as buyer, regulator, infrastructure provider should use different tools as collaboration, procurement, hiring and talent recruitment while intervein different innovative cases [10]. Finally, from industry perspective, Public and Private Sector Relations for Economic Growth: Evidence from Uzbekistan explain the PPP as main mode of public and private sector relation in procuring, renewing and maintaining public sector infrastructure. [11]

2.1.2 Space Economy public-private relationship

The majority literature focus on what the government do in new space economy. EVOLUTION OF GOVERNMENT AND INDUSTRIAL PARTNERSHIPS TO OPEN THE SPACE FRONTIER focus on what government should do in different phases of new space economy: from government-led Exploration to future private sector self-sufficient, the conclusion is that government should utilize policy, law, resource to reach the goal. [12] The reports from two agency emphases the procurement and collaboration model, Evolution of the Role of Space Agencies by European Space Policy Institute (ESPI) focus on balancing risk-sharing, control and reward in traditional procurement methodology and PPP methodology. [13] EVOLVING PUBLIC-PRIVATE RELATIONS IN THE SPACE SECTOR by Organisation for Economic Co-operation and Development (OECD) focus the models of partnering with private sector, for example co-funding, PPP, shared use of infrastructure. [3] The literature from Astropolitics: Evolution of the Space Economy: Government Space to Commercial Space and New Space by Walter Peeters, focus on the importance of private sector in future space industry. [2]

2.2 Comparative study in space economy

In comparative study, there are two types of literature: one that conduct comprehensive review on global space nations, and one focus on direct comparison. Mastering Space by United States and English author, John Agnew and Stuart Corbridge, is written in international political economy perspective, mentions space challenge from China, and management of market. [14] International Comparison of Approaches to Space Cluster Development by Red Kite Management Consulting, focus on the policy in major space faring nations, space cluster development and comparison between UK, Europe, USA , Australia and South Africa using case study. In the last part, the importance of public sector in space economy is analysed. [15] The Political Economy of the Space Age by Andrea Sommariva mentions importance of government investment in new space economy, the role of space agency and legal development in major space nations. [16] The Metamorphosis of The World Space Economy: Investigating Global Trends and National Differences Among Major Space Nations' Market Structure focus on the characteristics of the space economy in major space nations, like demand structure and commoditisation of space industry. [17] " The Geopolitics of Space" report, organised by the Istituto Affari Internazionali (IAI), in collaboration with Intesa Sanpaolo: "A Star-spangled Screen for the Protection of Great Power Competition?" by Julian Suess describes the increasing important role of outer space plays in geopolitics, The chapter "The Regulation of outer space activities" by Giulia Pavesi illustrates the main legal developments in the different sectors of space evolution. The chapter "The Global Space Economy: Definition, Evolution and Forecasts" by Jules Varma and Rodolfo Zontini discusses key structural questions related to the role of outer space in global economy. All the chapters contain the major power in space economy. [18]

For direct comparison, ESPI report: Rise of Private Actors in the Space Sector focus on private actors in the upstream part, compare U.S. and Europe cases. [19] A Technical Comparison of the Public SSA Services in the United States and the European Union written by researcher from United Status, Spain, France compares the satellite related service provide to people in United Status and European from data and technical perspective. [20] The Empire Strikes Back: Comparing US and China's Structural Power in Outer Space by Canadian and American authors compare the space policy, space structural power, international competition and collaboration environment between United Status and China. [21] China's Space and Counterspace Capabilities and Activities written by American author for the U.S.-China Economic and Security Review Commission is a comprehensive review on Chinese space industry in space military perspective. [22] China in Space: Ambitions and Possible Conflict is a article that United Status researcher evaluate Chinese space strategy and power, along with the potential conflict with United Status. [23]

2.3 History of evolving public-private relationship

2.3.1 United Status

United Status(U.S.) space economy gains experience from the success of 19th-century private-public cooperation on the transcontinental railroad and airline, as the word in NASA Commercial Orbital Transportation Services report: "The year 1869 saw the completion of the first transcontinental railroad that allowed for continuous travel between America's east and west coasts—a project that would not have been possible without the support of government bonds and land grants. In the first half of the 20th century, the 1925 Contract Air Mail Act (more commonly referred to as the Kelly Act) incentivized commercial aviation by allowing the U.S. Post Office to contract with private companies for mail delivery. This eventually led to the use of commercial aircraft for affordable passenger travel, as air travel transitioned from a dangerous, daredevil pastime to a routine operation. [24]

The experience gave U.S. an ambition idea of creating a new public-private relationship other than solely contract-procurement; In 1963, NASA procured both launch vehicle and service from private sector. Things took turn in 1982, while president Reagan announced National space policy, which aiming at enlarge involvement of private sector in space economy. The new policy was believed to enhance United Status space power by:

"• Maintaining a high-technology industrial base;
• Providing jobs for thousands of workers, thus adding to the federal tax base;
• Spawning numerous spinoff and supporting activities;
• Strengthening the U.S. global position;

• Providing a potential market for excess flight hardware, special-purpose tooling, test equipment, and propellants;
• Creating a market for U.S. government and facilities. " [24]

However, in the real world, the new policy only indicates the determination of government to do something, yet the consequential implementation is lengthy, laborious and throe, it requires great effort and may cause discomfort for both public and private sector. In 1983, for plan promotion, president Reagan signed the file that encourage government department to simplify the process of issuing license to private sector as a promotion of the policy; In same year, President Reagan issued NSDD 94 as further complement, aiming at better regulation and supervision by distributing responsibility to appropriate agency: "The U.S. Government will license, supervise, and/or regulate U.S. commercial ELV(Expendable launch system) operations only to the extent required to meet its national and international obligations and to ensure public safety.……At a meeting of the Council on November 16, 1983, President Reagan announced his intention to designate the Department of Transportation (DOT) as the agency with principal responsibility for fostering the private commercial ELV business. His rationale centre on the fact that DOT, as a department that understood the regulatory process and with experience as a deregulator (airline, railroad, etc.), was uniquely suited to remove regulatory barriers and to streamline regulations necessary to create a commercial space industry." [24]Still, Having the backup from government doesn't necessarily mean success: "Despite the legislation, U.S. launch firms remained largely uninterested in offering commercial launch services, finding it difficult to compete against the government subsidized space shuttle." [24].

In 1986 something unexpected happened. The space shuttle Challenger broke up in its ascent stage, causing seven deaths. The tragedy leads to challenges and contest on NASA as the primary satellite delivery route to space. Seven months later President

Reagan issued NSDD 254, limited NASA's dominance role as launch service provider. Since the largest supplier in the market has been weakening, there is a gap between supply and demand waiting for fill. In 1988, President Reagan issued Presidential Directive on National Space Policy, required U.S. space agencies to purchase launch service from private sector. In terms of governance, U.S. government set The Office of Commercial Space Transportation (AST) to regulate and promote U.S. space economy market. In 1995, AST was transferred to Federal Aviation Administration (FAA), the duty remains the same. One of the responsibilities of FAA is to remain simple and efficient while issuing license to the private sector, as the President Reagan visioned decades ago.

At the turn of the century, the replacement of the Space Shuttle provided an opportunity for NASA to seek alternatives to traditional public-private relationships. In 2000 NASA embarked on the Space Launch Initiative (SLI). The goal of SLI was to reduce the cost of access to space by encouraging the development of second-generation RLV (Reusable Launch Vehicle) owned and operated by the private sector. In the same year, American Astronomical Society distributed a total of $902,000 to four small businesses—Andrews Space, Microcosm Inc., HMX, Inc., and Kistler Aerospace Corp.—to conduct a 90-day study on the feasibility of developing commercial vehicles for contingency resupply to the International Space Station, capable of launching within one week's notice. What happened after shows that this is a preliminary attempt of a new public-private relationship.

In 2003 another catastrophe happened. The On Saturday, February 1, 2003, Space Shuttle Columbia disintegrated as it re-entered the atmosphere over Texas and Louisiana, all seven astronauts on board was scarified . Later president George W. Bush issued The Vision for Space Exploration The Vision for Space Exploration(VSE), a response to the Columbia disaster and the general state of human spaceflight at NASA, as well as a way to regain public enthusiasm for space exploration [25] . NASA push private sector participation further by launching a new concept called Exploration Systems Enterprise that be responsible for developing the new hardware and technology. Multiple companies respond to NASA's call, including Space Science, Earth Science, Biological and Physical Research, Aerospace Technology, and Space Flight. Among them Aerospace Technology, Space Science, and Space Flight enterprises were transferred to the Exploration Systems Enterprise. It shows the progressing participation of private sector in national space program: "NASA will rely more heavily on private sector space capabilities to support activities in Earth orbit and future exploration activities." [25]

In 2005, NASA administrator envisioned commercial capabilities as "the primary planned means of supporting ISS transport in the next decade." [3] With the requirement of involving private sector into space program from multiple previous plans and policies, NASA decided to rely on private sector to reach the goal, even though there were no mature goods from supply side: more specifically, for companies, the goods that NASA required is way ahead in terms of technology and complexity, what NASA demanded is the launch service with the capability to deliver payload to the specific human destination that located in LEO. The uncharted challenge facilitates NASA to find a different way of doing business with private sector: Commercial Orbital Transportation Services (COTS) program. In short words, the five-year plan is aiming at private sector develop cargo capability, with support from NASA, finally transfer payload to ISS. Since companies was yet unable to provide the goods required, NASA decided to change the role as traditional purchasing agent: "NASA decided to take on the role of an investor, technical consultant, and partner instead of a traditional Government customer that pays full development costs and fees to a prime contractor." [25] The private sector will not only receive funds, but also technical guidance and other public support. In the initial phase, NASA gathered proposals from interested companies, made selection and provided funds to the winning bidders. Then, the fixed-price milestone method was applied, which was suggested by NASA Exploration Systems Mission Directorate (ESMD) in 2004 market research. In one word, milestone payments from NASA to companies will only be guaranteed after completion of planned goals. The payment method guarantees the specific technological requirements and prevents budget overrun. The result of COTS was tremendous. With the success ISS resupply carried by orbital launch vehicle that manufactured by SpaceX and Orbital Sciences Corporation, the new relationship of public-private relationship has been proven effective, not to say the cost of project was significantly reduced compared to precedent.

U.S. has one of the most robust public-private relationship. NASA is mandated to "seek and encourage … the fullest commercial use of space," and its operating model seeks partners to support research, design, and other mission-related activities." [26] and NASA has a specific 3% budget that targeted small business firms. [27] U.S. Department of Defense (DOD) State:" The rapid growing commercial space sector, highlighted in the 2022 National Defense Strategy, presents an opportunity for the Department that we cannot overlook" [5]. Multiple big names from U.S. space private sector hang highly in the partner names list of Artemis Project; The trail launch of Starship has caught the attention of millions of people.

2.2.2 Europe

EU's unique, dual supranational and intergovernmental Character makes it a special case in space economy. [28] Europe has successfully combined resource and technological advantage from multiple nations, creating flourish space economy through on intergovernmental political system. In 1960s, there was emerging demand of launch services in Europe, since the importance of access to space is recognized. Under the background, the first agency that designed to be responsible for space activities, European Launcher Development Organization (ELDO) and European Space Research Organisation (ESRO), was formed in 1962. Later in 1973, France, the country that treat space as intense strategically importance area, proposed to form a new organization: Launceur a Trois Etages de Substitution (L3S).

In 1975, there were multiple breakthroughs in the European space sector. The proposal from British Minister that merge ELDO and ESRO into a single European Space Agency has come to reality: "ESA was founded to enable cooperation amongst European states in space, and in doing so, ESA member states "cooperate through ESA, and ESA cooperates with other partners" [3]. The L3S that French proposed has been expand and become a critical organization: Ariane Launcher Programme, the program create an important private company, Arianespace, the Ariane Launcher Programme and Arianespace is related to three of the major payload rockets in human history: Ariane, Soyuz and Vega. Later in 1979, the inaugural launch of Ariane, which is Ariane 1 payload rocket, was successful conducted. In 1980, world's first commercial launch service provider Arianespace company was formed, established the leading position of Europe in terms of space economy. The originally goal of the company was to manage and marketize the Ariane programme, nowadays Arianespace is one of the major players in the world. In 1999, the Galileo Project was proposed. The project was aiming for creating global navigation satellite system (GNSS) that managed by Europe, providing service for political, military European authorities and private sectors. There was an attempt on innovative public-private relationship called "Public-Private partnership" (PPP). Before PPP traditional public-private relationship was procurement, that was:" a private actor, provides a good ("built-to-order") or service on a "cost-plus" basis, with the cost and risks being incurred entirely by public resources" [13]. The definition of PPP was "arrangements where the private sector supplies infrastructure assets and infrastructure-based services that traditionally have been provided by the government". [29] PPP can strengthen cooperation between public and private sector in space economy, providing possibility to share cost and risk, and conduct long-term stable development. Although there were some vicissitudes, like the failure and forced pause on Galileo Project during 2004-2007; The new PPP model was eventually be proven successful, and the launch of satellites belong to Galileo project has became continuous normality.

In 2008, in the project ISS, Europe not only build modules of ISS by cooperating with Thales Alenia Space company in Torino but also resupply ISS using Automated Transfer Vehicle (ATV) Jules Verne. In 2016, Space 4.0 concept was launched. The concept emphasis on commercialization, integrate space into European economy and society, enhance European space competitiveness in the global market. At the same time," ESA business incubation centres has established: "The concept is to support entrepreneurs with a space-based business idea and help them developing their product while getting their company off the ground. In the process, they create and grow clusters of space-related start-ups across Europe." [29] In 2022, the European Centre for Space Economy and Commerce, officially opened in Vienna, shows the determination on boosting space economy and solidify public-private relationship. In 2023, ESA announced Commercial Cargo Transportation Initiative (CCTI) plan, aiming for developing launch vehicles that capable for handling the payload to ISS before 2028. For the process, the ESA urge private sector, the

European companies to compete each other. The plan represents new attempt on public-private relationship after the success of PPP: "Aschbacher said the commercial cargo program is in response to the recommendations of a high-level advisory group the agency chartered to examine what the agency should do in human space exploration. That group, in a report released in March, recommended an ambitious European human spaceflight program using commercial approaches." [30]

EU has innovated the traditional private-public relationship by introducing PPP, and it was proven success. The space 4.0 and CCIT is the new potential direction of space economy and private-public relationship.

2.2.3 China

In terms of space economy, China has taken a prudence and gradually route. The Chinese space industry starts lately: in 1970, while U.S. still carrying on the Appollo program and return to moon repeatedly, China has just launched the first satellite, Dong Fang Hong 1, using the Long March 1 rocket, whose heir is China's major choice of launching payload to LEO for the next 55 years. In 1980, to narrow the technological gap between China and the rest of the world, government announced Project 863, a 20-years plan. The result of the plan includes Shenzhou spacecraft, which take the first Chinese into space. In 1999, the inception two state enterprises, China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC), is the critical step of Chinese space industry, since the two corporations will deeply participate all the national program and project, like Tiangong space station. The two corporations are coordinated by China national space administration (CNSA) that was established in 1993.

Until 2014, Chinese space activities are mainly national. Things take turns when government launched Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment："To encourage the private capital's participation in China's construction of civilian space infrastructure. Efforts shall be made to improve policies on the civilian remote sensing satellite data, strengthen the government's procurement services, encourage the private capital to be used to develop, launch and operate commercial remote sensing satellites and provide market-oriented and professional services, and guide private capital's participation in the construction of satellite navigation ground application system." [31] The document caused policy and regulation adjustment, and in the nest year, private companies focusing on the orbital launch vehicle to LEO has started to establish. In 2019, China tried to boost space economy by launching Notice of State Administration of Science, Technology and Industry for National Defense (SASTIND) and the Central Military Commission Government agency(CMC) Equipment Development Department on Promoting the Orderly Development of Commercial Launch Vehicles, which further completes detail on regulation of private orbital launch vehicle test flight and launch, by given information on review launch permission, launch site providing and so on [32].

In 2020, the CERES-1, the orbital launch vehicle manufactured by galactic-energy, a private company, successfully take a satellite to sun-synchronous orbit (SSO), set a precedent for Chinese space private sector. In 2024, the Lijian-1 successfully take IRSS-1, the first satellite joint manufactured by The Sultanate of Oman and China, to the LEO. This is the first time that China provides the commercial payload launch service to a foreign country. As for the manufacturer, CAS space, the share are both hold by public and private sector. At the same year the Chinese satellite internet constellation is being built by satellite from private sector and orbital launch vehicle from public sector. Later this year, in Zhuhai Airshow, chief engineering of China National Space Administration Guoping Li reveled that China will create market for private sector, which the upcoming National Space Civil Use Infrastructure Mid-Long Term Development Plan (2026-2035) will tell. In 2025, Space Epoch company has conducted the first trial on their reusable launch vehicle.

China is still relatively new in terms of space industry and space economy, the private sector is not as strong as the ones in Europe and America, yet the nation is taking small steps once at a time in finding new relationship between public-private sector.

Chapter 3 Hypothesis

In new space economy, governments evolve from chief developer to customer of space products and services. [3] To better understanding the shift of role and new public-private relationship, the hypothesis of factors that may influence public-private relationships will be proposed.

3.1 The space manufacturing industry

The new space economy, compared to "traditional" space economy, has" lower cost manufacturing, growing intangible assets as data and software" features. Despite the simplicity of description, the range space industry is board, from manufacturing hardware to civil date use, it is reasonable to say the public-private relationship and influence factors is widely different among these areas due to the nature distinction: the data application industry will be focused on data privacy policy and law formulation, yet the advanced space research and development industry is still dominated by public sector.

The OECD categorizes the space industry into upstream and downstream, the upstream is related to the space industry and launch service, the downstream is related to operation and application of space hardware. In my thesis the discussion about space economy is focused on launch vehicle and satellite manufacturing industry, which is "space manufacturing" industry in the taxonomy.

Table 1 Space Industry Categorization

Upstream activities:	**-Space research and development (72: scientific research and development)**
	-Testing and engineering services (70: architectural and engineering activities: technical testing and analysis)
	-Space manufacturing (31: manufacture of air and spacecraft and related machinery)
	-Space launch (51: Air transport).
Downstream activities:	-Operation of space systems (61: telecommunications)
	-Supply of devices and products supporting consumer markets (e.g. GNESS chipsets and devices (26: manufacture of computer, electronic and optical products)
	-Supply of services supporting consumer markets (e.g. DTH providers, data-derived commercial services) (60: programming and broadcasting activities; 63: information service activities). [33]

Source: OECD Handbook on Measuring the Space Economy

Based on OECD study, the space manufacturing industry has strong characteristics of high R&D intensity [33]. Despite all the upstream industries sharing this same feature, the space manufacturing industry is the most intensive one, based on the gross value added (GVA) figure, which measures the industry's contribution to the gross domestic product or output.

Figure 3 Taxonomy of Economic Activities Based on R&D Intensity

ISIC activity	2-digit classification	R&D as % of GVA (OECD weighted average), 2015 values
M: Professional, scientific and technical activities	72: Scientific research and development	30.39
	69-75X: Professional, scientific and technical activities except scientific R&D (ISIC 69 to 75 less 72)	1.76
C: Manufacturing	**3031: Air and spacecraft and related machinery**	**31.69**
I: Information and communication	59-60: Audiovisual and broadcasting activities	0.32
	61: Telecommunications	1.45
	62-63: IT and other information services	5.92
C: Manufacturing	26: Computer, electronic and optical products	24.05

Source: OECD [33]

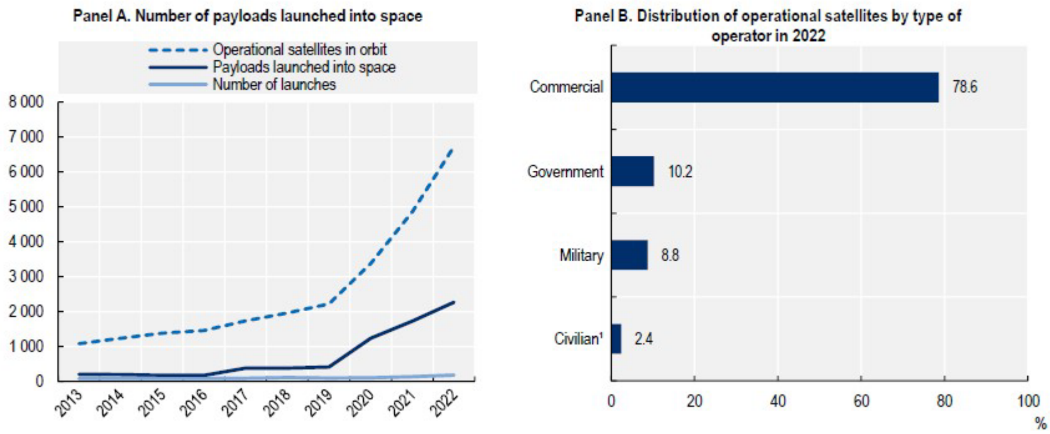
3.2 The investment of space manufacturing industry

With the prosperity of space economy, the private sector grows quickly, as figure 4 shows. The private sector investment plays an important role in large-scale program like satellite constellation, the importance is self-evident:" Over 77% of today's space expenditures come from non-governmental sources" [34]. However, the features of private investment in space manufacture are not as simple as revealed.

Figure 4 Start-Up Space 2023

Source: OECD

Figure 5 Increasing crowded orbits



Source: OECD [35]

In private investment in the space manufacturing industry, few players gained the majority of fund: 74% of seed investment from 2000 to 2021 goes to one company, Blue Origin. The other companies that receive 66% and 42% of total investment in 2019 and 2022 are: SpaceX, OneWeb, Blue Origin, Virgin Galactic; 73% of investment goes to U.S. domestic companies in 2022. [34] The giant fund from billionaires that invest in few space companies and the high concentration of new investment shows that the increase on space private investment should not be considered as a improvement on whole industry. Private investment are heavily influenced by external factors like interest rate, makes it unstable for space manufacturing industry, since the investment required are generally long-term. The OECD observed the high private investment in 2021 is correlated with high interest rate, in 2022 while the interest rate was increased, the decrease of private investment was observed. [35]

Generally, for high-risk/high-reward research, like space economy, the following characteristics should be noticed.

- High capital requirements: The supply of small volumes of equity can be particularly problematic for small actors and new technologies, as venture capitalists' transaction costs in assessing, monitoring and managing investments vary little with the size of the investments. Accordingly, smaller investments become less attractive.
- High legal/regulatory barriers: Small firms can incur high costs relative to their turnover in information search, screening and administrative processes (e.g. security clearances, spaceflight qualification, licensing, insurances, export restrictions).
- Large sunk costs: (large fixed cost and high Uncertainty): The final success of the research and development activities is highly uncertain.
- Long lead times: The high capital cost of investment and the long timescale for deployment and returns tend to make investors risk-averse with respect to new technologies. This issue is further elaborated in the bullet points below on barriers to R&D investments. [36]

On the contrary, the private sector invest preference is risk-averse, and do not necessarily support projects with low technological maturity, long lead times and/or uncertain market prospects [37]; Prefer quick scalable projects; [38] Focusing on cash-generating companies or early start-ups that require low levels of capital rather than higher risk investments into pre-revenue enterprises. [39] Plus, the knowledge spillover phenom would further limit the private funds' interest. Although private actors are playing an increasingly important role in space activities in OECD countries, governments provide the backbone of space funding. In upstream space activities, dominated by manufacturing and launch activities, public organizations sometimes account for some 60-70% of markets in both Europe and Asia. Governments invest in space capabilities to support broad socio-economic objectives and the development of scientific capabilities, for both R&D and operations. [3] In specific case, 70% of revenues in the upstream segment in Europe rely on public sector. [40] For U.S. , although direct figure is not found, we can still understand the importance from survey :" Some 16% of US (mainly upstream) commercial respondents to the 2014 US industrial base deep dive survey declared themselves "dependent" on US government space programmes" [41] For China, although the support to private sector is not as much as EU and U.S, yet by finding the fund source of major Chinese launch companies, I find multiple source correlate to public sectors like national companies, local government and research institutions. Involvement in government programmes can increase a space firm's visibility and credibility vis-à-vis private investors. The existence of stable, long-term government demand for the firm's goods and services can also be beneficial for attracting private investment. [42] Based on previous discussion, the investment and support from public sector is vital for private sector.

3.3 The typology of public investment and support

For better understanding the public investment and support to private sector, the author has categorized the government investment on space industry into direct investment and indirect investment.

3.3.1 Direct investment

Direct investment from public sector generally includes tax incentives, subsidies, debt and equity financing. [35] The worth-mentioning direct investment is the investment specifically on small and medium enterprises (SME). As previously mentioned, the large-scale enterprise may not have to worry about funds, regardless of the sources; Yet for SME, getting funded could be difficult. The barriers is high, small actors could be at a disadvantage when it comes to the vetting process and for administrative costs; first, because they have limited resources to prepare a dossier, and second, because the due diligence process on the venture capitalist side is equally time-intensive irrespective of whether the size and growth potential of the considered company is big or small, and that therefore quickly scalable projects are preferred [38] [43]; Also, SMEs face high costs of compliance with investor protection regulations, and the due diligence costs to investors of monitoring SMEs with more limited scaling opportunities compared to those of bigger firms, represent an obstacle for SMEs [43] [44]. The lead time of space industry may exceed traditional venture capital ownership periods; The situation in economic downturns tend to be more difficult with higher interest rates and great demand for collateral [45]. Therefore, the public space venture capital funds established could be a great help for SME, including CosmiCapital by CNES, Primo Space by ASI, and Orbital Ventures by Luxembourg, and the Competitive Space Start-ups for Innovation Initiative (CASSINI) by European Union. For U.S., 3% of NASA budget to support small business firms indicates their emphasis [27]; For China, "Chinese space foundation" that lead by government is partially responsible for boosting space economy.

3.3.2 Indirect investment

Indirect investment is the part that government does not invest in private sector, but through collaboration and partnership, or support private sector using political method. There are three methods in indirect investment that are considered as important factors that influence public-private relationships: the public-private partnership (PPP), the technology transfer and commercialization (TTCs) and the space policy.

The OECD defines public private-partnerships (PPPs) as "long term agreements between the government and a private partner whereby the private partner delivers and funds public services using a capital asset, sharing the associated risks" [3] The existence of PPP reveals the strong connection between R&D and funds: the high-risk R&D also makes the related funds high risk. The characteristics of PPP are illustrated down below:

- Funding: Public funds are not dispensed at outset. Instead, a PPP private partner receives periodic payments, typically based on reaching specific project milestones.
- Duration: PPPs often extend beyond construction or deployment and often include operations and maintenance.
- Requirement: "Performance versus Design". As PPPs should focus on performance rather than design requirements, performance requirements are based on

stakeholder expectations and define what needs to be accomplished to meet the objectives of the project.

- Risk Allocation: In traditional procurement, risk is fully borne by the public sector. PPPs, on the other hand, offer a way for risk to be shared with the private sector. [13] [46]

- Outcome: PPPs designed to deliver a public asset or a service, generally used in satellite communications, earth observation, satellite navigation [3] . In United Status, the PPP is always used to enhance private sector and space market [47].

The advantages of PPP compared to traditional procurement are: lower costs, faster development period for public sector and improvement of private sector by giving them the opportunity to develop the hardware used in national program, [26] the use of PPP also provide the demand in space market, therefore improve the space industry. When utilized appropriately, PPPs have the potential to foster markets, enhance national capabilities, and reduce costs, while advancing policy objectives. [48] It should be noted that the PPP discussed is only aiming for design and development (D&D) [49]. Due to previous discussion, I present H1:

H1 The more the public-private partnership space program, the higher the competitiveness the domestic space manufacturing industry.

Public sector still dominates space manufacturing industry technologies due to high uncertainty of R&D for private sector and previous technological accumulation from national space programs. In new space economy, the diversified application of space technology is mentioned as one of the important characteristics, and the space technological transfers and commercialisation (TTCs) is one of the most important ways to realize the goal. The definition of TTCs is: "transfers from publicly funded space programmes to different sectors of the economy (private companies, for commercialization and public benefit." [50], the transfer can happen inside or outside the space industry, with the same goal of creating economic value.

In the case of technology transfer inside the industry, the transfer will benefit directly domestic industry by reducing R&D time. In terms of transfer technology outside space industry, like to transport and manufacturing industry, hospitality industry, health and medicine industry, environmental monitoring and agriculture and food sectors [51], the space technology could benefit other industry in a disruptive way as the memory foam. The space industry can be seen as a technology pool due to the feature that the technologies are developed for the space. Although there is no direct benefit towards space industry, yet it could draw investment and attention due to the speciality and positive effect of space technology. Despite the income from TTCs outside the space industry is potential investment, yet for TTCs inside the space industry, there will be direct technological support, increasing the space industry in the direct way. Therefore, I present H2:

H2 The more the use of space TTCs, the stronger the domestic space industry.

Aside from collaboration and investment, the internalized factors of public sector influence the public-private relationship as well, which are government policy and program. Government use policy or program to assist businesses to boost or reshape specific economic activities [52], reasonable policies can make up for the inherent defects of the market mechanism, enhance the productivity of enterprises, and promote economic development [53] [54]. The adequate and purposive policy can support private sector: "long-term stability of measures seems to have a certain positive effect on input additionality" [55], the existence of demand-side policies (e.g. regulation, procurement) can affect the supply of both internal R&D funding, debt and venture finance. [35] The "critical policy and program", which are the policies and programs directly linked to private sector, aiming for conducting collaboration or improved regulation, could boost private sector. For example, in ESPI 2017 private sector report, the COTS program is mentioned as a highly effective example and have paved the way for new collaborative schemes between private and public actors in the space sector. [19] Other than program that required to utilize private sector competence, the policy that launched for the boost of space economy or standardize the regulation of space industry have positive impact on private sector, for example, before COTS, U.S. government has intentionally distribute the function of license space private sector to FAA, which simplified the process. Based on previous discussion, I present H3:

H3 The index of industry after the critical policy/program implementation will be higher than the index of industry before the critical policy.

Chapter 4 Data and Methodology

Generally, the method is select intertemporal data of a region from new space economy era, do the comparison with itself, then compare the final result between U.S., EU and China. The direct comparison between three regions will not be conducted, since there are many irrelevant variables primarily contribute to the modern space industry, such as first mover advantage, budget, strategic goals.

4.1 Hypothesis 1

H1: The more the public-private partnership space program, the stronger the competitiveness of the domestic space industry.

4.1.1 Data related to PPP space program

To answer the question: what program can be categorized to PPP? I use the table proposed by Moon J. Kim in 2023, whose study is focused on improving and clarifying the typology of PPP in space industry [47]. Basically, in space industry there are four types of PPP: Operation Concession (Ocon); Partially Finance-Design-Develop (PFD); Partially Finance-Design-Develop and Fully Own-Operate (PFD-FO); Partially Finance and Fully Design-Develop-Own-Operate (PF-FDO).

Table 2 Space Public-Private Partnership Typology

Space PPP Type	Task Allocation	Typical Risk Allocation	Analogous Types from PPP Literature
Operation Concession (OCon)	Public entity Finances, Designs, and Develops, and transfers the space system to Private entity which Operates. Public entity retains ownership.	**Private**: Business and Operational **Public**: Financial, Construction, Technical, and Business	Operation and Maintenance
Partially Finance-Design-Develop (PFD)	Private entity either 1) Finances, Designs, and Develops with Public entity doing the same or 2) solely takes on one or two of the tasks. Public entity Owns and Operates the space system.	**Private**: Financial, Construction, and/or Technical (whole or partial) **Public**: Financial, Construction, Technical, Business and Operational (whole or partial)	Build-Finance
Partially Finance-Design-Develop and Fully Own-Operate (PFD-FO)	Private entity either 1) Finances, Designs, and Develops with Public entity doing the same or 2) solely takes on one or two of the tasks. Private entity Owns and Operates the space system.	**Private**: Financial, Construction, and/or Technical (whole or partial), and Business and Operational **Public**: Financial, Construction, and/or Technical (whole or partial)	(Partially) Build-Own-Operate (Partially) Design-Build-Finance-Operate
Partially Finance and Fully Design-Develop-Own-Operate (PF-FDO)	Private entity and Public entity Finance together, but Private entity Designs, Develops, Owns, and Operates the space system.	**Private**: Financial (partial) and Construction, Technical, Business, and Operational **Public**: Financial (partial)	Build-Own-Operate Design-Build-Finance-Operate

The PPP is used in four space areas: satellite communications, earth observation, satellite navigation [3] and international advanced program (COTS for ISS supply, hardware development for Artemis program). In the case of new space economy, the program of satellite communication, earth observation and satellite navigation will be selected due to the similarity with the programs conducted by private sector in new space economy and the rarity of advanced program. The number of PPP used in satellite communications, earth observation and satellite navigation will be collected intertemporally for Europe, United Status and China, the overall number of correlated space program will also be collected, to see the changing trends of percentage of PPP-used in three areas. Data from advanced space program will be neglected due to its rarity. Normally the satellite launched is the result of PPP program, therefore the satellite launched in national space program is identified; for the situation that one contract building multiple satellites, the overall number will be count as one to reduce data interference.

4.1.2. Data related to competitiveness of domestic space industry

For competitiveness of space industry, "Competitiveness of Space Industry "indicates that the general measurement includes: the measure of national exports/sales from space technology, and national R&D and as a percentage of national GDP [56]; since the competitiveness is functional as a result in hypothesis 1, the national exports/sales related to space will be selected.

4.1.3 Methodology

The comparison is intertemporal and internal. The use of PPP will be counted by calculating the proportion of PPP used in satellite communications, earth observation, satellite navigation program, then the fluctuation could be found. For space industry competitiveness, the intertemporal space manufacturing industry export data will be collected, and the trend will be compared. Based on the theory, if the proportion of PPP is raised, the export data at the same period should raise.

4.1.4 Europe

For EU satellite communications, earth observation, satellite navigation program, all the related programs held by ESA was counted; From each program, the satellite model is identified, then the detailed information of each satellite is collected, including satellite contract signing date, contract type, contractor information, to judge whether the satellite is built under PPP or not, in EU case, if a program is PPP it would be marked, makes it easy to identify.

In EU case of national sales related to space, due to the data availability and credibility, the specific data related to European "Statistical classification of products by activity (CPA)" sector: 30.30.40, 51.22.11, 51.22.12 is selected from Eurostat database. These sectors contain all the export regarding satellite and launch vehicle, as the detail listed below.

30.30.40 Spacecraft (including satellites) and spacecraft launch vehicles:

This subcategory also includes:

- intercontinental ballistic missiles (ICBM) and similar missiles

- satellites

51.22.11 Space transport services of passengers

This subcategory includes:

- space transport services of freight

- launching and placing of satellites in space

51.22.12 Space transport services of flight

This subcategory also includes:

- services provided by space laboratories [57]

4.1.5 United Status

In U.S. case, The NASA Space Communications and Navigation (SCaN) Program is responsible for providing communication and earth observation, the Global positioning system (GPS) is responsible for satellite navigation, therefore all the satellites and their details will be collected to find PPP proportion. For data of competitiveness, the data from The Observatory of Economic Complexity (OEC) platform, harmonize system sector HS6 88.02.50: Spacecraft, satellites and spacecraft launch vehicles is selected.

4.1.6 China

Despite the use of PPP is quite common in U.S. and EU, there is only one official record of PPP program in China, which is a satellite development program in 2017. Yet the PFD-FO type of PPP is identified in Chinese space program: the situation that the private firm launch a satellite constellation program, the program is developed, operated, and financed by private sector, and partial funded by public sector. The data of this type of company with program will be collected. Export figure is from OEC database, category HS6 88.02.50 in Harmonized System 1992 for 6-digits, which represents Spacecraft, satellites and spacecraft launch vehicles.

4.2 Hypothesis 2

H2 The more the use of space TTCs, the stronger the domestic space industry.

4.2.1 Data relates to space TTCs

According to OECD "Space Technology Transfers and their Commercialisation", there are several ways for public R&D technology transfer to other actors:

Table 3 Main channels for public R&D technology transfer

Channels		Description
Formal	Collaborative research	Small and big research projects carried out jointly by public and private actors, with different funding models (they can be fully or partially funded by industry). This also includes public-private co-publications.
	Contract research	Specific channel where a private actor commissions to a public research organisation a research project with the goal to generate knowledge or a new technology necessary to solve a problem.
	Academic consultancy	Provision of advisory services by a public research institution to industry counterparts, to support the development of new technologies/knowledge.
	Intellectual property rights transactions	The licensing and selling of IP generated by academic and public organisations to industry.
	Research and labour mobility	Mobility of personnel between research institutions and firms. This may involve industry hiring or training workers, student placements, personnel intersectoral mobility, etc.
Informal	Scientific publications	Widely used, in particular by universities, to transfer knowledge. To be distinguished from joint publications between public and private actors, which belongs in the collaboration category.
	Conferencing and networking	Informal interactions between researchers and industry actors in the context of conferences and similar events. Knowledge is transmitted in various ways, through presentations, demonstrations, informal trainings, at a relatively low cost.
	Networking facilitated by geographic proximity	Informal interactions between public research staff and industry researchers, facilitated by locating science parks near university campuses, or firms' laboratories within university campuses.
	Facility sharing	Public and private actors sharing of infrastructure, e.g. laboratories and equipment, typically owned by research organisations.
	Courses and continuing education	Trainings offered by research organisations, often universities, to private actors, as well as university lectures by industry representatives

Source: OECD, Space Technology Transfers and their Commercialisation

Due to data availability, tracking patent issued by space agency is the priority way to collect data, patent is one the most direct methodology to transfer know-how, and patenting the outcomes of public space R&D remains one of the most common channels adopted by space agencies and technology transfer offices to promote the commercialisation of inventions [50]. If the patent is not traceable, the second-choice collaborative and contract research, since this figure could be found by inspecting the detail of space program. The research and labour mobility could be a supplementary data. All the informal data will not be selected due to the vague effect.

It should be noted that Infrastructure and collaborative platforms, including sharing government testing facilities and services, and establishing clusters, incubators and collaborative platforms are also channels of TTCs [50], these methodologies are also mentioned in previous public-private relationships literature review. Yet due to data availability these channels are neglected.

4.2.2 Data related to space manufacturing industry grow

Due to the data availability and different statistic figures selected by organizations of different countries and regions, the industry final sales, market size or gross output are selected to observe the trend of industry grow, due to their shared function of trend indication.

4.2.3 Methodology

The data regarding agency file patent will be collected intertemporally to see the trend, so does the space industry index. Based on hypothesis, the growth of number of patents should lead to the industry growth, if not, then the hypothesis is rejected.

4.2.4 Europe

ESA runs a Europe-wide space technology transfer initiative with the scientific and industrial world [55]. For Europe, the data related patenting could be found in collaborative research regarding patenting in space sector by the European Space Policy Institute (ESPI), European Patent Office (EPO) and European Space Agency (ESA) in 2024. There are four separate studies in this research related to space industry:

- Cosmonautics
- Quantum Technologies and Space
- Spaceborne Sensing and Green Applications
- Propulsion Systems for Space

Despite not all the data is strongly correlated to the space manufacturing industry, yet for international comparability, the data from all the four sources are accepted. Due to the availability issue of cosmonautics, the area that relate strongest to space manufacturing industry, only present data until 2017, therefore the period between 2009 to 2017 is selected. For the data related space industry economic index, the total final sales presented by "Eurospace facts & figures 2024" by Eurostat is selected.

4.2.5 United Status

The number of patents filed by NASA could be found in a third-party report. For the data related to space industry growth, the U.S. Bureau of Economic Analysis (BEA) has provided "Space economy gross output" as a measure of domestic space industry. Due to the limited data availability, the data from 2012 to 2023 will be counted.

4.2.6 China

In Chinese case, it is difficult to use patent data to represent space TTCs. The logic behind space TTCs is that agency identify the patent with potential to commercialize, unlike NASA and ESA that file patent, CASA doesn't hold responsibility for filing patent. Despite the China Aerospace Academy of Systems Science and Engineering and Shanghai Academy of Spaceflight Technology subordinate to state-owned enterprise CASC hold the responsibility of technology transfer, yet intertemporal data is difficult to get. Therefore, the data related to collaborative research and labour mobility will be used, I found three situations related to technology transfer, which will be used to collect data.

- The private firm that CEO, CTO or technical team that previously worked in public sector as engineer or technician.
- Collaborative development program between private sector and public sector.
- The private firm that established by state-owned space enterprise.

For Chinese space industry data, the market size is the available figure. Due to availability, the period 2015-2021 will be selected.

4.3 Hypothesis 3

H3 The index of industry after the critical policy/program implementation will be higher than the index of industry before the critical policy.

4.3.1 Data related to critical policy/program

The critical policy and program, of U.S., EU and China in new space economy will be viewed. The "critical policy and program" are defined as: 1. Policy that directly aiming at the development of space industry. 2. Program that urge public sector to utilize private sector competence.

4.3.2 Data related to index of industry

Due to the data availability and different statistic figures selected by organizations of different countries and regions, the industry final sales, market size or gross output are selected to observe the trend of industry grow, due to their shared function of trend indication.

4.3.3 Methodology

Based on the hypothesis, the index of industry will be higher after the policy has implemented. However, if the industry continuously grows, then the growth rate should be higher after the implementation.

4.3.4 Europe

There is an iconic program in Europe starting in 2023, which is The Commercial Cargo Transportation Initiative (CCTI). It is a competition launched by ESA which initiates a first phase of activities for European companies to eventually demonstrate a complete cargo delivery service to and from space stations in low-Earth orbit by 2028, to be specific, demonstration mission delivering a minimum of 2 tons of pressurized cargo to the ISS, as well as safely returning a minimum of 1 ton back to Earth. The initiative will develop a way to bring cargo to and from space stations in low-Earth orbit before the end of this decade, providing Europe with access to space, further bartering prospects, and the opportunity for European industry to develop commercial services for cargo transportation to low-Earth orbit on the global market. [58] [59]. Due to the CCIT's potential impact on European industry, this program is selected.

For the data related to index of industry, due to availability and correlation, the EU export data of Spacecraft, incl. satellites, and suborbital and spacecraft launch vehicles, from 2021 to 2024 will be collected to considered.

4.3.5 United Status

U.S. value space as one of the most important industries for the nation. From policy perspective, each president must launch a new space policy to the congress, waiting for approval. In the numerous policies and programs, I selected Commercial Satellite Data Acquisition (CSDA) as the program to study, due to the data availability and timing. The CSDA program aims to identify, assess, and acquire data from commercial providers, which may offer a cost-effective means of supplementing earth observations collected by NASA, other U.S. Government agencies, and international collaborators. The goal is to explore the potential of commercial satellite data in advancing the agency's Earth science research and application objectives. [60]

For data related to industry, the data from BEA database: "Computer and electronic products" which includes manufacturing of satellites; ground equipment; search, detection, navigation, and guidance systems (GPS/PNT equipment) is selected. Considering the availability, the data from 2012 to 2023 will be collected to have a comprehensive view. Another case study: U.S. policy S.442 - National Aeronautics and Space Administration Transition Authorization Act of 2017, will be carried out to see how government utilize the successful experience from COTS.

4.3.6 China

Due to the late start of new space economy in China, there are many policies launched for private space industry after 2015, for example, the "Satellite Engineering Management Guidelines" in 2016, "Notice on the Guidelines for Preliminary Technical Research Projects for the 13th Five-Year Plan for Civil Aerospace" in 2018. Among them I choose "Notice of State Administration of Science, Technology and Industry for National Defense (SASTIND) and the Central Military Commission Government agency (CMC) Equipment Development Department on Promoting the Orderly Development of Commercial Launch Vehicles." Published in 2019, due to the significance of supporting private launch vehicle in policy level [32].

For data related to industry, since the policy aiming at developing the private sector launch vehicle development, the launch vehicle market size from 2018 to 2023 is selected.

4.4 Complementary information

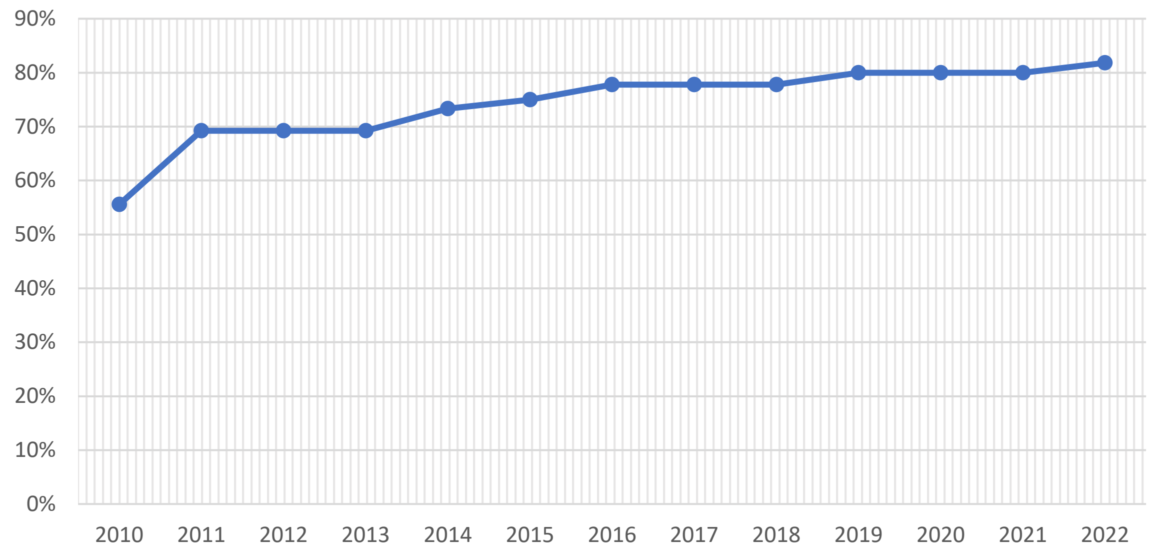
Before studying, few risks of qualitative study are noticed. Cultural bias is the misunderstanding of a researcher while conducting study based on other cultural background, the researcher could be constrained by the culture and environment that he/she lived and grow in. In my study, three regions are included, to minimize the cultural bias, during data collection the material wrote by relative foreign researchers are included (e.g. American researcher 'perspective on China, European researcher's perspective on America…). Data credibility is vital to qualitative study due to the importance as corner stone. To guarantee data credibility, the data from official agency is prioritized. Compared to quantitative study, qualitative study is flexible and exploratory, to utilize the advantage, the hypothesis will not be simply denied if the data and discussion does not support it, the possibility to correct or refine hypothesis, or learning from denying will be valued despite the thesis is conducting in the deductive way. Comparing with other public-private relationship study, the space industry is special due to following characteristics: government possess absolute technological advantage in the past decades; high-risk; high barriers to entry; long-term innovation requirement; sensitive to national security. The complexity needs to be considered throughout the study.

Chapter 5 Empirical study

5.1 Hypothesis 1

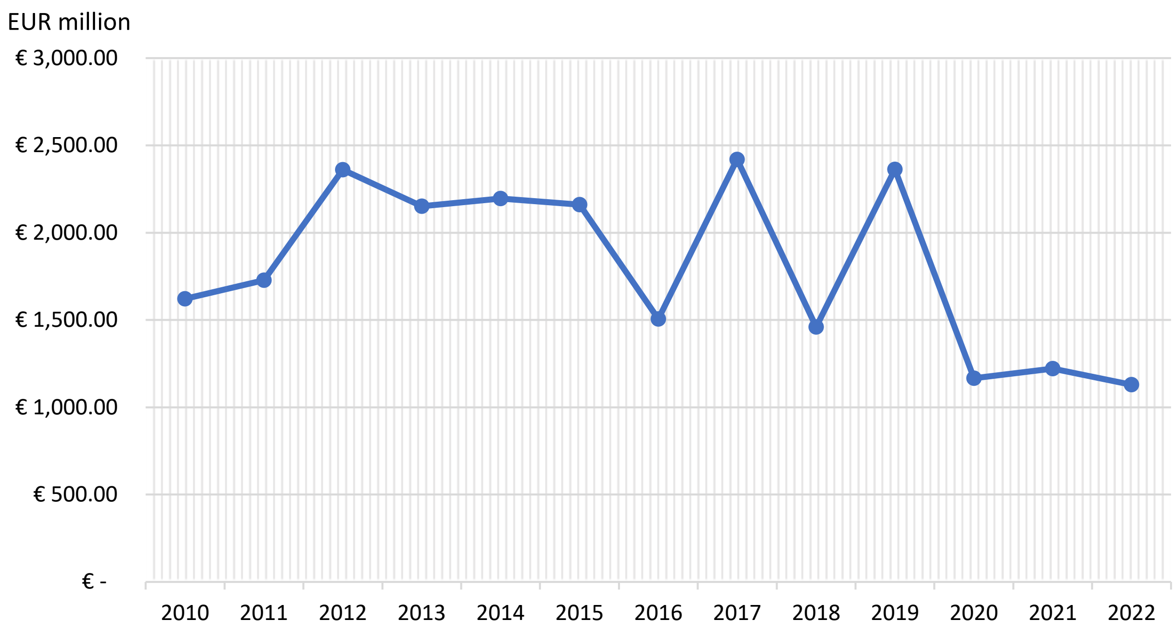
5.1.1 Europe

Figure 6 PPP used in ESA program



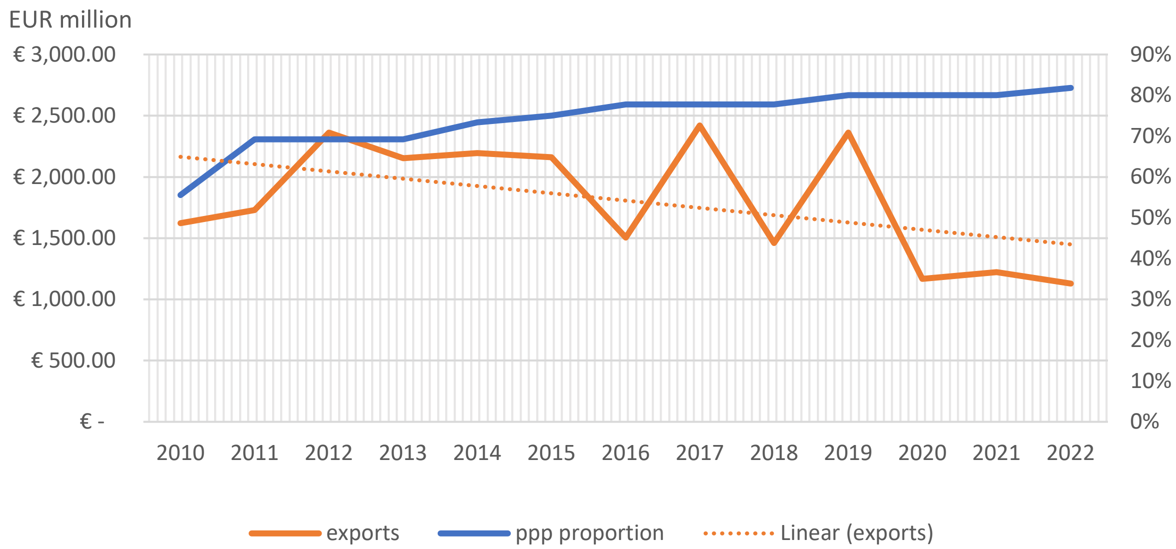
Source: Author analysis

Figure 7 Extra-EU exports in selected area from 2010 to 2022



Source: Eurostat

Figure 8 Comparison

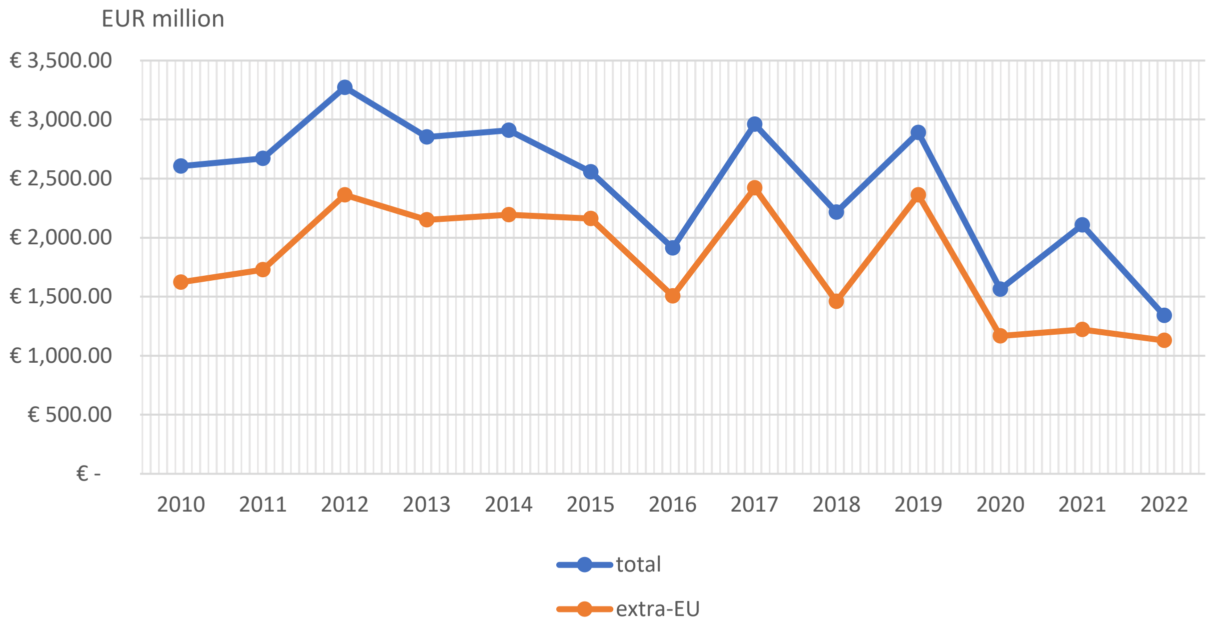


Source: Author analysis

The downward trend line that represents exports does not match the upraising PPP proportion from 55% to above 80%, therefore the hypothesis is rejected. The use of PPP in EU constantly increases from 2010 to 2022, yet the extra-EU exports fluctuated severely, and the CAGR is negative. It is worth noticing that the PPP used in period 2011-2013, 2016-2018, 2019-2021 holds constant, my deduction on reason is the gap between space programs.

For the data of export, only the export that extra-EU is counted; to confirm the influence of export destination, the extra-EU and total export is compared in figure 9, which shows the similar trend of decreasing and exclude the interference.

Figure 9 Total EU exports in selected area from 2010 to 2022

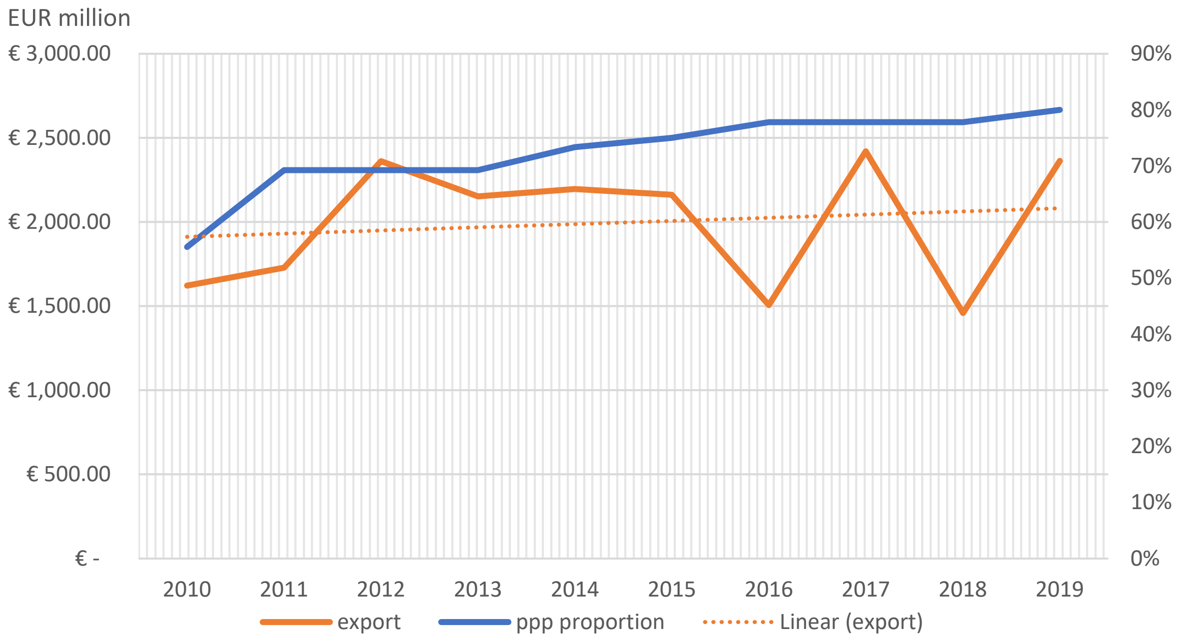


Source: Eurostat

The decrease from 2019 could be explained by Covid 19 pandemic. If the data after 2019 is moved, as the figure 10 shows, the overall export has increased from €

1,621.75 million euro to € 2,363.31 million euro, and the trend of export has became upward, which match the trend of PPP proportion.

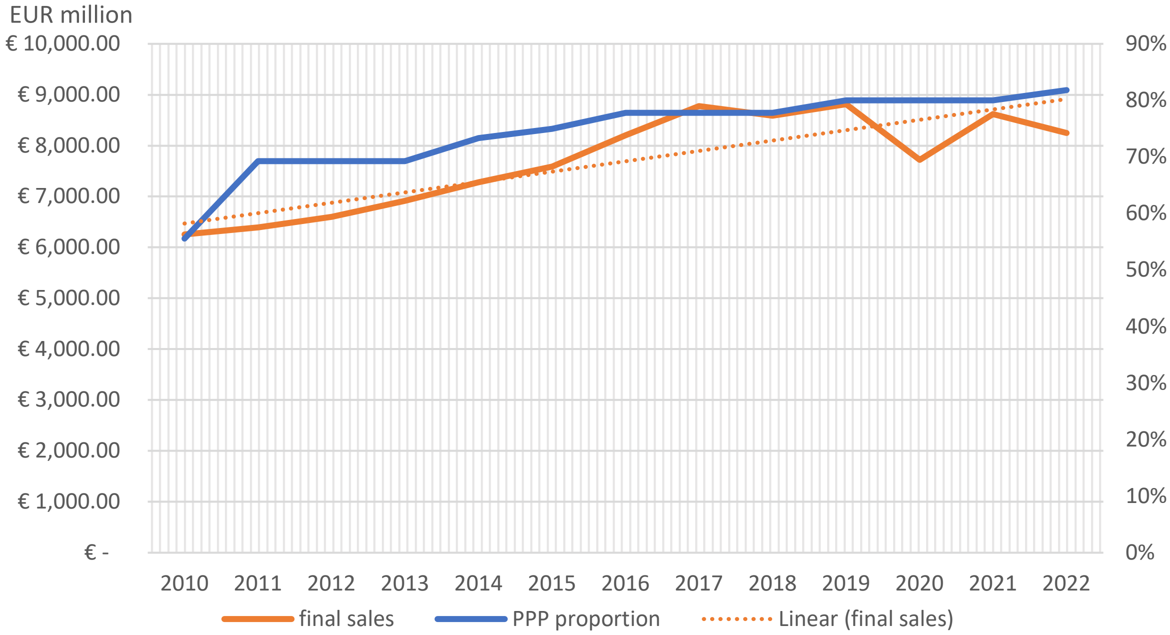
Figure 10 Comparison from 2010 to 2019



Source: Author analysis

The export is influenced by external factor, since competitiveness is a dynamic and comparative figure, especially in international market. The trend of export and index of industry itself could be opposite. To see the trend EU space industry, the final sales of EU space industry final sales by Eurostat is selected. The figure11 That compare EU space industry trend with PPP proportion trend shows positive result before 2019, for final sales from 2019-2022, the final sales dropped like export data.

Figure 11 EU Final sales and PPP proportion

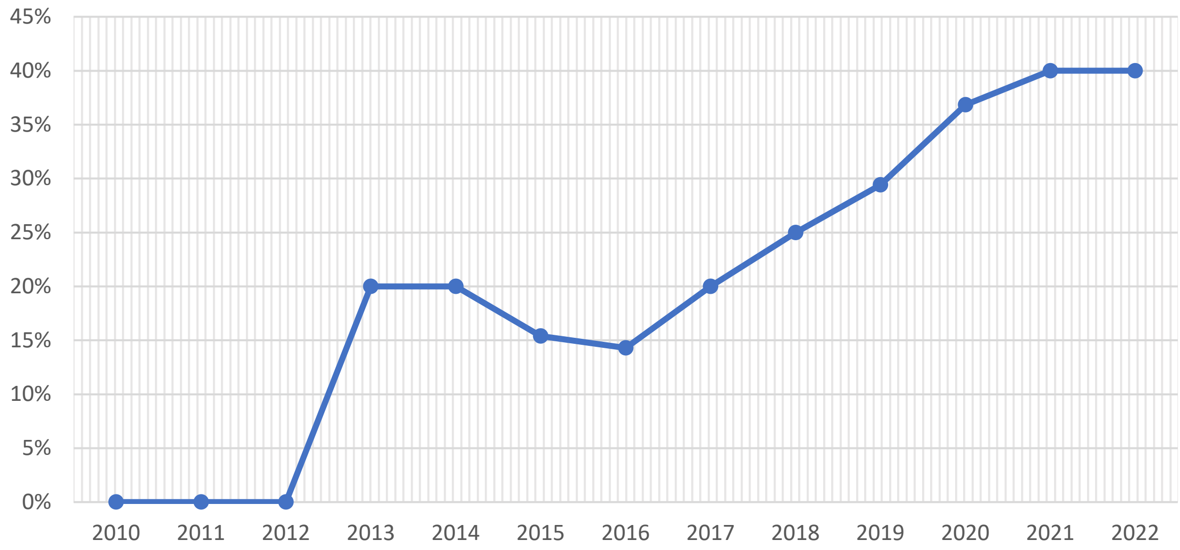


Source: Author analysis

The European PPP program belongs to PFD type.

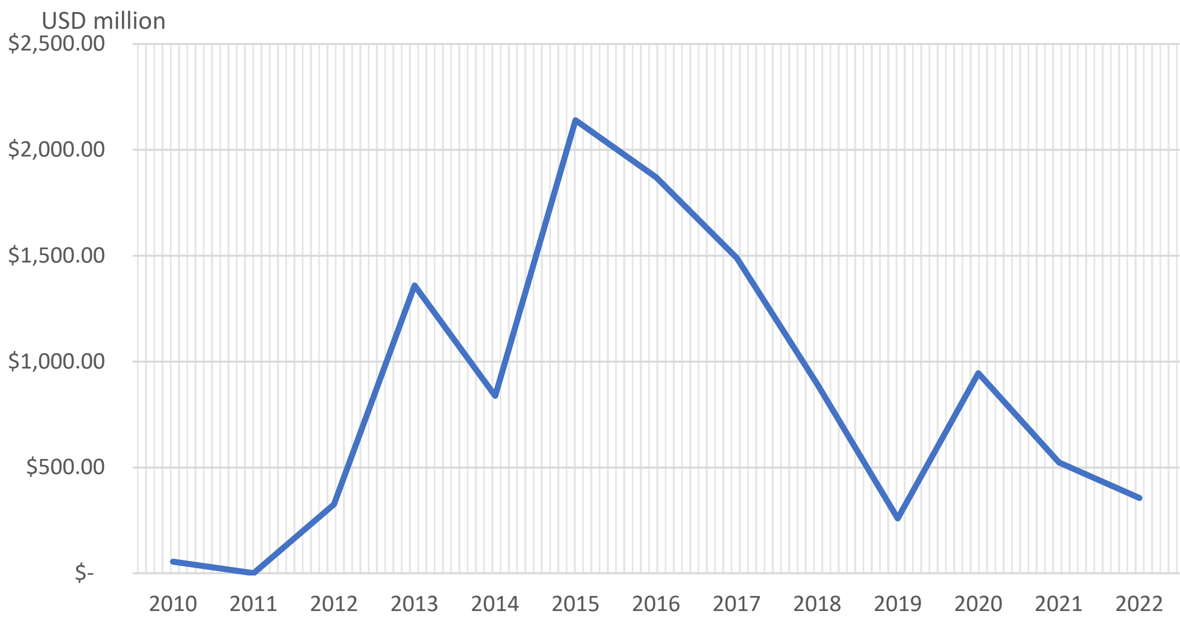
5.1.2 United Status

Figure 12 PPP proportion



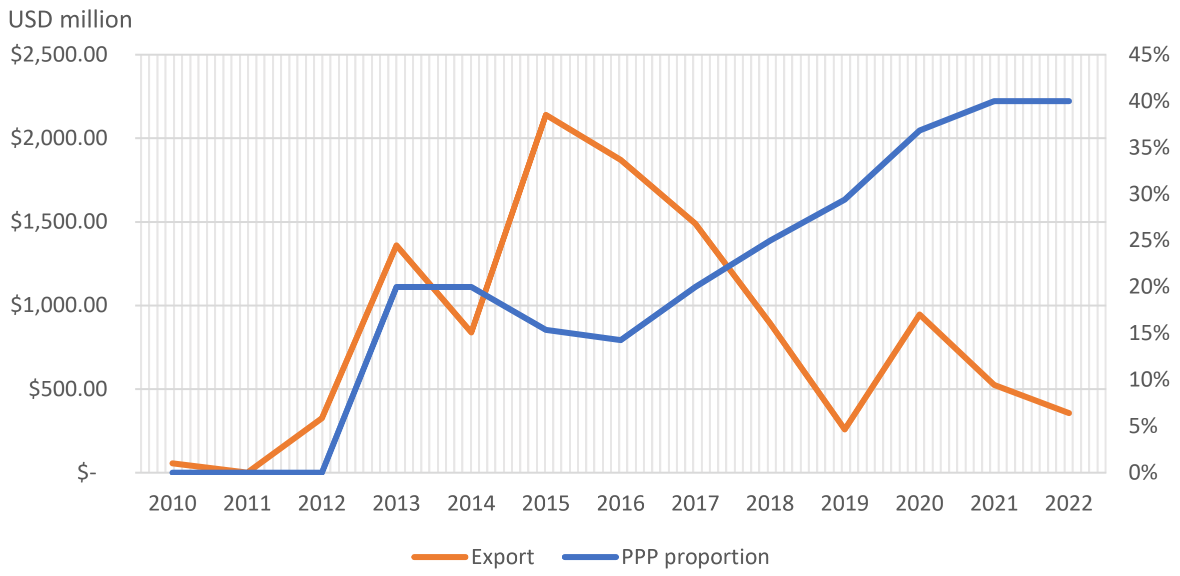
Source: Wikipedia

Figure 13 U.S. exports 2010-2022



Source: OEC

Figure 14 Comparison

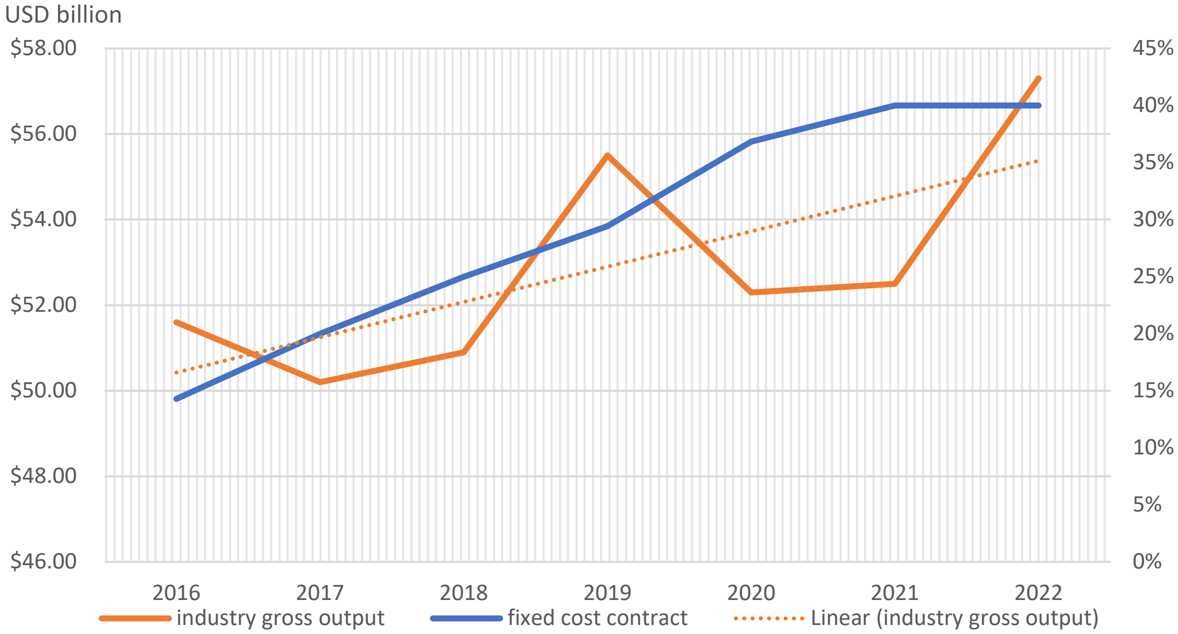


Source: author analysis

Despite the same positive increase compared 2022 to 2010 for export and fixed-cost contract, and the same increase from 2012-2013, yet during the period of fixed-cost contract increase from 2016 to 2022, the export is not increased, whether neglecting data from 2019 or not. Therefore, the hypothesis is rejected.

The massive drop of export from 2015 to 2019 might cause by the U.S. export regulation on spacecraft, like International Traffic in Arms Regulations (ITAR) and the Export Administration Regulations (EAR), which becomes stricter by time. To have a comprehensive view, the index of industry is collected, and the comparison was shown in figure 15, which shows positive trend from 2016 to 2022, and match the trend of fixed-cost contract proportion.

Figure 15 Industry gross output and PPP proportion 2016-2022



Source: BEA

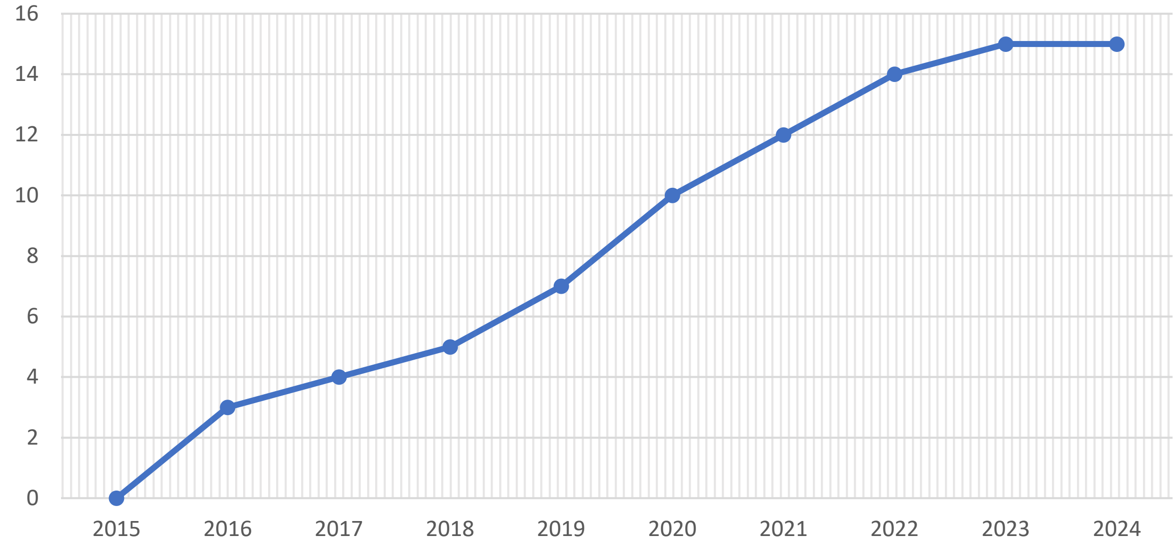
After inspecting all the satellites in SCaN program and GPS program, I found out the U.S. PPP cases are belong to PFD type as the fixed-price contract: the financial, operational and business parts belong to the NASA, and private sector is responsible for building the satellite under the fixed cost contract while bearing related risks. In fact, the SCaN and GPS fixed-cost contract has great similarity with the NASA Bigelow Expandable Activity Module (BEMA) program that aiming to attach an expendable habitat to ISS, and the BEMA program lies in PFD category in that dissertation. [47] A case study of Falcon 9, which is an iconic result from PPP program, will be conducted for supplementary discussion.

There are several reasons that NASA use seldom "traditional" PPP (PF-FDO in typology). First, the SCaN and GPS contracts is signed early. In SCaN case, the TDRS haven't use fixed-cost contract until the third generation satellite contract, whose launch started in 2016, the TDRS series satellites launch was started in 1983, for the first two generation that contains most of the satellites, the contract is signed before 2002; In GPS case, the fixed-cost contract was signed in Block III satellite contract which was launched from 2018; The previous blocks are launched from 1978 to 2016; Second, the continuity of satellite constellation build lead to the contracts are signed one time for a group of similar satellites, therefore even NASA wants to use PPP at certain time, it is not possible until the satellites from current contract have finished launching. Third, NASA did not show great interest on using PPP recently. In the NASA Authorization Act of 2005, the U.S. Congress began asking NASA to start collaborating with commercial partners but without actual guidance. More specific direction was provided in the NASA Authorization. The adequate budget of NASA might be a reason of not using PPP, due to the cost-saving characteristic of PPP.

However, NASA did show interest in using PPP in future GPS and SCaN program [61]. Other than satellite communications, navigation and earth observation area, the use of PPP is emerged in other ongoing space program, as NextSTEP and Artemis program. However, it should be notice that some of the U.S. PPP programs are failed, for example EnhancedView satellite imagery in 2010, DARPA space plane and in orbit service in 2020 [47].

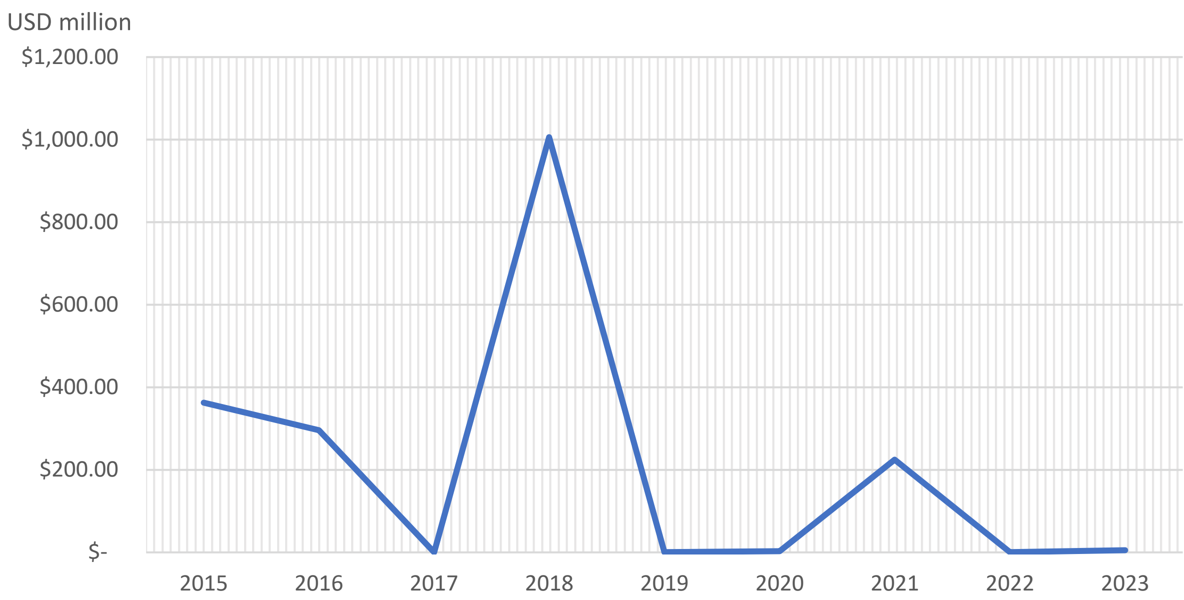
5.1.3 China

Figure 16 Number of PPP firm



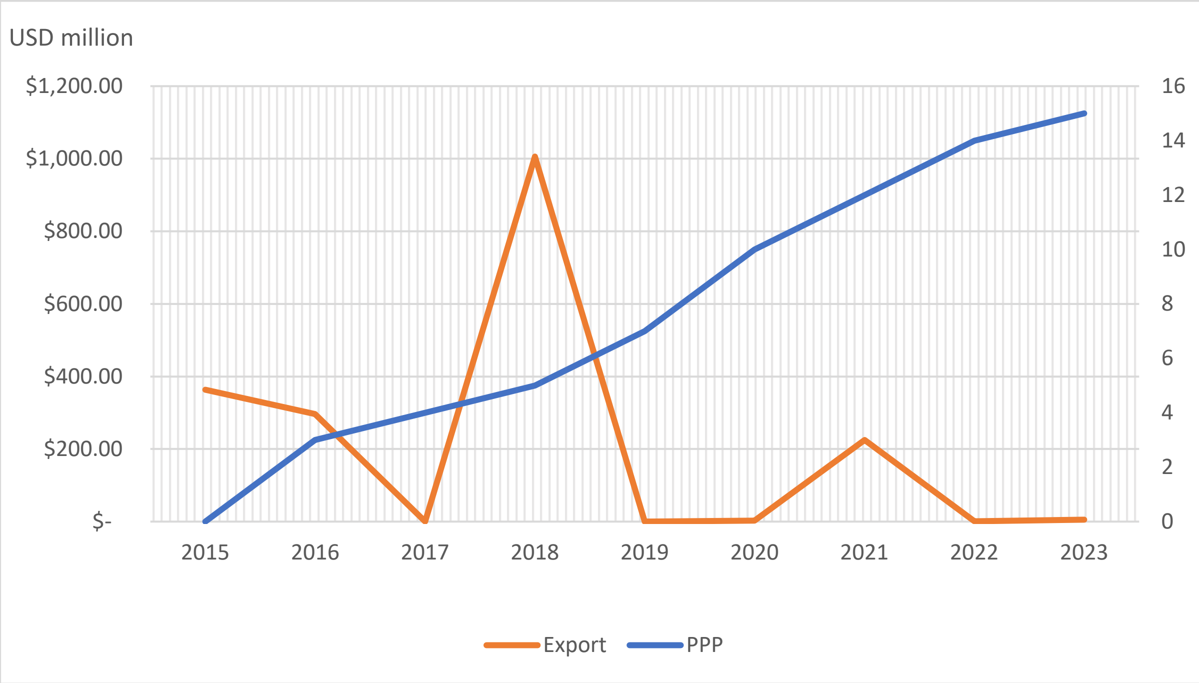
Source: Author count

Figure 17 China space industry exports 2015-2023



Source: OEC

Figure 18 Comparison



Source: Author analysis

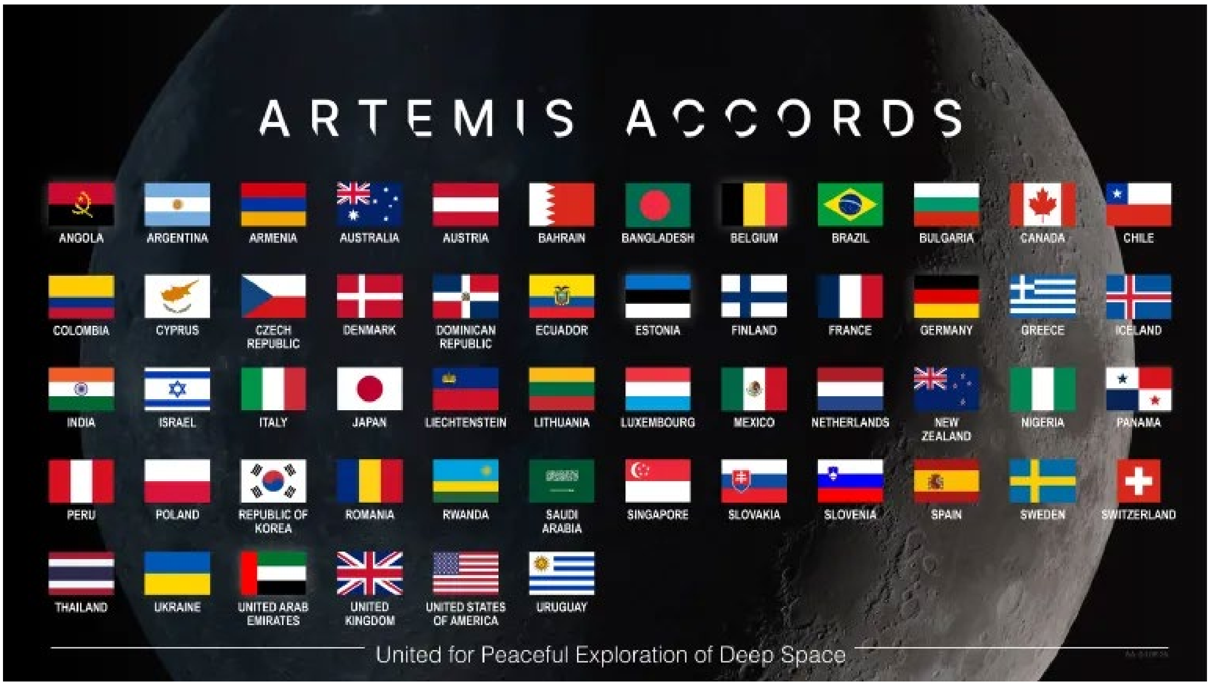
The increase of PPP does not match the chaos trend of export. The hypothesis is rejected.

The number of PPP is increasing continuously, yet the export figure fluctuate wildly. It is difficult to analysis increase and decrease, there is a small drop from 2015 to 2017, yet from 2017 to 2019 there is a roller-coaster style raise and drop, from 2020 to 2022 there is a smaller raise and drop. The figure in 2017, 2019, 2020, 2022 and 2023 is not 0, but numbers small enough that can't be shown in the chart. Yet overall there is a drop comparing figure in 2023 and 2015.

The cause of these might be quality of data for export , the export data comes from OEC, which specifically record international trade data, the source of data is listed on the website and OEC only do the process of data, despite the perceived credibility, the data with extremely low trade in 2017, 2019, 2020, 2022 and 2023 is strange.

Another reason for export data is that Chinese space international trade is heavily limit by U.S. policies. In 2011, the US Congress enacted the Wolf Amendment, the ability of China's commercial space firms to compete is curtailed by strict International Traffic in Arms Regulations (ITAR) rules, These US policies dissuade foreign organizations from collaborating with China [21]. Several CEOs and legal counsels of space companies based in third countries (not the United States or China) told us they were "afraid [. . .] to violate US export control regulations "and considered that "any hint of Chinese involvement will cause problems with US regulators. "They explained how they felt obliged to choose between working with the United States or with China, and that they could not afford to leave the United States aside because "there are almost always American components in space projects." These US policies inflict a glass ceiling on China's global space network, limiting its ability to collaborate with other actors. [21] Further evidence of U.S. prevent Chinese international collaboration could be seen in Artemis program participate country, from the point of view of major space power, only China is left alone.

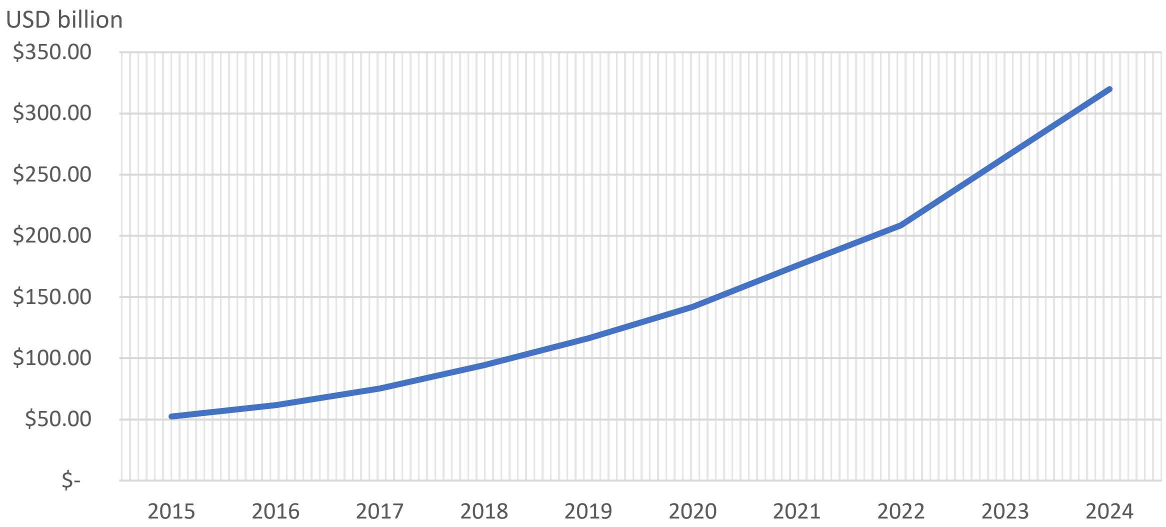
Figure 19 Artemis accords participate country



Source: NASA

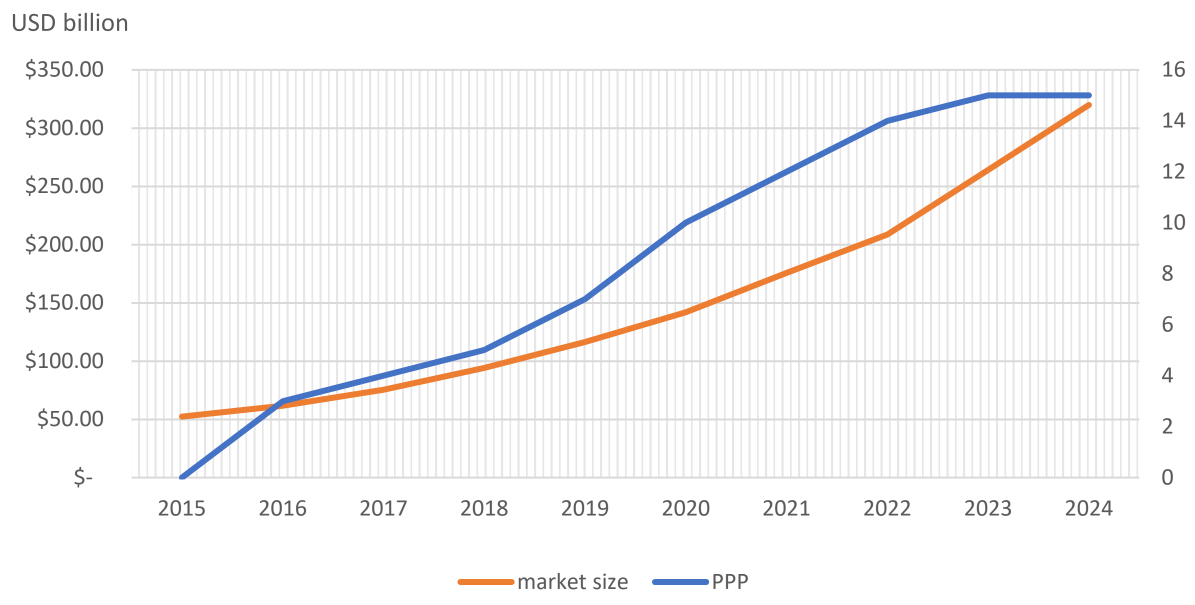
For the export data, the use of industry market size is used to eliminate the externality.

Figure 20 Chinese space industry market size



Source: CNSA

Figure 21 Comparison



Source: Author analysis

The growth of Chinese space industry matches the trend of PPP. However, it should be notice that figure on the PPP side is influenced by establish time: it means the increasing trend might correlate to increasing number of firm with satellite program, and basically all Chinese space manufacturing firm with satellite program has partial public investment. The reason could lead to second notice to the result, which is the Chinese unique administrative system that governing space industry: the space firms are governed by domestic government, generally provincial government and municipal government, who was given large investment freedom and responsible for economic growth as well as national policy implementation, after the policy of boosting space economy in 2014, it is a responsibility to discover the space company potential and help them financially or with resource, also aiming for domestic economy growth.

The reason of PPP figure as number of firm is the unique patterns of collaboration in China space industry. From the first Chinese satellite launched in 1970's to 2014, the China space industry is dominate by two state-owned enterprises, China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation (CASIC), which evolved from state-owned research centre. Two enterprises handled basically all Chinese space program, including satellite navigation and communication, earth observation, human spaceflight, space station, and moon landing. In 2014, with government launched "Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment" that support private company to join space industry, the private sector in China space industry started to emerge.

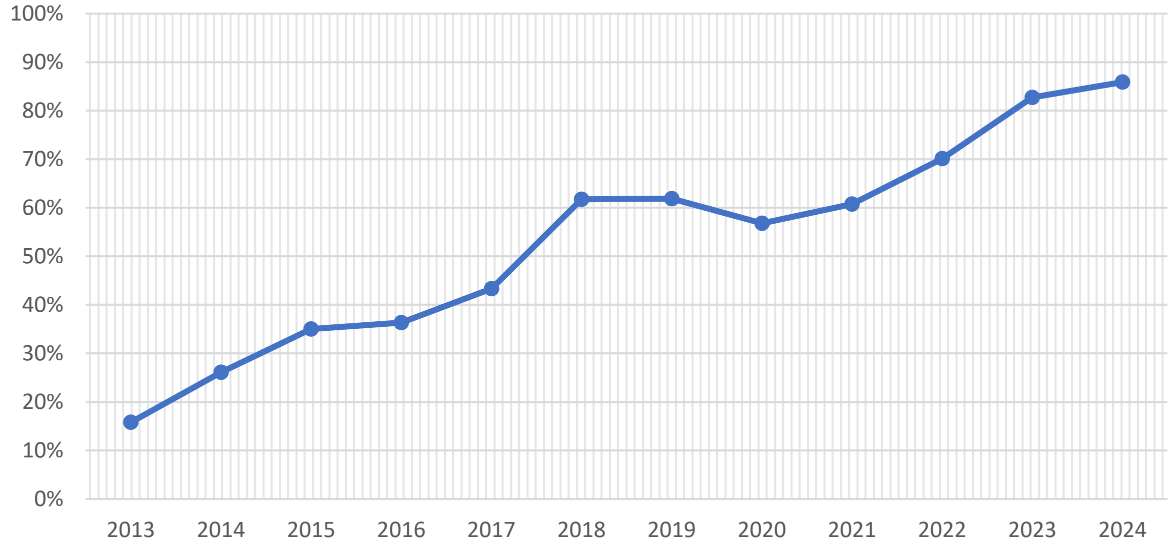
To conduct PPP, there must be a space agency to negotiate with private sector. In Chinese case, the Chinese space agency, China national space administration (CNSA), does not responsible for collaborating with private sector; the reason is quiet simple: due to the average age of private sector, the competitiveness is weak compared to state-owned enterprise, for example, in 2024, the Long March series launch vehicle, which is developed by CASIC, still holds 75% share of 68 times of launch; the private sector is governed by local government, even if there is a public-private collaborative program, the private sector is usually work with local government, not space agency, like G60 satellite constellation program that jointly developed by Shanghai Municipal People's Government and Shanghai GESE company.

5.1.4 Case study: Falcon 9

Despite the low frequency of PPP use, U.S. did have an iconic success example that illustrate the potential of PPP, which is Merlin engine and Falcon 9 launch vehicle, developed by SpaceX for the ISS resupply PPP program. Back in the day, U.S. was responsible for resupply ISS, instead of developing the hardware with public sector as usual, NASA decided to work with private sector in collaborative funding way. At the time NASA deliberately focus on new-established firm, rather than the firms that has worked together for years like Boeing and Lockheed Martain, to discover the potential of U.S. space industry. After SpaceX was selected, the Falcon 9 and merlin engine was developed to satisfy the requirement, and in 2012 it successfully resupplied the ISS. The COTS is a pioneering PPP application case in U.S. space history [62].

After launch for resupplying International Space Station in 2012, Falcon 9 gradually dominated U.S. launch market, it is worth noting that in 2022, 2023 and 2024, Falcon 9 was launched 87, 116 and 156 times, making it the most-launched American orbital rocket in history [63]. All the competitiveness, technical advantages, and reputation of SpaceX and Elon Musk attributed to NASA choosing SpaceX for COTS program. This is a positive case that shows how PPP aiding domestic space industry.

Figure 22 Share of Falcon 9 in U.S. launch market, categorized by model



Source: Author count

One of the most important reason of Flacon 9's dominance is the cost. To have a strict comparison, the cost efficiency of mainstream launch vehicle was calculated by following formula, based on public data. Falcon 9 has absolute cost advantage among the launch vehicles that target LEO, and the result is supported by OECD cost efficiency data.

$$\boldsymbol{Cost\ Efficiency} = \frac{\boldsymbol{Launch\ Price(kg)}}{\boldsymbol{Max\ Payload(USD)}}$$

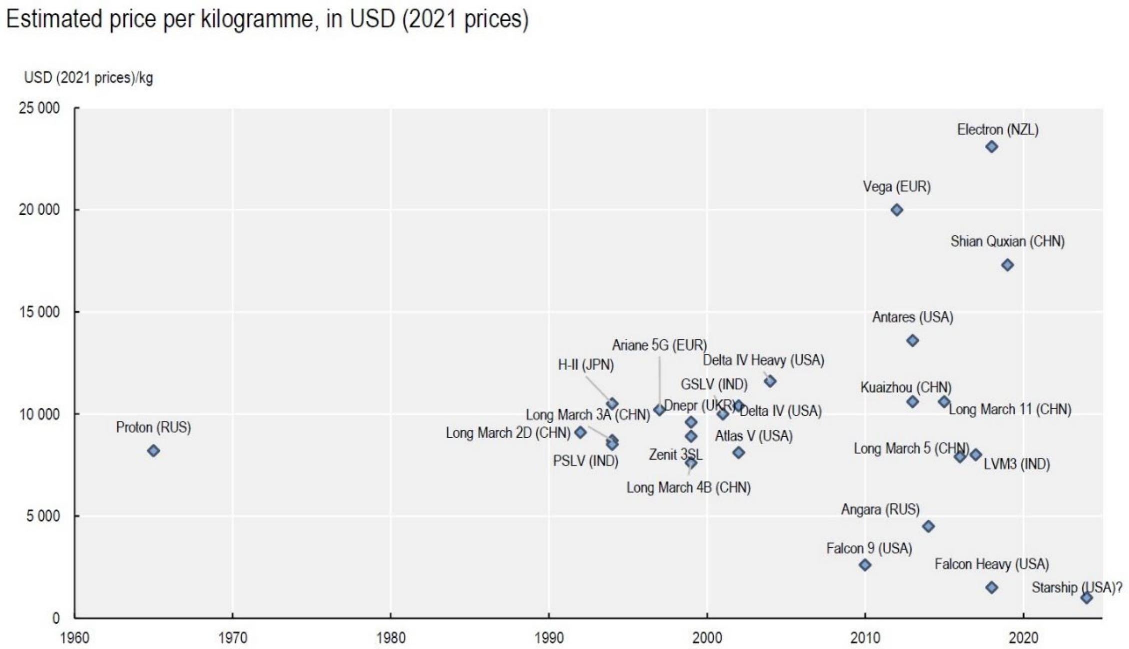
Table 4 Cost efficiency of main stream launch vehicle

Nation	Launch vehicle model	Max Payload to LEO (kg)	Reusable	Cost efficiency (USD)
U.S.	Flacon 9(reusable)	16500	Yes	4060
U.S.	Atlas V	19000	No	8631
U.S.	Delta 9250H	28000	No	12500
EU	Ariane 5ES	21000	No	6523*
EU	Ariane 6(64)	21500	No	5811
China	Long March series	25000	No	< 7645

Source: author analysis

Note: *the price is using Ariane 5, not 5ES. *The result is calculated in the condition where the launch vehicle is max loaded.

Figure 23 Price estimates to low-earth-orbit for selected operational and experimental launchers



Source: OECD [64]

5.1.5 Comparative study

In the study of H1, the hypothesis is rejected on both EU, U.S. and China case. Yet the detail might reveal vital facts.

The data shows Covid-19 impact Europe space industry more than U.S. and China. The export data shows a direct huge drop from 2361 million euro to 1167 million euro for EU case, very close to 50%, and the following two-year data did not show strong revival. The U.S. and China export impact by pandemic is not obvious due to the continuously drop before 2019 and big fluctuation, yet looking at industry index data, after pandemic both U.S. and China has breakthrough high after the peak before 2019, yet Europe is still recovering and try to return to high point in 2019.

In terms of PPP data, despite the same name of PPP, yet the detail and logic are completely different. The European PPP is the most "traditional" one: co-funding, sharing risk, co-development; Despite the U.S. PPP is categorized as PFD, which is the same as European case; yet the American PPP is fixed-price contract, the risk is only transferred to the private side, not shared. In Chinese case, despite categorized as PF-FDO PPP, yet the logic is the public fund invest in private companies with satellite constellation program, instead of saying that the public sector is funding the program, it's better to say the public sector is funding the company. The difference of PPP shows the different situation of satellite program development in three regions. The reason behind could be different PPP environment including capital market accessibility and public-private sector relationships. [47]

After switching from export data to industry index, the hypothesis is supported in both three cases, it could be the eliminate of externality improves the quality of data, or my reasoning for the interconnection between data for hypothesis was wrong. For U.S. and China case, the deglobalization could be observed: China export is limited, and U.S. export is self-limited. It could attribute to the severe competition in international space industry, yet I believe the communication and collaboration will lead to greater success, since in my space supply chain analysis, China and America is interdependent.

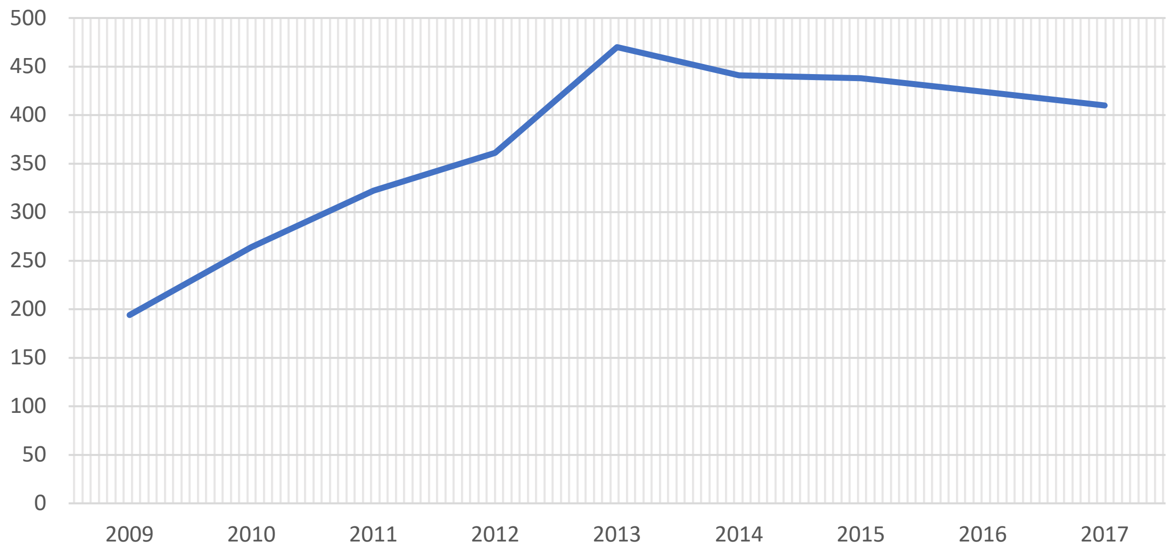
Despite the low interest in using PPP in most of the satellite program, yet U.S. do have the most success result from PPP case. The reason could be disruptive thinking by Elon Musk and the engineers, but I believe the vital point is the strong industrial foundation that America has developed for years and improved at any cost during the cold war and moon-landing era.

The H1 study has following limit: 1. The other PPP case utilized in on-orbit serving, deep-space exploration, military sector is not counted due to data issue and the rarity. The result might be different if data from these sectors were counted. 2. The data related to competitiveness could be more detailed, as Futron's 2014 Space Competitive Index [65] shows, using a analytic framework rather than single indicator could be better interpret the competitiveness, along with qualitative data.

5.2 Hypothesis 2

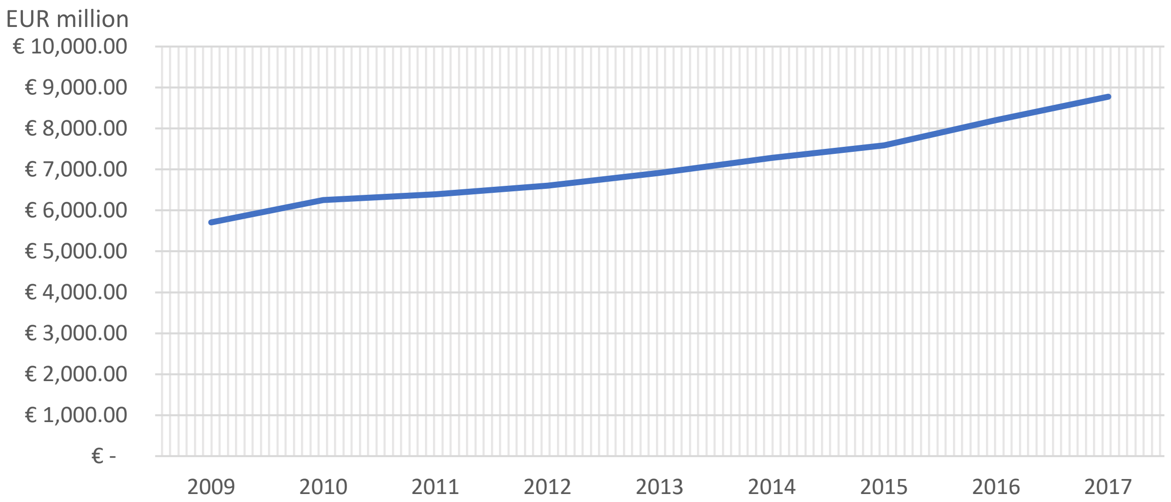
5.2.1 Europe

Figure 24 Patents filed by ESA



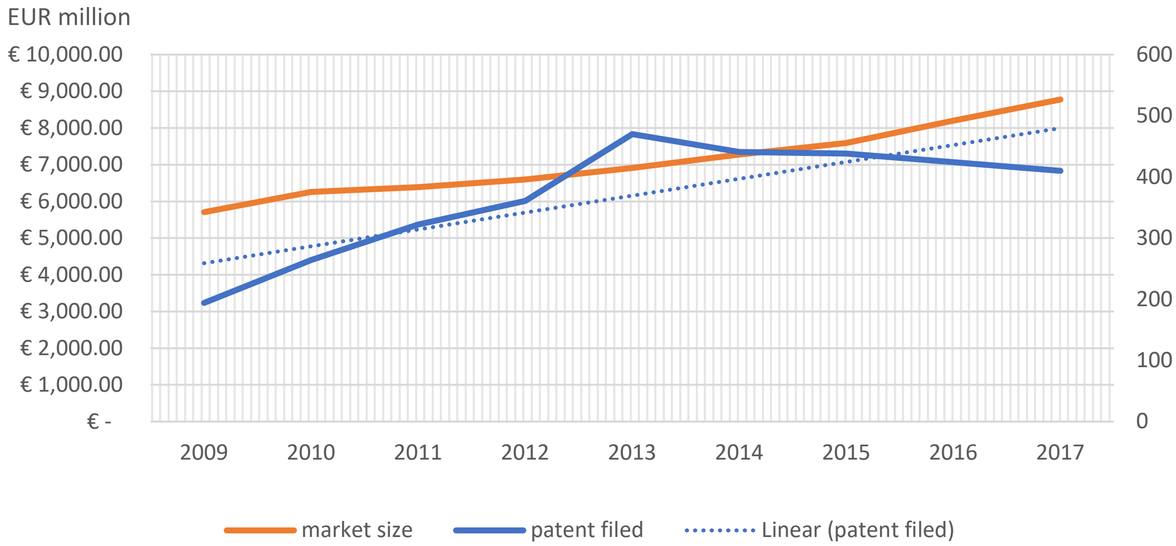
Source: European Patent Office (EPO)

Figure 25 European space industry final sales



Source: Aerospace and Defence Industries Association of Europe (ASD)

Figure 26 Comparison



Source: Author analysis

The trend line of patent filed is matched with the market size, from 2009 to 2013, when the number of patents filed, the market size grows simultaneously. Therefore, in European case, the hypothesis is accepted. It should be noted that when the number of patents filed decrease from 2013 to 2017, the market size continues to grow, which could lead to the fact that these two variables are uncorrelated.

However, the limit of data should be mentioned: in European case, the patent data is combined by data from four areas:

- Cosmonautics
- Quantum Technologies and Space
- Spaceborne Sensing and Green Applications
- Propulsion Systems for Space

The data may contain patents that are not aiding space industry, but other industries, for example, the “Spaceborne Sensing and Green Applications” has patents transferred because of the potential of circular economy application. Despite in hypothesis part, the author did mention that the patent that are used in other industry will lead to attention towards space industry.

There are general notices about using patent filed number as data:

1. The difference between patents cannot be seen in the figure, therefore the difference of economic value generated and the impact on current product/technology cannot measured.

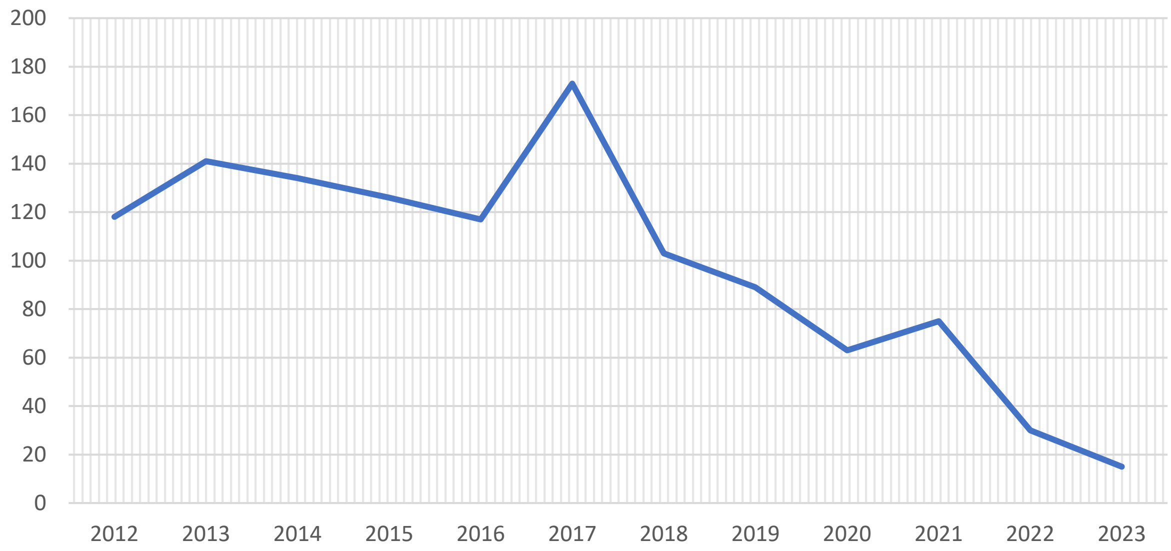
2. There is sometimes a significant time lag between the initial investment and the realised outcomes, sometimes several decades. Time lags are particularly relevant for space activities exacerbated by long technological development lead times and small markets with limited commercial opportunities [50].

3. The number of patents might be influenced by strategy of space agency; the number of patents might raise if there are ongoing innovative space programs.

4. The number of patents is not guaranteed to be linearly grow: the development of technology might be limited, and innovation rate is quite random.

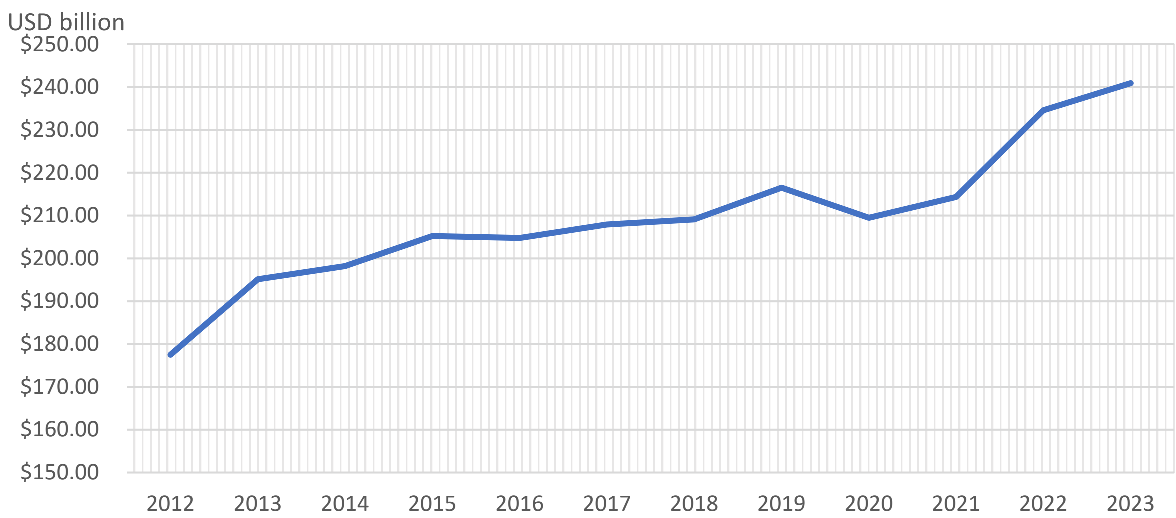
5.2.2 United Status

Figure 27 Patent filed by NASA



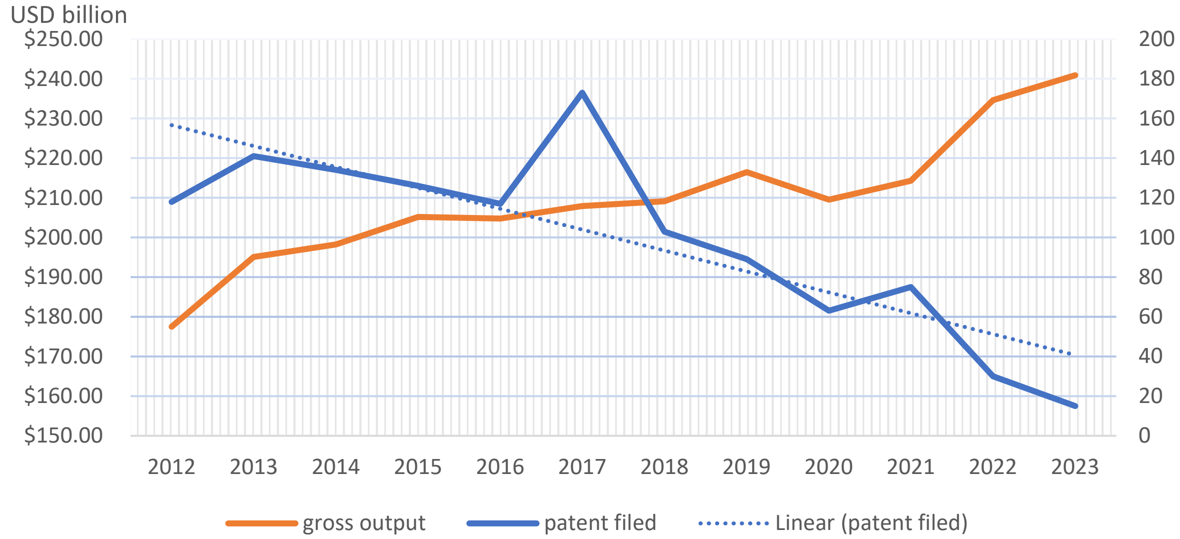
Source: https://insights.greyb.com/nasa-patents/

Figure 28 Gross output of U.S. space industry



Source: BEA

Figure 29 Comparison



Source: Author analysis

The number of patients increased in 2012-2013,2016-2017, 2020-2021. During three periods the gross output increase simultaneously, the hypothesis is accepted. It's worth mentioning that the patent filed trend line is downward sloping, and the gross output is upward sloping, while the space patent number decreases, the gross output keeps on increasing, showing the possibility that two variables are not correlated.

The patent data source did explain the reason of low amount of patent filed in 2022 and 2023, which is caused by the gap between application and publish [66], yet even if the data of 2022 and 2023 is neglected, the trend stays the same.

Despite the quality of data, there are some general notices on patents:

1. The difference between patents cannot be seen in the figure, therefore the difference of economic value generated and the impact on current product/technology cannot measured.

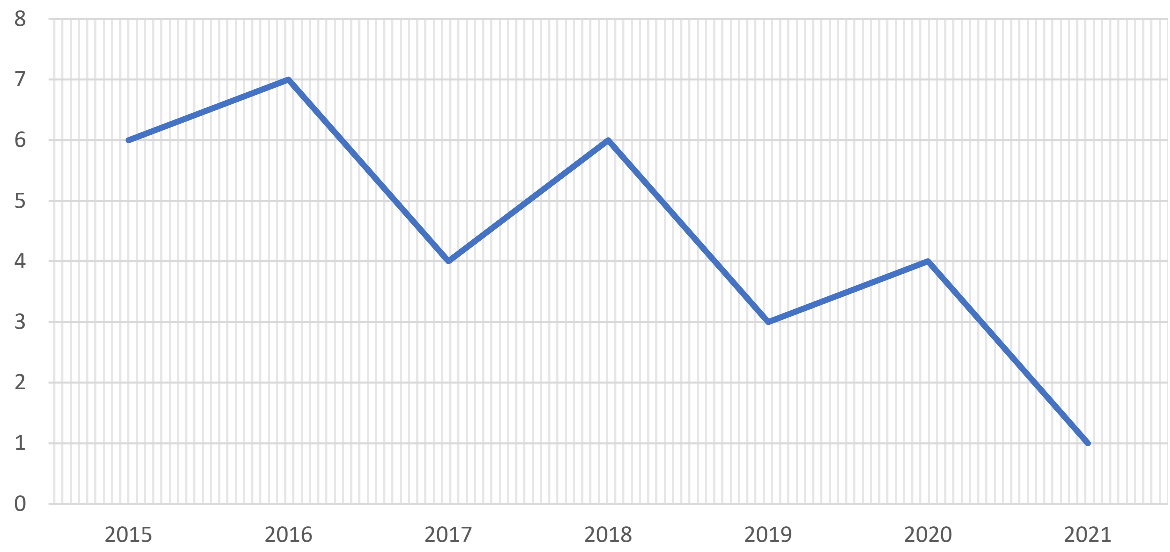
2. There is sometimes a significant time lag between the initial investment and the realised outcomes, sometimes several decades. Time lags are particularly relevant for space activities exacerbated by long technological development lead times and small markets with limited commercial opportunities [50].

3. The number of patents might be influenced by strategy of space agency; the number of patents might raise if there are ongoing innovative space programs.

4. The number of patents is not guaranteed to be linearly grow: the development of technology might be limited, and innovation rate is quite random.

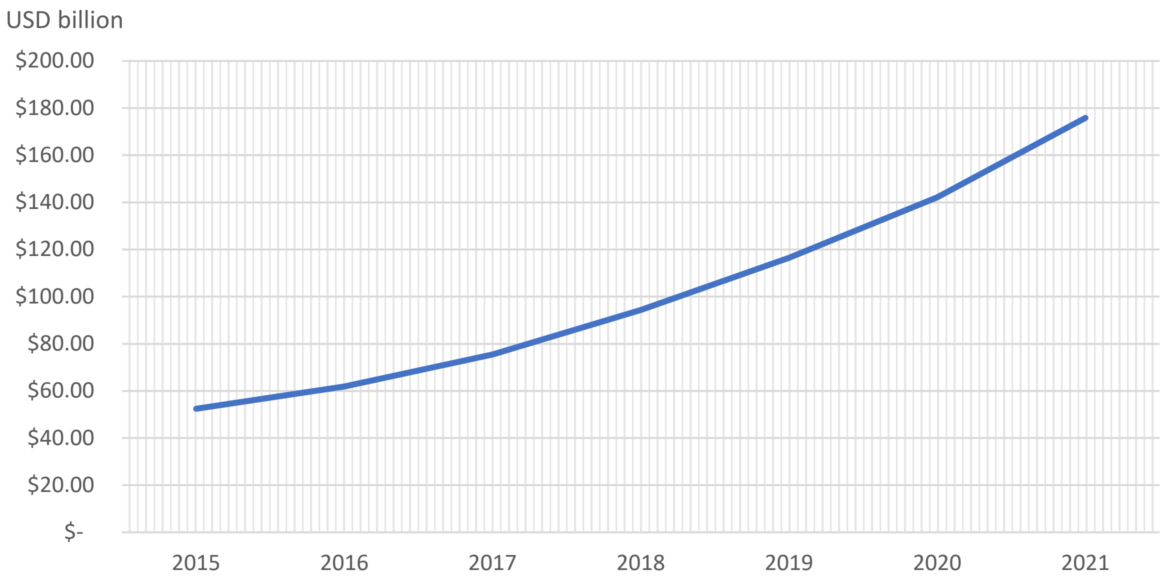
5.2.3 China

Figure 30 Number of TTCs Related Company



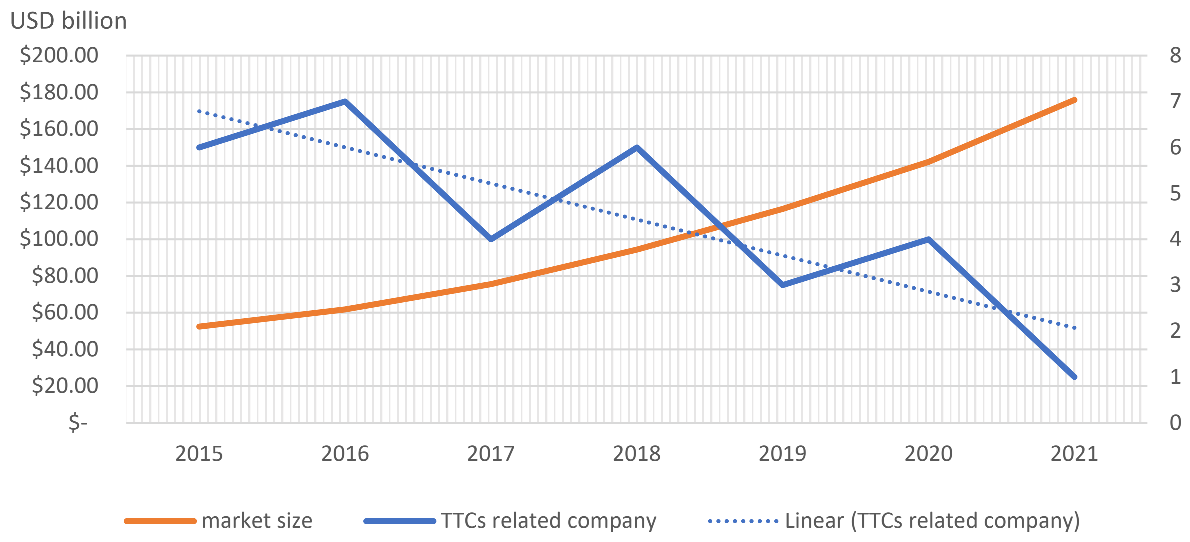
Source: Author count

Figure 31 Space industry market size



Source: CNSA

Figure 32 Comparison



Source: Author analysis

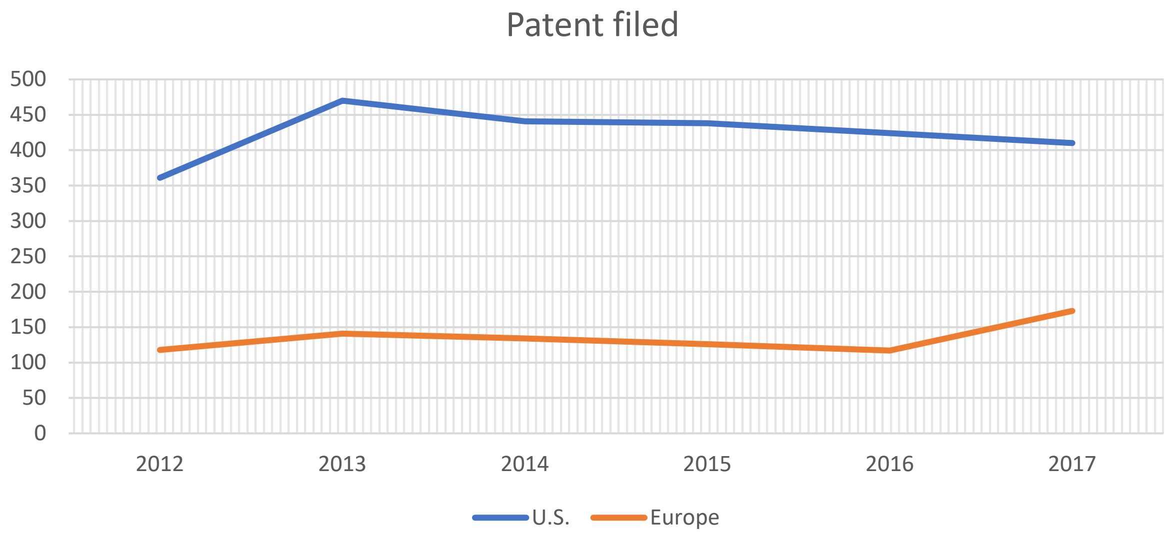
The number of patents filed increase in 2015-2016, 2017-2018, 2019-2020. The continuously increasing market size support the hypothesis, yet the fact that while number of patents decrease the market size still increases might illustrate the two variables are potentially not correlated.

It is worth mentioning that the data of Chinese TTCs is quite special, due to the situation that China is always relying solely on public sector in space industry, and private sector didn't start to grow until the policy published in 2014, the outcome is strong "technical transfer" representing by the establishment of space private companies: the know-how of private sector are mainly carried by people who previously worked in state-owned corporations and research institutions. In all the data, even the collaborative case is counted as labour mobility, since the companies related are established by the people who formally worked in space public sector. The Chinese technology transfer might be the most severe one, yet it is hard to present by data. The data is strongly decided by the establish time of company. The continuously upraising trend of industry might be the result of being in the initial period of industry expansion.

5.2.4 Comparative study

In study of H2, the hypothesis is supported in all cases. For EU and U.S. ESA has announced Technology Transfer Programme back in 2013, and Technology Transfer Programme Office is part of ESA. ESA utilize ESA Business Incubation Centres (ESA BICs) network to maximize the effect not only in European level, but in nation level [55]. In Italy level, Agenzia spaziale italiana (ASI) plays an important role as "technology broker" [67] NASA has set technical standards and has the resources to transfer technology to private aerospace companies to support their development. [24] In terms of number of patents filed, EU has absolute advantage as figure 33 shows, it might attributed to the strong ESA network and emphasis on TTCs as a methodology of boosting economy. Considering the compulsory requirement on the reveal of technological detail, it is understandable that the critical technology transfer may not conduct through public channel, which brings to the China case, despite the fact that China's private aerospace companies lack adequate support from national laws and policies in the current economic environment [3], yet the private sector in space industry is mainly built on the knowledge from public sector. Despite the hypothesis is supported, yet in all cases, the situation that the index of industry increases while number of patents filed decreases happened. This could be evidence support that there is no actual connection between patents filed and space industry growth.

Figure 33 Patent filed, EU and U.S. comparison



From data selection, aside the general problem listed below, the data from Europe, U.S. and China both has flaws. In Europe case, the data from Cosmonautics, Quantum Technologies and Space areas, Spaceborne Sensing and Green Applications and Propulsion Systems for Space are all counted; In U.S. case, there is a gap between patent application and publish; In China case, the number of TTCs directly link to the number of new established firm.

1. The difference between patents cannot be seen in the figure, therefore the difference of economic value generated and the impact on current product/technology cannot measured.

2. There is sometimes a significant time lag between the initial investment and the realised outcomes, sometimes several decades. Time lags are particularly relevant for space activities exacerbated by long technological development lead times and small markets with limited commercial opportunities [50].

3. The number of patents might be influenced by strategy of space agency; the number of patents might raise if there are ongoing innovative space programs.

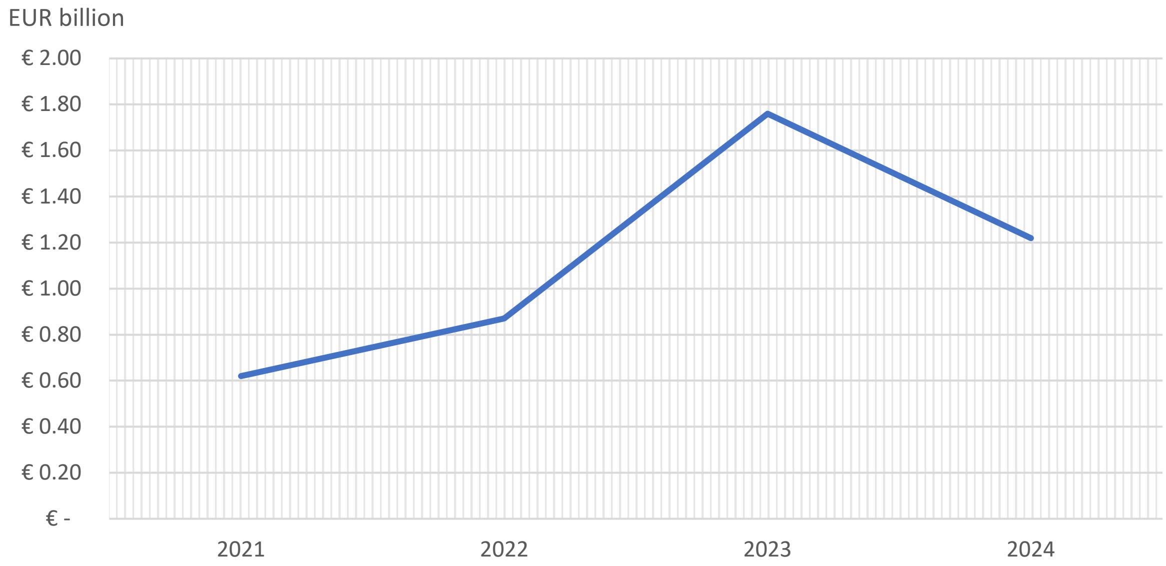
4. The number of patents is not guaranteed to be linearly grow: the development of technology might be limited, and innovation rate is quite random.

There are two limits of the H2 study. As mentioned in chapter 4, the patent data is only part of TTCs data, including other data could lead to difference. Another limitation is the patent transfer inside and outside the space industry cannot be categorized (China is exception yet only contain data inside industry) makes further study on specific effect impossible.

5.3 Hypothesis 3

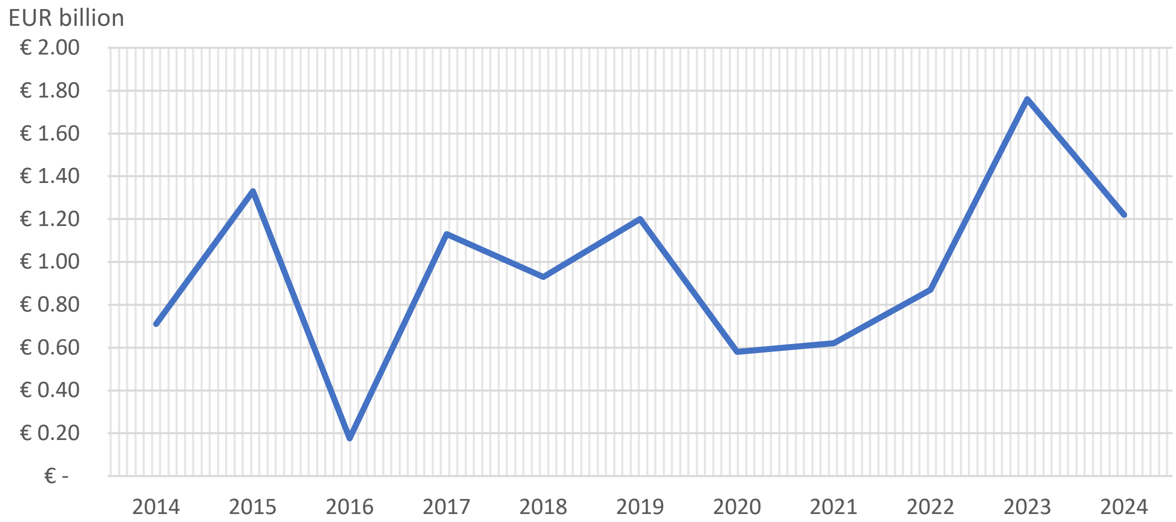
5.3.1 Europe

Figure 34 Europe spacecraft export 2021-2024



Source: Eurostat

Figure 35 Europe spacecraft export



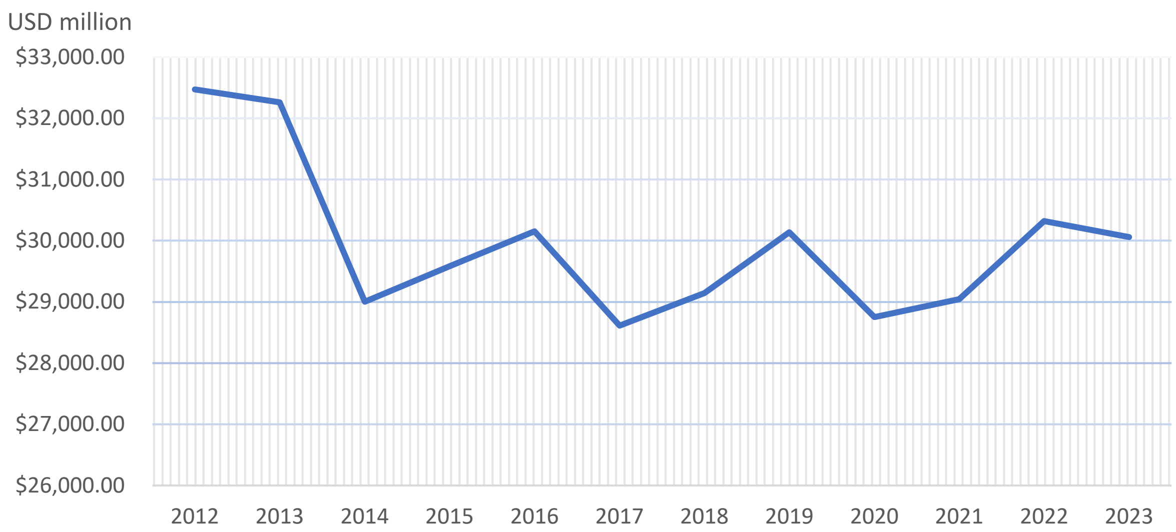
Source: Eurostat

The program “The Commercial Cargo Transportation Initiative (CCTI)” was launched in 2023 may. Unfortunately, there is no monthly data, therefore the specific growth trend after 2023 May is unknown. From figure 33 the growth rate from 2022-2023 is higher that 2021-2022 yet suffered from the drop during 2023-2024. In the figure 34 which contains data with larger time span, despite the decrease trend, the absolute value in 2024 is the second highest from 2015(2024 1.22 billion, 2019 1.20 billion), not to say in 2023 the export reaches the peak. However, the hypothesis is not supported due to the drop from 2023 to 2024.

The reason of reject might be caused by the lack of future data. Despite the program was announced in 2023, yet the contract was signed in 2024 may with Thales Alenia Space and The Exploration Company, the planned mission data is in 2028, therefore the effect on industry may not happen yet. The high point in 2023 might be caused by successful programs launched by ESA, which are Jupiter Icy Moons Explorer (JUICE), Euclid and Aeolus, the contract fulfilled of official programs may stimulate European spacecraft market. The analysis by other data, like market size or industry sales, is not possible due to the lack of 2024 data.

5.3.2 United Status

Figure 36 U.S. Computer and electronic products Gross output



Source: BEA

The gross output is clearly increased after the program announced in 2017, until 2019, the trend after might attributed to the influence of COVID-19 pandemic. The fluctuation of gross output is quite severe, to be specific on trends, the CAGR from 2012-2016, 2017-2023, and2015-2017, 2017-2019 will be analysed to study both long-term and short term, to mitigate the impact of pandemic and massive drop from 2013-2014.

Table 5 CAGR of different period

Time period	CAGR
2012-2017	-2.5%
2017-2023	0.7%
2015-2017	-0.17%
2017-2019	2.6%

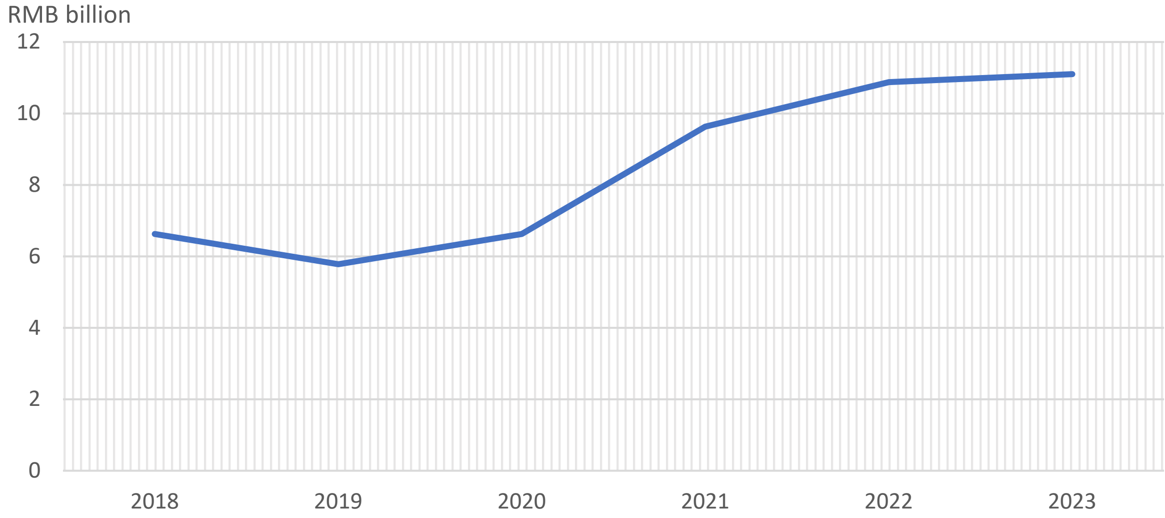
Source: Author analysis

Despite of small increase around 3% in both cases, yet the data support hypothesis, since CAGR from 2012 or 2015 to 2017 are both negative, the figure become positive after the program is announced after 2017, the growth of industry gross output is confirmed in all the conditions. Therefore, the hypothesis is supported. Yet, the data has natural flaw that it contains data other than satellite manufacturing, which may have significant impact on the result. The most detailed data in BEA database related to satellite industry is "Computer and electronic products", which not only represent satellite manufacturing, but also a set of related activities: "Computer and electronic products: Includes manufacturing of satellites; ground equipment; search, detection, navigation, and guidance systems (GPS/PNT equipment).

Despite the data support the hypothesis, it should be mentioned that the action of government to buy data from private satellite might not benefit the industry, but the companies with greater competence, for example, those who already have satellite constellations, the companies with higher funds, the companies with cost or technology advantage.

5.3.3 China

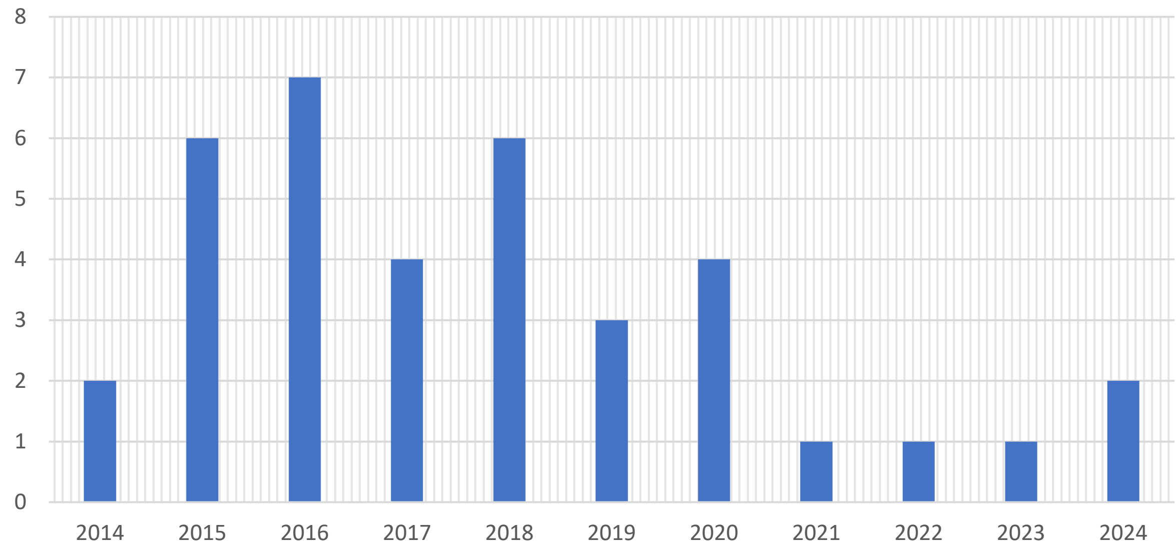
Figure 37 China launch vehicle market size



Source: Leadleo.com

The Chinese launch vehicle market size has grown fast after the policy implemented in 2019 and continue to grow in 2023. Based on the trend of Chinese launch vehicle market size, the hypothesis is accepted in Chinese case. However, there is one notice: The data in and before 2017 is untraceable, due to the fact that only 40% of Chinese launch vehicle are established before 2017, not to say the duration of launch vehicle development. The raise could also benefit from the early stage of the Chinese space industry.

Figure 38 Number of Launch vehicle company



Source: Author count

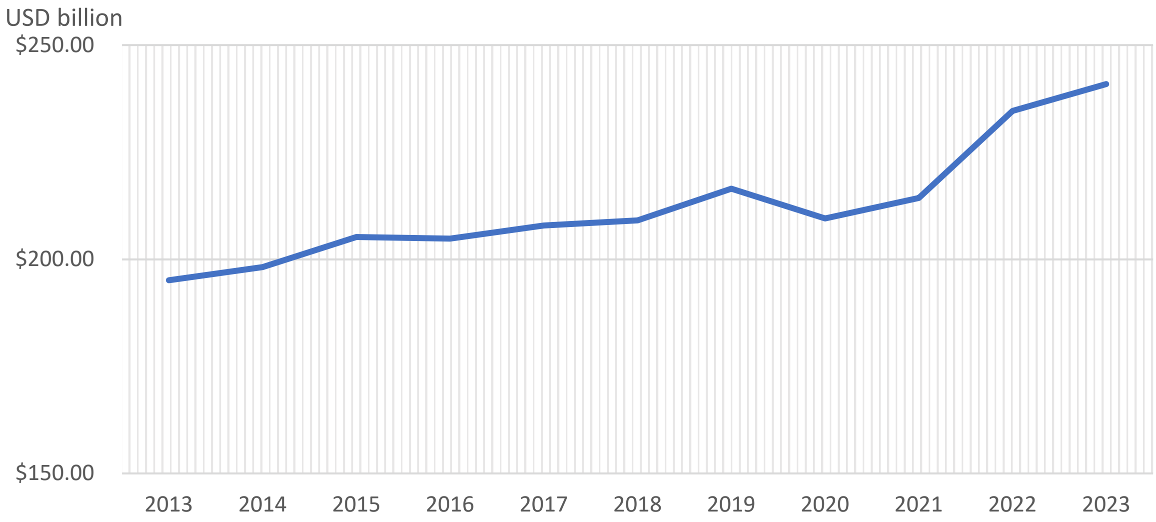
5.3.4 Case study: U.S. S.442 policy

The case study is added due to the previous common sense on the effect of COTS: in ESPI 2017 private sector report, the COTS program is mentioned as an innovative example to" have been highly effective and to have paved the way for new collaborative schemes between private and public actors in the space sector." [19] The influence from the success of COTS is undoubtful, yet here I propose a hypothesis: U.S. space industry didn't realize the benefit from the success of COTS, until 2017, when S.442 - National Aeronautics and Space Administration Transition Authorization Act of 2017 comes out, in which the request on NASA to utilize the experience of COTS is proposed [68].

To conduct study, I will use the data of U.S. space industry gross output from 2013-2017, 2017-2023, and U.S. domestic number of launches from 2013-2017, 2017 to 2023, to have a comparison on the impact of COTS and S.442 policy, due to the fact that

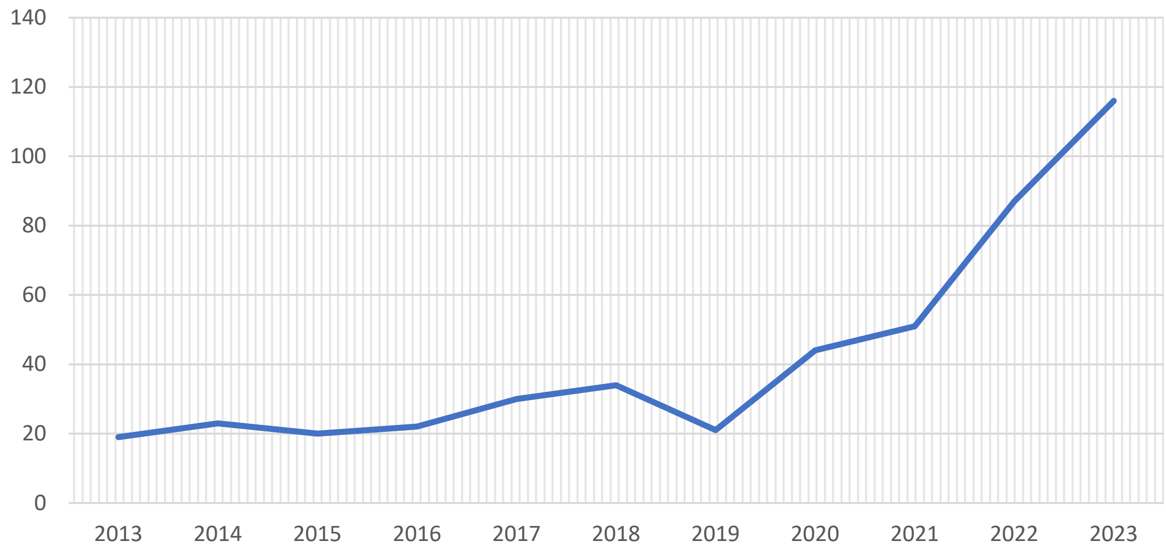
COTS is confirmed success in 2013, and the S.442 policy is published in 2017. The CAGR will be calculated to see the trend of growth rate. The U.S. domestic number of launches is an indicator on domestic space economy competence that shows the number of space program and payload launch (mainly satellite). Generally, the high launch number is a positive sign of space industry growth.

Figure 39 Gross output of U.S. space industry, 2013-2023



Source: BEA

Figure 40 U.S. launch number



Source: Wikipedia

Table 6 CAGR comparison

Gross output	2013-2017	1.60%
	2017-2023	2.49%
	2017-2019	2.20%
Launch Number	2013-2017	12.10%
	2017-2023	25.28%

Source: Author analysis

In terms of gross output, the trend of 2013-2017 is quiet flat, generally growing in a slow pace; after 2017, the gross output from 2017-2023 period kept increasing, yet it could be attributed to the raise from 2021-2022. To eliminate the interference, the

CAGR from 2017-2019 will be amended. From CAGR data, the CAGR of gross output is larger after 2017, yet the change is very small for only 0.89%. For the case from 2017-2019, the number decrease to 0.6%. The hypothesis is not supported by grossout figure due to the small variation.

For launch number, despite the lows in 2019, the number of launches did increase after 2017, and the growth rate get higher after 2021, which is proved by CAGR, which shows a fierce growth by 13.18%. The hypothesis is supported by the number of launches.

5.3.5 Comparative study

The hypothesis is rejected in EU case, accepted in U.S. and China case. In European case, the data has flaw since the CCTI program is conducted in 2023, and the data after 2023 is seldomly exist, the only available related data is export data, which may be influenced by externality, as discussed in H1 study. The future data may or may not support the fact that CCTI influence European space industry. In U.S. case, the hypothesis is supported, yet the data itself doesn't only contain satellite related data, therefore potential interference could exist. As for Chinese case, the direct-support policy has stimulated the growth of launch vehicle industry.

The policy or the program indicates the different phase and condition of U.S., EU and China space private sector: U.S. has strong private sector and the space policy that guided to utilize private competence early in 2017, EU is collaborating with private sector to accomplish innovative advanced program in 2023, China is still developing private sector in 2019.

For U.S. S.442 policy study, it shows that a successful case, especially an innovative successful case on public-private collaboration, could become an example that public sector wishes to copy or use as a guidance for the following policies or programs. Yet the success of a new public-private collaboration itself may not stimulate private sector growth, but the formal policy or program related that announced by public sector. In the real world, despite government announced to support space economy, the private sector generally tends to be conservative [24], until the formal action was taken. It might be explained by the high risk in space industry; especially private sector has limit risk-resistance. There are cases that company was selected by national program yet went bankruptcy (Rocketplane Kistler).

Chapter 6 Conclusion

The thesis tried to answer a question: "What factors influence public-private relationship in new space economy era, for Europe, United Status and China?". To answer the question, related literature was presented, following by proposing the initial idea on the answer, which was later transferred into hypothesis. For testing the hypothesis, the data and methodology is defined and collected. After testing hypothesis in EU, U.S. and China cases, the difference on "whether the hypothesis is accepted" is used as a tool to conduct the comparative study.

6.1 Findings

The public sector is still dominating the public-private relationship in new space economy.

Despite the development of private sector, the public sector still dominant the public-private relationship in terms of policy, economy, regulation and demand. As mentioned in study of H3, the Europe, United Status and China is on different phase of developing private sector, yet what the government do in all cases has certain impact on public-private relationship.

Despite the different public-private relationship, industry power and resource, the public sectors make the full use to develop space industry by exploring the most suitable method.

The public sector of United Status, Europe and China faces completely different situation: industry, resources, environment, political system and structure; during the study I found all the public sectors are using the best method they could apply to collaborate with private sector and facilitate the development. There has been some mistakes while trying innovative method, but because of the remedy the impact is not catastrophic.

Despite the goal is the same, yet Europe, United Status and China path is different.

The goal of United Status, Europe and China in space sector is developing an autonomous and powerful space sector that could benefit reflexively on economic value, employment rate, scientific and technological power, international competitiveness and possibility to explore space, yet the way of reaching the goal is completely different. For example, all three regions have their own satellite navigation system, Europe built it while utilizing PPP, United Status built it just using cost-plus and fixed-price contract, China instead, only used the public sector competence. A question was raised during the study: is there a best way for developing space economy and industr? Based on my reading, I don't think there is a best way, only the most suitable way. Among three regions, the space policy decision making system is different, the enforcement body is different, the private sector origin is different: Europe has Arianespace transfer from public to private; China has the employee from state-own enterprise starting their own business. Due to the historic reason, the phase of space economy is different. If considering the case of United Status, which is a great private sector that government can rely on as the ultimate phase, then Europe is on the second place while China is on third place: still finding a way to collaborate with private sector. Yet the United Status has set the goal to utilize and develop private sector from 80's and didn't realize until 2006.

The space industry continues to grow, so does the importance of private sector.

From the data of space industry index, all three regions are developing continuously. Yet the private sector has proven itself to be a great complement to public sector, for being a diverse, flexible and cost-effective choice. The Europe, United Status and China has created the suitable environment for private sector to grow, and the result is delightful: more private companies are establishing from time to time, announcing ambition goal and funded with great amount.

Despite the certain risk-tolerance attitude of private sector in space industry, the private sector heavily depends on public support.

The entrepreneur who enters space sector, especially those who enter space manufacturing industry, generally has spirit of exploration and risk-tolerance attitude. Yet during the growth of private sector, the public sector support is vital: the support can be direct investment, provide demand, collaboration, TTCs, policy support, act as intermediary. All the government support has certain spill-over effect, such as confirming the attitude of support space industry. As previously mentioned, the long-term development, high-risk characteristic in space industry is not the preference of private fund. However, there is exception: company with great fund and come from other industry: such as Geely company from Chinese automotive industry and Blue Origin from e-commerce sector. This kind of companies has better resistance on risk, higher tolerance on period of development, makes them self-sufficient.

The difference on policy, strategy, methodology, index used makes comparative study difficult due to lack of international common standard.

Using PPP as an example, despite categorized as PPP, yet the situation in United Status, Europe and China is completely different, makes the comparative study difficult. The index used by bureau of statistics is different as well. It is understandable that the action and index choice is different, since for the development of space industry, comparing with past and be better is the right mindset, not comparing with others; Yet it does make the comparative study more difficult to conduct. However, it’s delightful to see many authors, such as OECD, are trying to provide common standard in multiple areas of space industry.

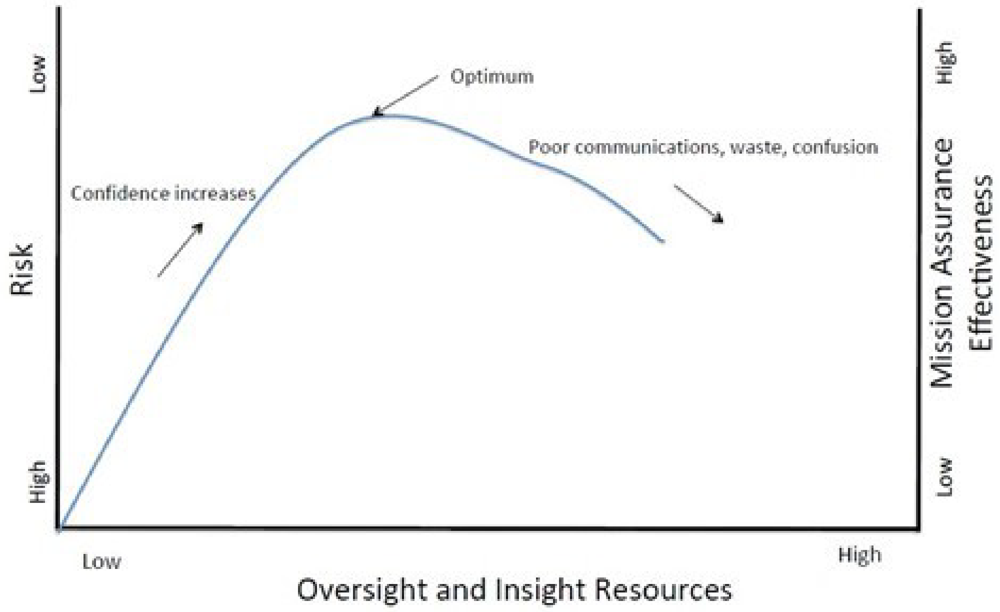
6.2 Limitations and potential research

Other than limitations from comparative study in chapter 5, there are some limitations. The thesis didn’t include the market detail: such as market concentration and potential monopoly situation. The trend of space industry showed in the figure is not studied thoroughly. The detail on policy enforcement, government supervision and intervention are missed. The hypothesis is constructed in the positive way.

There are potential study topics that excluded from the thesis because of the lack of data and incompatible of methodology, yet could be studied at future:

- The difference of forms of government and structure of agency.
- The impact from domestic space industry to public sector decision-making.
- The balance between government intervein. For example, further increases in government supervisors and assurance staff can cause confusion, unnecessary work, ambiguous accountability, and turmoil to the point that mission assurance effectiveness actually reverses, and the government finds itself spending more money, getting less product effectiveness, and decreasing safety. [69], as the figure shows.

Figure 41 Oversight and Insight Resources and effectiveness



6.3 Final thoughts

After the study, the public-private relationship reminds me of an illustration used in space economy literature, which draws a scene that two dancers performing pas de deux. The two sectors are so interdependent with the public sector takes the helm. The public-private relationship will continue to evolve with the growth of private sector and the constantly adjust public sector strategy.

Bibliography

[1] U. a. Jolly, “A New Landscape for space applications,” OECD, 2022.

[2] W. Peeters, “Evolution of the Space Economy: Government Space to,” *Astropolitics*, 2022.

[3] OECD, “Evolving public-private relations in the space sector: Lessons learned for the post-COVID-19 era,” *OECD SCIENCE, TECHNOLOGY AND INDUSTRY*, 2021.

[4] T. L. Xin He, “Government-business Relations:,” *International Conference on Logistics Engineering, Management and Computer Science*, pp. 237-241, 2015.

[5] H.-K. K. M. O.-F. Masahiko Aoki, in *The role of government in East Asian economic development*, Oxford: Clarendon Press, 1996.

[6] J. Zysman, in *Governments, markets, and growth: financial systems and the politics of industrial change*, Cornell University Press, 1983.

[7] R. Lehne, in *Government and business: American political economy in comparative perspective*, Shanghai, Fudan University Press, 2007.

[8] R. Lehne, in *Government and Business: American Political*, SAGE Publications, Inc, 2017.

[9] J. Zysman, Governments, Markets, and Growth, Cornell University Press, 1983.

[10] Deloitte, “Revisiting the government’s role in catalysing modern innovation”.

[11] J. Kurbonov, “Public and Private Sector Relations for Economic Growth: Evidence from Uzbekistan,” *European Journal of Business and Management*, vol. 8, pp. 186-189, 2016.

[12] G. L. Martin, “EVOLUTION OF GOVERNMENT AND INDUSTRIAL PARTNERSHIPS TO OPEN THE SPACE FRONTIER”.

[13] E. S. P. Institute, “ESPI Report 70 - Evolution of the Role of Space Agencies - Full Repor,” Vienna, 2019.

[14] J. A. and, MASTERING SPACE, Routledge, 1995.

[15] R. K. M. Consulting, "International Comparison of Approaches to Space Cluster Development," 2021.

[16] A. Sommariva, The Political Economy of the Space Age, Vernon Press, 2018.

[17] P. Barbaroux, "THE METAMORPHOSIS OF THE WORLD SPACE ECONOMY:INVESTIGATING GLOBAL TRENDS AND NATIONAL DIFFERENCES AMONG MAJOR SPACE NATIONS," *Journal of Innovation Economics&Management,* pp. 9-35, 2016.

[18] E. G. J. S. J. V. R. Z. G. P. Fabrizio Botti, "The Geopolitics of Space," Istituto Affari Internazionali, Rome, 2023.

[19] E. S. P. Institute, "The Rise of Private Actors in the Space Sector," 2017.

[20] C. P. H. M. H. A. G. M. M. P. F. Mariel Borowitz, "A Technical Comparison of the Public SSA Services in the United States and the European".

[21] E. T. JEAN-FRÉDÉRIC MORIN, "The Empire Strikes Back: Comparing US and China's Structural Power in Outer Space," *Global Studies Quarterly,* pp. 1-13, 2023.

[22] G. A. E. W. a. I. E. Mark Stokes, "China's Space and Counterspace Capabilities and Activities," 2020.

[23] N. Goswami, "China in Space: Ambitions and Possible Conflict," *Strategic Studies Quarterly,* vol. 12, pp. 74-97, 2018.

[24] NASA, "Commercial Orbital Transportation Services: A New Era in Spaceflight," 2014.

[25] [Online]. Available: https://en.wikipedia.org/wiki/Space_policy_of_the_United_States.

[26] M. M. M. E. C. S. M. R. Troy Thomas, "Strategies for Space Agency Success in a Commercial Era," BCG, 2024.

[27] NASA, "State of NASA procurement report: Fiscal year 2022 in review," 2023.

[28] D. o. t. E. U. t. t. U. S. Status, "The European Union: A Guide for Americans,"

2016.

[29] E. B. I. Centres, “The largest incubation network in Europe,” [Online]. Available: https://commercialisation.esa.int/esa-business-incubation-centres/.

[30] J. Wörner, “Global Space Economic Workshops,” 2017.

[31] CNSA, “Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment,” 2014.

[32] CNSA, “Notice of State Administration of Science, Technology and Industry for National Defense (SASTIND) and the Central Military Commission Government agency(CMC) Equipment Development Department on Promoting the Orderly Development of Commercial Launch Vehicle,” 2019.

[33] OECD, “The OECD Handbook on Measuring the Space Economy,” 2022.

[34] BryceTech, “Start-Up Space 2022: Update on investment in commercial space ventures,” 2022.

[35] OECD, “Space economy investment trends: OECD insights for attracting high-quality funding,” 2024.

[36] D. Machado, “Quantitative indicators for high-risk/high-reward research,” *OECD Science, Technology and Industry Working Papers*, 2021.

[37] J. a. S. W. Haskel, Capitalism without Capital, Princeton University Press, 2017.

[38] D. Machado, “Quantitative indicators for high-risk/high-reward research,” OECD, Paris, 2021.

[39] [Online]. Available: https://www.euroconsultitalia.it/.

[40] Eurospace, “Facts and Figures 2022: The European space industry in 2021,” 2022.

[41] U. D. o. Commerce, “US Space Industry ’Deep Dive’; Assessment: Small Businesses in the Space Industrial Base,” 2013.

[42] NASA, “Committee on Capitalizing on Science, Technology, and Innovation: An Assessment of the Small Business Innovation Research Program”.

[43] OECD, "Recent trends in SME and entrepreneurship financing," *Financing SMEs and Entrepreneurs 2022: An OECD Scoreboard,* 2022.

[44] K. B. L. P. John Thompson, "Alternative Financing Instruments for SMEs and Entrepreneurs: The case of capital market finance," *OECD SME and Entrepreneurship Papers.*

[45] OECD, "Financing SMEs and Entrepreneurs 2013: An OECD Scoreboard," 2013.

[46] P. B. a. I. Hawkesworth, "How To Attain Value for Money: Comparing PPP and Traditional Infrastructure Public Procurement," *OECD Journal on Budgeting,* 2021.

[47] M. J. Kim, "Coherence to Choices: Informing Decisions on Public-Private Partnerships in the Space Sector," 2023.

[48] OECD, "Competition Issues in Public-Private Partnerships," 2020.

[49] B. a. Vidal, "The Implementation of a Public-Private Partnership for Galileo: Comparison of Galileo and Skynet 5 with Other Projects".

[50] OECD, "SPACE TECHNOLOGY TRANSFERS AND THEIR COMMERCIALISATION," 2021.

[51] OECD, "Space economy in Figures," 2019.

[52] J. J. S. Lester M. Salamon, "Economic Power and Political Influence: The Impact of Industry Structure on Public Policy," *American Political Science Review,* vol. 71, no. 3, pp. 1026 - 1043, 1997.

[53] J. Y. Lin, "New structural economics: A framework of studying government and economics," *Journal of Government and Economics,* vol. 2, 2021.

[54] Y. W. Li Song, "Financial subsidies, tax incentives and technological innovation in China's integrated circuit industry," *Journal of Innovation & Knowledge,* vol. 8, no. 3, 2023.

[55] B. Westmore, "Policy incentives for private innovation and maximising the returns," *Economic Studies,* 2014.

[56] S. Tkatchova, "Competitiveness of Space Industry," *Space-Based Technologies and*

Commercialized Development: Economic Implications and Benefits, p. 20, 2011.

[57] U. S. W. House, "National Space Policy of the United States of America," 2010.

[58] ESA, "Competition: developing Europe's space cargo return service," 2023. [Online]. Available: https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Competition_developing_Europe_s_space_cargo_return_service.

[59] ESA, "Commercial Cargo Transportation Initiative: ESA commerciziation gateway," 2023. [Online]. Available: https://commercialisation.esa.int/opportunities/commercial-cargo-transportation-initiative/.

[60] NASA, "Commercial Satellite Data Acquisition Program," [Online]. Available: https://www.earthdata.nasa.gov/about/csda.

[61] N. P. K. B. James Stegeman, "HOW PUBLIC PRIVATE PARTNERSHIPS ENABLE NASA FUTURE SPACE COMMUNICATION NEEDS," NASA, 2018.

[62] NASA, "Public-Private Partnerships for Space Capability Development," 2014.

[63] Wikipedia, "Falcon 9," [Online]. Available: https://en.wikipedia.org/wiki/Falcon_9.

[64] OECD, "The Space Economy in Figures," 2024.

[65] "Futron's 2014 Space Competitive Index".

[66] [Online]. Available: https://insights.greyb.com/nasa-patents/.

[67] [Online]. Available: https://insights.greyb.com/nasa-patents/.

[68] "S.442 National Aeronautics and Space Administration Transition Authorization Act of 2017," [Online].

[69] V. A. J. W. Dyer, "AEROSPACE SAFETY ADVISORY PANEL ANNUAL REPORT FOR 2013".

[70] 1, 20919. [Online].

[71] McKinsey&Company, "How business interacts with government," 2009.