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Analysis of space agencies' technology portfolios

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Abstract

This study provides a comprehensive analysis of the temporal and comparative trends of the upstream and downstream portfolios of space companies. The research sectors initially skewed towards the upstream sector. However, since 2000, the downstream sector has seen an exponential surge, becoming dominant. Most space companies studied show a higher cosine similarity with the downstream sector. Interestingly, a shift towards the upstream sector has been observed during 2020 - 2023, likely due to the rise of private space companies that rely on the support of national and international space agencies.

In a broader context, the study reveals interesting dynamics when comparing the strategic focus of different space entities. There are instances of both competition and collaboration, with some entities displaying similar strategic objectives, while others show divergent priorities. Some entities prioritize upstream technologies, such as launch vehicles and ground stations, while others lean towards downstream technologies, including Earth observation and space science. These differences can be attributed to varying technological priorities, strategic objectives, and resource availability. The research also uncovers a noticeable disparity between certain entities, suggesting potential for collaboration and specialization in distinct technological areas. This could pave the way for strong alliances in research and project development, leading to mutual benefits and advancements in space technology.

In conclusion, the study anticipates that space companies will increasingly concentrate their efforts on the development of upstream technologies. They are expected to make significant investments to secure cutting-edge technology, which can then be supplied to private companies. These private entities, in turn, can leverage this technology to deliver large-scale services to terrestrial populations. This strategy allows the space entities to maintain their technological edge in critical areas of international balance, while also opening up avenues for substantial returns.

Introduction

The space industry, with its vast potential and strategic importance, has been a subject of interest for researchers and practitioners alike. The industry's dichotomy, characterized by the upstream and downstream sectors, presents a unique landscape for exploration. This work delves into the temporal and comparative trends of these sectors, providing a comprehensive analysis of the portfolios of various space companies.

The genesis of this research is deeply rooted in the emergence of the new space economy. The advent of this economy has revolutionized the dynamics of the space industry, giving rise to a multitude of private entities that are actively participating in space exploration and exploitation. This shift from a government-dominated landscape to a more diverse and competitive arena has led to a surge in innovation and investment. The new space economy has not only expanded the boundaries of the industry but also introduced a complex interplay between the upstream and downstream sectors. This research aims to unravel these complexities, offering a comprehensive analysis of the portfolios of various space companies in the context of this rapidly evolving space economy. The insights derived from this study could potentially guide strategic decision-making, fostering growth and sustainability in the new space economy.

The study traces the evolution of the industry, highlighting the initial dominance of the upstream sector and the subsequent surge in the downstream sector since the turn of the millennium. It further explores the strategic focus of different space entities, uncovering instances of both competition and collaboration. The paper also anticipates future trends, predicting a renewed focus on the development of upstream technologies by space companies.

1. Introduction on space agencies

1.1 Definition and purpose of space agencies

Space agencies, often operate in the fields of human space exploration, aeronautics, and space transportation. They refer to government agencies and international organizations whose primary purpose is to develop and utilize the resources in space. These agencies consist of engineers, scientists, and researchers who are responsible for planning and designing space exploration missions. The role of a space agency is to implement and manage space programs, as well as promote science and technology research in space (Space Connect , 2022). Government space agency organizations are established with objectives that include national prestige, exploitation of remote sensing information, communications, education, and economic development. These agencies tend to be civil in nature (vs military) and serve to advance the benefits of exploitation and/or exploration of space. This can be done by sending satellites into orbit around Earth and beyond, which collect data about how our planet works, how it changes over time, and how it interacts with other planets and objects in our solar system. According to data from April 2022, there are 5,465 operational artificial satellites in Earth's orbit. Approximately 3,433 of these satellites belong to the United States (Statista, 2023). Space agencies are also responsible for building spacecraft and other tools that help scientists gather data from outer space. Planetary exploration is a cornerstone of space agency activities. NASA's Mars rovers, including Curiosity and Perseverance, are prime examples of missions that acquire an extensive volume of data. These rovers are equipped with an array of scientific instruments that capture images, analyse soil and rock compositions, and assess the Martian environment.

Moreover, space agencies engage in international collaborations to enhance the impact and accessibility of their data. The European Space Agency’s Copernicus program exemplifies this approach by providing open access to a comprehensive repository of

Earth observation data. These datasets find application in a wide range of fields including environmental monitoring, urban planning, agriculture, and disaster response.

1.2 Historical context

The journey of humans into space began on October 4, 1957, when the Union of Soviet Socialist Republics (U.S.S.R.) launched Sputnik, the first man-made satellite to orbit Earth. This event took place during the Cold War, a period of political tension between the Soviet Union and the United States. The two superpowers were in a race to develop intercontinental ballistic missiles (ICBMs), which could carry nuclear weapons across continents. Sergei Korolev, a rocket designer from the U.S.S.R., had developed the first ICBM, a rocket named R7, marking the beginning of the space race.

The launch of Sputnik, atop an R7 rocket, escalated this competition. Sputnik was equipped with a radio transmitter that emitted beeps which could be detected on Earth as it orbited our planet every 96 minutes. This evidence of its presence in orbit was heard by people worldwide. The realization that the U.S.S.R. had surpassed U.S. technologies, potentially posing a threat to Americans, caused concern in the United States. A month later, on November 3, 1957, the Soviets launched Sputnik II, which carried a living creature, a dog named Laika, achieving another significant milestone in space exploration. Before the launch of Sputnik, the United States had been developing its own satellite-launching capabilities. After two unsuccessful attempts, the United States successfully launched a satellite named Explorer on January 31, 1958. The team responsible for this achievement was primarily composed of German rocket engineers who had previously developed ballistic missiles for Nazi Germany. Explorer carried several scientific instruments into space for conducting experiments. One such instrument was a Geiger counter for detecting cosmic rays. This experiment was operated by researcher James Van Allen and led to the discovery of what are now known as the Van Allen radiation belts around Earth. In 1958, all space exploration activities in the United States were consolidated into a new government agency called the National Aeronautics and Space Administration (NASA). When NASA began operations in October 1958, it absorbed several other research and military facilities including what was formerly known as the National Advisory Committee for Aeronautics (NACA) and the Army Ballistic Missile Agency (the Redstone Arsenal) in Huntsville.

The first human to travel into space was Yuri Gagarin, a Soviet cosmonaut who orbited Earth on April 12, 1961, on a flight that lasted 108 minutes. Just over three weeks later, NASA launched astronaut Alan Shepard into space on a suborbital trajectory—a flight that reaches space but does not complete an orbit around Earth. Three weeks after that, on May 25, President John F. Kennedy set an ambitious goal for the United States: "I believe that this nation should commit itself to achieving the goal before this decade is out of landing a man on the moon and returning him safely to Earth." In addition to launching the first artificial satellite, dog and human into space, the Soviet Union achieved other significant milestones in space exploration ahead of the United States. These included Luna 2 becoming the first human-made object to impact the Moon in 1959. During the 1960s NASA made strides towards President Kennedy's goal of landing a human on the moon through Project Gemini where astronauts tested technology needed for future moon flights and their ability to endure extended periods in spaceflight. Project Gemini was succeeded by Project Apollo which took astronauts into lunar orbit and onto its surface between 1968 and 1972. In 1969 Apollo11 sent Neil Armstrong and Buzz Aldrin to become the first humans to walk on its surface while Michael Collins orbited above in Apollo11's command module. During these missions astronauts collected samples of lunar rocks and dust which scientists continue to study today to learn more about our moon. During this time NASA also launched a series of probes called Mariner which studied Venus Mars and Mercury.

The end of the Cold War led to an era of increased international collaboration in space exploration. The International Space Station (ISS) represents a prominent example of international cooperation, with agencies such as NASA, ESA, Roscosmos, JAXA, and CSA participating. The ISS has been continuously inhabited since 2000 and serves as a space laboratory for scientific research, technological experiments, and fostering diplomacy. In recent years, space agencies have shifted their focus to joint human and robotic missions, near-Earth asteroids, Mars and destinations beyond our own solar system. Robotic missions to explore other planets, such as the Mars rovers and spacecraft like the Voyager probes, have expanded our knowledge of the solar system and beyond. In 2012, the Curiosity rover landed on Mars, embarking on a mission to investigate the planet's geological history and habitability.

1.3 Global landscape

The global landscape of space agencies is a complex and dynamic arena that reflects a multitude of nations and organizations engaging in space exploration, research, and technological development. Each space agency has a unique mission and scope, often aligned with the goals and interests of their respective countries or consortiums. Here, we will delve into the major space agencies globally and elucidate their primary missions and key activities.

1.3.1 National space agencies

The National Aeronautics and Space Administration (NASA) was established in 1958 with the purpose of advancing human knowledge through scientific discoveries in space. NASA's mission is to explore the unknown in air and space, innovate for the benefit of humanity, and inspire the world through discovery. This mission is aligned with four major strategic goals: expanding human knowledge through new scientific discoveries, extending human presence deeper into space and to the Moon for sustainable long-term exploration and utilization, addressing national challenges, and catalyzing economic growth (NASA, 2023). In terms of budget, NASA's funding comes from the annual federal budget passed by the United States Congress. For fiscal year 2022, NASA received a total of $24 billion. This represented a growth of 3.3% over the previous year. Since its inception, the United States has spent nearly US$650 billion (in nominal dollars) on NASA. NASA's future plans focus on human exploration, technology, and science. The agency plans to return to the Moon to learn more about what it will take to support human exploration to Mars and beyond1. This includes landing astronauts on the lunar South Pole by 2024.

The European Space Agency (ESA) was established in 1975 from the merger of the European Launcher Development Organisation (ELDO) and the European Space Research Organisation (ESRO), both established in 1964. ESA is responsible for setting a unified space and related industrial policy, recommending space objectives to the member states, and integrating national programs like satellite development, into the European program as much as possible. ESA's mission is to ensure that investment in space continues to deliver benefits to the citizens of Europe and the world. It aims to push the frontiers of science and technology, provide services to the public and private sector, and promote European industries (ESA, 2023). ESA works to support the United Nations' Sustainable Development Goals (SDGs) as part of its commitment to improve life on Earth while making scientific and engineering breakthroughs in space. In terms of budget, ESA's budget for 2021 was €7.15 billion (Statista, 2023). ESA's activities fall into two categories – 'mandatory' and 'optional'. The 'mandatory' activities include the agency's basic activities such as studies on future projects, technology research, shared technical investments, information systems and training programmes. The 'optional' programmes cover areas such as Earth observation, telecommunications, satellite navigation and space transportation.

The Russian State Space Corporation (RFSA), commonly known as **Roscosmos,** is a state corporation of the Russian Federation responsible for space flights, cosmonautics programs, and aerospace research. The agency's primary goals include conducting research on space legislation and sectoral policies, drafting laws, developing aerospace sector plans, and defining sector objectives. It is also responsible for organizing, verifying, and approving significant national research projects, as well as supervising and coordinating research. Furthermore, it manages international exchanges and cooperation in the space sector. In terms of budget, Roscosmos had an annual budget of approximately $1.92 billion in 2021 (Jamestown, 2023). This budget supports various activities including policy development and execution of state space programs.

The China National Space Administration (CNSA) is the national space agency of the People's Republic of China. It was established on April 4, 1993, following the division of the Ministry of Aerospace Industry into CNSA and the China Aerospace Corporation (ICAS, 2021). CNSA's primary goals include conducting research on space legislation and sectoral policies, drafting laws, developing aerospace sector plans, and defining sector objectives. It is also responsible for organizing, verifying, and approving significant national research projects, as well as supervising and coordinating research. Furthermore, it manages international exchanges and cooperation in the space sector. In terms of budget, CNSA had an annual budget of approximately $11.94 billion in 2022. This budget supports various activities including policy development and execution of state space programs. The CNSA has outlined four primary objectives: the launch of its inaugural Mars probe and orbiter in 2020; a return mission to Mars for exploration and sample collection; an expedition to an asteroid; and the formulation of a plan for Jupiter exploration. In addition to these, the CNSA continues to prioritize lunar exploration, manned spaceflight, and the development of "high-resolution, targeted observation and survey systems". By 2030, China aims to establish itself as a formidable power in space exploration. As for its roadmap, CNSA has been involved in several significant projects. One such project is the International Lunar Research Station (ILRS), a planned lunar base currently being led by Roscosmos and CNSA. The ILRS will serve as a comprehensive scientific experiment base built on the lunar surface or in lunar orbit that can carry out multi-disciplinary and multi-objective scientific activities including exploration and utilization, lunar-based observation, basic scientific experiment and technical verification, and long-term autonomous operation (ICAS, 2021).

The Japan Aerospace Exploration Agency (JAXA) is the national air and space agency of Japan, formed on October 1, 2003, through the merger of three previously independent organizations. JAXA is responsible for research, technology development, and the launch of satellites into orbit. It is also involved in more advanced missions such as asteroid exploration and possible human exploration of the Moon. Its motto is "One JAXA" and its corporate slogan is "Explore to Realize". In terms of budget, JAXA had a budget of around $4.9 billion (Statista, 2023). JAXA's management philosophy is to realize a safe and affluent society using space and the sky. With broad wisdom, it aims to create fruitful results of leading technological developments and deliver this to human society. Its code of conduct includes bringing joy and wonder to people through the evolution of everyday life in human society, setting aspirations high and keeping a creative mind to overcome difficulties, and acting with responsibility and pride to meet the confidence and expectation of society (JAXA, 2023).

The Indian Space Research Organisation (ISRO) is the space agency of India, involved in science, engineering, and technology to harvest the benefits of space and its applications (ISRO, 2023). Established in November 1969, ISRO is the implementation arm of the Government of India's Department of Space (DOS). ISRO's primary goals include conducting research on space legislation and sectoral policies, drafting laws, developing aerospace sector plans, and defining sector objectives. It is also responsible for organizing, verifying, and approving significant national research projects, as well as supervising and coordinating research. Furthermore, it manages international exchanges and cooperation in the space sector. In terms of budget, ISRO has an annual budget of approximately $1.5 billion in 2023/2024 (ISRO, 2023). This budget supports various activities including policy development and execution of state space programs.

The Canadian Space Agency (CSA) is a government agency responsible for managing all of Canada's civil space-related activities, including space research and development, satellite communications, space science, Earth observation, and human spaceflight. The CSA's mandate is to promote the peaceful use and development of space, to advance the knowledge of space through science, and to ensure that space science and technology provide social and economic benefits for Canadians (Canadian Space Agency, 2022). For the fiscal year 2022-23, the CSA has set its planned spending at $388.3 million, which represents a 3.9% decrease in planned spending compared to the previous year (SpaceQ, 2022). This budget allocation reflects the CSA's commitment to its strategic goals and targets for the year. In terms of targets for 2022, the CSA aims to align its Departmental Results Framework (DRF) results with the Space Strategy for Canada. A new departmental result "Canada remains a leading space-faring nation" has been added to support the core responsibility of Canada in Space (Canadian Space Agency, 2022).

The Centre National d'Etudes Spatiales (CNES) is the French national space agency, which was established in 1961. It is administratively a "public administration with industrial and commercial purpose" and is headquartered in central Paris. The agency operates under the supervision of the French Ministries of Defence and Research. It operates from the Toulouse Space Centre and the Guiana Space Centre, but also has payloads launched from space centres operated by other countries. CNES concentrates on five areas: Access to space, Civil applications of space, Sustainable development, Science and technology research, Security and defence. It is Europe's largest and most important national organization of its type (CNES, 2023). In terms of budget for 2022, CNES has an allocation of €2.566 billion. This includes a contribution to the European Space Agency of €1.184 billion, a national program budget of €740 million, an investment program for the future of €29 million, a recovery plan of €55 million, and own resources of €558 million (CNES, 2023).

The Italian Space Agency (ASI) is a national public entity with the task of promoting, developing, and disseminating scientific and technological research applied to the space and aerospace field. The ASI's target is to promote scientific and technological research in the field of space and aerospace. It aims to develop innovative services while pursuing excellence. The agency coordinates and manages national projects and Italy's participation in European and international projects (ASI, 2023). In terms of goals, ASI aims to promote the growth of the national space industry, which is recognized as an international excellence. This goal can be achieved thanks to the government's push, the three-year plan, and the funds made available by the National Recovery and Resilience Plan (Pnrr). For 2022, the funds allocated to ASI amount to a total of 880 million euros, of which approximately 570 are related to Pnrr and the rest from the National Complementary Fund (ASI, 2022).

The Deutsches Zentrum für Luft- und Raumfahrt (DLR) is the national aeronautics and space research centre of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport, security and digitalisation is integrated into national and international cooperative ventures (DLR, 2023). DLR's strategic goals include the establishment of partnerships with the very best, the implementation of the UN's 2030 Agenda for Sustainable Development, and an increase in internationality. The Internationalisation Strategy 2030 envisions an increasingly international organisational culture that is forward looking, cost effective and future-proofed and develops it further on the basis of strategic goals and measures (DLR, 2023). In terms of budget for 2022, DLR has a budget of about €850 million for research and operations. Approximately half of this sum comes from competitively allocated third-party funds. The Center also administers the space budget for the German government with about €1270 million. Germany contributes around €4 billion (current economic conditions) to ESA programs with a focus on climate protection, European sovereignty, New Space and international cooperation (DLR, 2022).

The Korea Aerospace Research Institute (KARI) is the national aeronautics and space research agency of South Korea. Established in 1989, KARI's extensive research and development work spans across aeronautics, space, and related technologies. KARI's strategic objectives include building upon indigenous launch capabilities, strengthening national safety and public service, and industrializing satellite information and applications technology. In line with the global trend towards sustainable development, KARI also aims to contribute to the UN’s 2030 Agenda for Sustainable Development. KARI's Internationalisation Strategy envisions an increasingly international organizational culture that is forward-looking, cost-effective, and future-proofed. In terms of budget, KARI had an annual budget of 600 million US$ for the fiscal year 2023 (Seoulz, 2023). This budget is utilized for research, operations, and the development of systems and core technology for aircraft, satellites, and space launch vehicles.

1.3.2 Non-national space agencies

Non-national space companies represent a dynamic and innovative segment of the global space industry. In contrast to national space agencies, which are government-funded and typically focus on national space exploration and research, non-national space companies are privately-owned enterprises with a diverse set of missions and objectives. These companies have transformed the space landscape by introducing commercial and market-driven approaches to space exploration, technology development, and space-based services. They contribute to space activities ranging from satellite deployment and space tourism to global internet access and space logistics. The following technical explanations provide insights into the key activities, missions, and data contributions of some of the most significant non-national space companies.

SpaceX, also known as Space Exploration Technologies, is an American aerospace manufacturer and space transport services company. It was founded in 2002 by Elon Musk with the goal of reducing space transportation costs and enabling the colonization of Mars (Profolus, 2022). In 2022, SpaceX raised a total of $2.2 billion, with their latest funding round in July raising $250 million (Statista, 2022). This funding supports the company's ambitious plans for the year. In terms of targets for 2022, SpaceX aimed to achieve an average of one launch per week, totaling to 52 launches for the year. However, they surpassed this target and are now aiming to outdo themselves yet again in 2023. As part of its roadmap for 2022-23, SpaceX is working on a next generation of fully reusable launch vehicles that will be the most powerful ever built, capable of carrying humans to Mars and other destinations in the solar system. This is being done through their Starship spacecraft and Super Heavy rocket.

Blue Origin, founded by Jeff Bezos, is an American aerospace manufacturer and space transport services company. Its vision is to enable a future where millions of people are living and working in space for the benefit of Earth. In 2022, Blue Origin raised a total of $167.4M in funding. The company's annual revenue was reported to be $42.8M. The target for Blue Origin in 2022 was to amplify its fleet of New Shepard vehicles to meet the growing demand from potential customers desiring the experience of suborbital flights that the company offers. The company planned to boost spaceflight launches in 2022, aiming to fly twice the number of people it did in 2021. Regarding its roadmap for 2022-23, Blue Origin is working on developing reusable launch vehicles and in-space systems that are safe, low cost, and serve the needs of all civil, commercial, and defense customers (Blue Origin, 2022).

Virgin Galactic, a British spaceflight company within the Virgin Group, is pioneering the future of space travel. The company's primary target is to provide suborbital spaceflights to space tourists and suborbital launches for space science missions1. Virgin Galactic's goal is to generate the majority of its revenue from ticket sales for flights into space through a spaceflight services program (Investopedia, 2023). As for the roadmap, Virgin Galactic is building a new class of spaceships to succeed SpaceShipTwo. The new class of space tourist ship for Virgin Galactic, called Delta, is coming together with a new deal to fly Axiom Space astronauts along with contracts to secure key suppliers.

OneWeb is a global communications company that specializes in broadband satellite Internet solutions. It offers enterprise expansion, mobile backhaul, disaster recovery, community broadband, streaming, and other solutions. The company serves government, maritime, aviation, agriculture, and other sectors. In 2022, OneWeb hosted a "beyond connectivity" challenge, inviting ideas for payloads and applications of commercial and sustainable value that they can build together into the technology roadmap for their fast-evolving system (OneWeb, 2022). In terms of targets for 2022, OneWeb aimed to amplify its fleet of satellites to meet the growing demand from potential customers desiring the experience of suborbital flights that the company offers. The company planned to boost spaceflight launches in 2022.

Rocket Lab, Inc. is a publicly traded aerospace manufacturer and launch service provider that operates and launches lightweight Electron orbital rockets, providing dedicated launches for small satellites (Wikipedia, 2023). The company plans to build a larger Neutron rocket as early as 2024. In 2022, Rocket Lab set new company records with nine Electron launches and 100% mission success. The company also made significant progress on the development of Neutron with hardware in production, the launch pad and production complex sites selected and under construction, and an engine test stand at NASA Stennis already supporting the Archimedes test program. In terms of financials, Rocket Lab reported a Q4 2022 revenue of $51.8 million, an increase of 88% year-over-year. The fiscal 2022 Revenue was $211 million, representing full-year growth of 239% (Yahoo Finance, 2023).

Sierra Nevada Corporation's Space Systems, now known as Sierra Space, is a leading aerospace manufacturer and launch service provider that has been delivering state-of-the-art solutions for nearly 60 years (SNC, 2023). The company's primary target is to provide end-to-end space services for diverse users and to become the "premier commercial destination" in low orbit. In terms of goals, Sierra Space aims to redefine the aerospace industrial base through disruptive innovation by delivering high-tech and multi-domain, open architecture solutions for their customers' most critical missions. They are also working on the development of Dream Chaser, a spacecraft designed for cargo and crew transports of up to seven people. As for the budget in 2022, Sierra Space's space business generated $400 million in annual revenue and projected that increasing to $4 billion in 5 to 10 years. In addition, Sierra Space raised nearly $300 million in new funds at a $5.3 billion valuation in 2023 (CNBC, 2023).

1.4 Budget and funding

Within the realm of space exploration, the intricacies of financial resourcing and allocation are fundamental components shaping the trajectory of space agencies. This financial landscape is characterized by a tripartite framework, consisting of government budgets, public-private partnerships, and commercial ventures, each with a distinct role in financing space endeavors. These diverse funding models are instrumental not only in fueling missions and the development of pioneering technologies but also in generating economic impacts within the space sector.

Government budgets form the backbone of space agency funding, particularly for national space agencies. These budgets are allocated by the government and are often subject to annual review and approval processes. The funding levels are influenced by multiple factors, including national priorities, economic conditions, and political considerations. The United States, for instance, allocated approximately $62 billion to its space programs in 2022, making it the country with the highest space expenditure in the world. These funds are typically used for a wide range of activities, including research and development, mission planning and execution, infrastructure maintenance and upgrades, and personnel costs. Government budgets for space agencies are driven by both civilian and defense applications. For example, NASA’s approved FY 2022 budget for all sectors is $24 billion.

Partnerships Public-private partnerships (PPPs) represent a significant shift in the funding landscape for space agencies. In these arrangements, government agencies collaborate with private sector companies to share the costs and risks associated with space exploration. This approach leverages the efficiencies and innovative capabilities of the private sector while also benefiting from government oversight and regulation. The International Space Station (ISS) National Laboratory is a prime example of a successful PPP in the space sector. The ISS National Lab is committed to accelerating research in space by involving a diverse range of non-traditional space users. These users are active in various fields such as life science, physical science, technology development, and remote sensing. The ISS National Lab primarily collaborates with organizations that contribute financially to the benefits they receive from the ISS. It also works with other organizations that address national science and research priorities. This research caters to commercial and entrepreneurial needs, as well as other significant objectives like the pursuit of new knowledge and education (ISS National Lab, n.d.). The Commercial Crew Program by NASA is another example of such collaboration. Under this program, NASA collaborates with private companies like SpaceX and Boeing to develop commercial crew transportation to the International Space Station (ISS). Public-private partnerships not only leverage private sector investments but also bring innovation and efficiency to space activities. SpaceX's Crew Dragon missions, for instance, have not only demonstrated the effectiveness of this partnership model but have also introduced a new era of commercial space travel.

The rise of **commercial ventures** in the space sector has introduced a new dynamic to space agency funding. Companies like SpaceX have demonstrated that private entities can not only participate in but also drive innovation in space exploration. For instance, SpaceX's Starlink project is a prime example of this. Starlink, with its thousands of small satellites orbiting the Earth at a low altitude, is designed to provide worldwide internet coverage. Each Starlink launch significantly boosts SpaceX's revenue. Morgan Stanley's forecasts suggest that Starlink could potentially rake in tens of billions of dollars in annual revenue, greatly enhancing SpaceX's overall budget and capabilities.The commercialization of space also includes space tourism. Companies such as Virgin Galactic and Blue Origin are offering suborbital spaceflights to customers who are willing to pay. Although these ventures are still in their early stages, they are paving the way for new revenue streams and stimulating economic activity in the space sector. These companies though typically generate revenue through contracts with government agencies, commercial satellite launches, and other space-related services. In 2020 alone, investment deals for space startups worldwide reached $7.6 billion. Private companies must sell to NASA and other government customers since today those organizations are the only source of in-space demand. But as SpaceX has demonstrated, private companies now have not just the desire but also the ability to send people into space. And once we have private citizens in space, SpaceX and other companies will be poised to supply the demand they've created (Harvard Business Review Staff & Sarang, 2021).

In summary, the financial foundation of space agencies is built on a combination of government budgets, public-private partnerships, and commercial ventures. Government budgets continue to be the main source of funding, allowing agencies to carry out a broad range of missions. Public-private partnerships enable cost-effective collaboration and innovation, while commercial ventures offer potential for revenue generation and economic expansion. These funding models not only propel space exploration and research but also spur technological progress and economic growth in the space sector.

1.5 Impact on Society

Space agencies, those pioneering entities delving into the farthest reaches of the universe, wield a profound impact on the socio-economic tapestry of our terrestrial world. Within the scientific and economic community, the far-reaching contributions of space agencies in terms of technological innovations and scientific discoveries have been instrumental in shaping industries, advancing research, and enhancing our understanding of the universe. In this comprehensive analysis, we shall explore the multifaceted impact of space agencies, illuminating the intricate web of technological breakthroughs and scientific revelations that have rippled through society, all through the lens of economics and scientific discovery.

Space agencies have been at the forefront of technological innovation. The space industry is utilizing emerging technologies, including 5G, advanced satellite systems, 3D printing, big data, and quantum computing, to upgrade and scale operations in space. Many services, such as weather forecasting, remote sensing, global positioning system (GPS) navigation, satellite television, and long-distance communication, rely on space infrastructure. Moreover, new space industry trends, like smart propulsion, space robotics, and space traffic management are also gaining traction (StartUs Insights, 2023). Together with increasing private investment in the industry, startups develop technologies to ease movement, operations, and communications between Earth and space. Some examples will follow.

- **Advanced Materials**: Space agencies are instrumental in the development of cutting-edge materials. For instance, NASA's work in aerospace materials has led to the creation of advanced composites known as carbon fiber-reinforced polymers. These materials are prized for their exceptional strength-to-weight ratio. Today, they find applications not only in spacecraft but also in industries such as aviation and automotive manufacturing. For example, the Boeing 787 Dreamliner's airframe incorporates carbon-fiber composites, significantly reducing its weight and improving fuel efficiency.

- **Miniaturization of Electronics**: The drive for miniaturization, a hallmark of space agency missions, has had a substantial impact on consumer electronics. Take the smartphone, a ubiquitous technological marvel. Its remarkable computing power and portability are a direct result of miniaturized components developed for space missions. Integrated circuits, originally designed for space applications, have found their way into mobile devices, enabling advanced computing capabilities on a handheld scale.
- **Energy Efficiency and Sustainability**: The solar panels adorning the roofs of homes and businesses, generating clean energy from sunlight, have roots in space technology. Space agencies pioneered the development of high-efficiency solar cells for spacecraft power systems. Solar panels on Earth have followed suit, experiencing increased efficiency and affordability. This transformation has played a pivotal role in the global shift toward renewable and sustainable energy sources, reducing carbon footprints and enhancing energy sustainability.

Space agencies have been instrumental in driving scientific discovery. For 20 years, the astronauts aboard the International Space Station have conducted science in a way that cannot be done anywhere else (NASA). In 2021 alone, the universe revealed more of its secrets than ever before thanks to a variety of exploratory missions and their cutting-edge instruments. Researchers have turned the Earth into a giant telescope to view powerful jets from a black hole. Solar system surveys have revealed new moons and massive comets previously lurking undetected by scientists (Space.com Staff & Howell, 2021). Some examples of scientific discoveries will follow.

- **Earth and Climate Sciences**: The utilization of Earth observation satellites, an essential component of space agencies' missions, has revolutionized our understanding of our planet. For instance, the European Space Agency's (ESA) Sentinel series of Earth observation satellites provide critical data for applications like monitoring deforestation, tracking sea-level rise, and assessing air quality. This data empowers policymakers, scientists, and industries to make informed decisions, shaping environmental policies and disaster management strategies.

- **Planetary Exploration**: Mars rovers, like NASA's Curiosity and Perseverance, are remarkable products of space agency missions. Their findings on the Martian surface have profound implications for our understanding of the Red Planet and, by extension, the history of our solar system. The discovery of ancient riverbeds, evidence of past water, and the potential for microbial life on Mars captivate the scientific community. Such findings stimulate the imagination of space entrepreneurs and economists eyeing space mining and colonization opportunities.
- **Medical Innovations**: The study of human physiology in space has yielded valuable insights with terrestrial applications. Consider the use of ultrasound technology. It was initially developed for astronaut health monitoring. Today, portable ultrasound devices are common in medical practice, enabling non-invasive diagnostics in remote or underserved areas. Similarly, research into countermeasures for muscle atrophy in space has led to innovations such as robotic exoskeletons, which find use in rehabilitation and assistive technology.

1.6 Challenges and Future Goals

Space agencies face a multitude of challenges in their quest to explore and understand the universe. Overcoming Earth’s gravity to launch spacecraft into space is a significant challenge, requiring immense energy and sophisticated technology. Current spacecrafts are relatively slow, making interstellar travel a long-term endeavour. The increasing number of satellites and other objects in space has led to congestion, increasing the risk of collisions (World Economic Forum, 2022). Unlike on

Earth, there’s no GPS in space, making navigation a complex task. Long-term space missions require sustainable sources of food and other essentials, as resupplying from Earth is not feasible. Zero gravity environments can have adverse effects on the human body, and space travel also increases exposure to radiation, leading to a higher risk of cancer. The isolation and confined spaces in spacecraft can lead to psychological issues, known as ‘space madness’. As space becomes more commercialized, new regulations are needed to manage the use of space and mitigate new threats. Questions about the morality of investing in space exploration and exploitation in light of social exclusion, inequality, and challenges on Earth have been raised. The increasing presence of certain countries in space may put pressure on other countries to invest in space programs for fear of being left behind (World Economic Forum, 2022).

2. The New Space Economy

2.1 Introduction: Overview of the New Space Economy

The New Space Economy is a rapidly growing and multifaceted industry that extends beyond space tourism. It encompasses a wide range of activities, including satellite communications, earth observation, space exploration, and even asteroid mining. The New Space Economy is not just about the exploration of space; it's also about the utilization of space for economic benefit. The term 'space economy' covers the goods and services produced in space for use in space (World Economic Forum, 2022). This includes everything from communication satellites that provide global connectivity to earth observation satellites that monitor climate change and aid in disaster management. The importance of the space economy in the modern world cannot be overstated. It is expanding globally due to the development of governmental space programs around the world, the multiplication of commercial actors in value chains, durable digitalization trends, and new space systems coming of age. The space economy contributes to new economic activities often far removed from initial investments in space infrastructure. Furthermore, advances in broadband access and energy sources derived from space exploration could be critical for countries that were left behind by previous industrial revolutions (Brookings Institution, 2023).

The New Space Economy represents a significant shift in our approach to space exploration and utilization. It's not just about reaching new frontiers in space; it's also about how we can leverage our activities in space for economic benefit on Earth. As we continue to invest in and develop this new economy, it will undoubtedly play an increasingly important role in our lives.

2.2 Space Market Growth Estimates: market size, projections, key factors

The current size of the space market is substantial and continues to grow. As of 2021, the total global space economy was estimated at $469 billion, a significant increase from estimates a decade prior. This includes a range of activities involved in researching, exploring, and utilizing space. By 2023, the global space economy grew by 8%, reaching $546 billion with commercial growth climbing nearly 8%, reaching $427.6 billion (Space Foundation, 2023). Future projections for the space market are promising. The market is projected to grow to approximately $1.1 trillion by 2030. Other projections for the future size of the space economy in 2040–2045 are by Goldman Sachs, Bank of America, and the U.S. Chamber of Commerce: "trillion dollars," $2.7 trillion, and $1.5 trillion, respectively. The global medium and large satellite market size was valued at USD 7.90 billion in 2022 and is projected to grow from USD 6.91 billion in 2023 to USD 9.52 billion by 2030 (Fortune Business Insights, n.d.). Several factors are influencing this growth. Advances in technology, increased private sector investment, and rising demand for space data are reshaping the sector. The challenges to manufacturing, launching, and operating satellites and other space-based assets have diminished significantly due to technological advancements. Digital and advanced technologies are helping new players access satellite operators' data and explore new business applications. The economics of space have never been more compelling. Over the past few years, challenges to manufacturing, launching, and operating satellites and other space-based assets have diminished significantly. Satellites have been “miniaturized,” costing less to produce and operate than ever before. And thanks to reusable rocketry, launch costs are much lower today (Deloitte, 2023).

This growth in the global space sector is creating opportunities for new players and new offerings for incumbent ones. The continued vitality of the global space economy was driven by $427.6 billion in revenue for commercial space ventures. Some of the fastest growth came in the communications sector, which saw rising demand for satellite broadband services. This sector grew to $28 billion from $24 billion in 2021, an increase of more than 17%. Satellite manufacturing for the commercial sector also boomed with a 35% increase in satellites sent to orbit from 2021 to 2022 (Space Foundation, 2023). Increased government space spending across the globe tracked with the wider revenue gains. Governments spent an additional $9 billion on space, raising the percentage of defense spending in government budgets to 45% in 2022 compared to 41% in 2021. Much of that increase came as the United States increased its budgets for civil and military space programs to $69.5 billion, accounting for nearly 60% of global government space spending (Space Foundation, 2023).

2.3 Upstream and downstream sectors of the space economy

The space economy is broadly divided into two sectors: upstream and downstream. The upstream sector encompasses the scientific and technological foundations of space programs, including research and development, manufacturing, and launch activities (European parliament, 2021). This sector is responsible for the design and manufacture of space systems and their launch vehicles, as well as the development and deployment of ground stations across the globe (OnSpace, 2021). The downstream sector represents the operational aspect of the space infrastructure and the products and services that directly rely on satellite data and signals to function. This includes satellite operators who own the satellite systems and market their capacities to service providers. These service providers, in turn, deliver communications, navigation, and geographic information services to the end-users by integrating the satellite signal into packaged solutions (OnSpace, 2021). The interplay between these two sectors forms the backbone of the space economy, driving its expansion and increasing its global reach. The dynamics of this relationship are influenced by various factors, including the development of governmental space programs, the multiplication of commercial actors in value chains, and the advent of new space systems.

The **upstream** sector, representing the scientific and technological foundations of space programs, is focused on sending objects into space and space exploration. It includes a limited number of players who design and manufacture space systems and their launch vehicles. The ground segment network, which is also part of the upstream sector, designs and delivers hardware and software to deploy ground stations across the globe. Government agencies fund space technology R&D for both their own uses and dual-uses, with public efforts emerging from an increasing number of countries.

The **downstream** sector includes satellite operators who own the satellite systems and market their capacities to the service providers. These service providers deliver communications, navigation, and geographic information services to the final users by integrating the satellite signal into packaged solutions. The service providers, whether governmental (civil/military) or commercial, require solutions tailored to their needs, for communications, navigation, or geographic information services, augmented by value-added services (Moranta, 2022). This sector plays an essential role in Europe where industry focuses mainly on application markets and where socio-economic considerations have become the main driver of space policy. In 2021, the downstream sector accounted for an estimated $300 billion, or 89% of the total space market (OnSpace, 2021). This growth has been fueled by a number of factors. Advances in technology have led to cost reductions in manufacturing, launching, and operating satellites. The miniaturization of satellites and the advent of reusable rocketry have made space more accessible and affordable. Additionally, digital and advanced technologies are enabling new players to access satellite operators' data and explore new business applications.

The future projections for the downstream sector are promising. In 2018, communications activities, which are a major part of the downstream sector, comprised around 26% of the total space economy. By 2040, this share is predicted to grow to over 50% as the use of satellite and other space-based technology for internet infrastructure comes into use (Statista, 2022). The growth of the downstream sector is influenced by both public and private entities. Public agencies have traditionally been the main drivers of space policy and investment. However, the success of private businesses in commercial markets, from satellite manufacturing and launch services to the provision of space-based services, has shaped the approach to space in many regions, including Europe (Moranta, 2022).

In 2021, public and private markets put $10 billion of fresh capital to work in space companies, fueling a new wave of dynamism and innovation throughout the space ecosystem. Investments in the downstream sector of the space economy have been unprecedented. In 2018, start-up equity investments represented some USD 3 to 3.25 billion, which was around 16% of all the equity capital invested in space companies since 2009 (McKinsey, 2023). These investments are driven by the potential for high returns and the growing interest in space technologies and services.

2.4 Focus on GNSS and Earth Observation

The space market is a complex and rapidly evolving field, with several key categories playing a pivotal role in its growth and development, especially in the downstream of the space economy. These categories include Earth observation (or remote sensing), and Global Navigation Satellite Systems.

Radio Navigation Satellite Services (RNSS) are systems that enable users with a compatible device to ascertain their location, speed, and time by interpreting signals from satellites. These signals are supplied by a range of satellite positioning systems, which include global and regional constellations, as well as Satellite-Based Augmentation Systems. The types of systems providing RNSS signals include **Global Navigation Satellite Systems (GNSS)**, which are global constellations, regional constellations, and Satellite-Based Augmentation Systems (SBAS). From 2021 to 2031, it is projected that the yearly distribution of GNSS receivers will increase from 1.8 billion units to 2.5 billion units. This growth will be primarily driven by the Consumer Solutions, Tourism, and Health sector, which is riding the wave of global smartphone and wearable sales, accounting for approximately 92% of worldwide shipments. As a result, by 2031, the worldwide installed base of GNSS devices is anticipated to exceed 10 billion units. The mass market segments of Consumer Solutions, Tourism and Health, and Road and Automotive will play a significant role, contributing to 98% of all devices in use. In terms of revenue, the global GNSS downstream market, which includes both device sales and service-related revenues, is predicted to grow at a compound annual growth rate (CAGR) of 9.2% over the next decade, totaling €492 billion by 2031. Value-added services will generate over 82% of these revenues, amounting to €405 billion in 2031. In addition to the dominant mass market segments, the professional markets of Agriculture, Urban Development and Cultural Heritage, and Infrastructure will be the primary contributors to the global GNSS revenue stream.

Earth Observation (EO) involves the use of remote sensing and in-situ technologies to record the physical, chemical, and biological systems of our planet. It's used to monitor various aspects such as land, bodies of water (including seas, rivers, and lakes), and the atmosphere. EO that relies on satellites involves the use of equipment mounted on satellites to collect data about Earth's features. Consequently, these satellite-based platforms are ideal for tracking and identifying shifts and patterns in a variety of physical, economic, and environmental applications worldwide. Once the EO data is processed, it can be integrated into sophisticated models to generate valuable information and intelligence, such as forecasts, behavioral analysis, climate projections, and more. This data can be further enhanced by in-situ measurements (EUPSA, 2022). In 2021, the worldwide revenue from Earth Observation (EO) data and value-added services reached €2.8 billion. The top five segments, namely Urban

Development and Cultural Heritage, Agriculture, Climate Services, Energy and Raw Materials, and Infrastructure, accounted for 55% of these global revenues. However, it's projected that the Insurance and Finance segment, which generated €145 million and contributed 5.2% in 2021, will experience significant growth over the next decade, becoming the largest contributor to global EO revenues in 2031 with €994 million and an 18.2% market share. By 2031, the global EO data and value-added services market is expected to nearly double, reaching €5.5 billion. The anticipated growth in EO data and value-added service revenues within the Insurance and Finance segment is largely due to the expected rapid adoption of solutions that support parametric insurance. In 2021, the total revenues for EO data across all segments amounted to €536 million. From 2021, the EO data market is predicted to grow at a compound annual growth rate (CAGR) of 3.5% by 2031, resulting in total revenues of €797 million. From 2021, the EO value-added services market is expected to grow at a CAGR of 6.8%, resulting in total revenues of €4.7 billion by 2031. The Earth observation industry in Europe is primarily made up of Small and Medium-sized Enterprises (SMEs) that are predominantly engaged in downstream activities. In contrast, the rest of the world has a higher percentage of businesses that require substantial capital, indicating a more balanced mix of industrial maturity. This includes a higher concentration of start-ups, Large System Integrators (LSIs), and larger average company sizes. This could be attributed to a more robust and consistent domestic demand and easier access to private investments (ESA, 2023). Earth observation is increasingly recognized as a valuable resource for organizations, leading to a trend of backward vertical integration. This involves moving a step back in the value chain to either acquire or form a partnership with a satellite provider.

2.5 Areas of Growth in the Space Market

The space industry has been experiencing significant growth and transformation, with new opportunities emerging in various sectors, such as satellite manufacturing and launch services, space exploration and tourism, in-space manufacturing and services.

Satellite Manufacturing and Launch Services: This refers to the process of creating satellites and the systems used to send them into space. The market includes activities such as satellite manufacturing, integration of satellite payload to the rocket, launch assembly system, and launch infrastructure. Satellites are used for various applications such as satellite communication, satellite broadcasting, remote sensing, earth observation, satellite navigation, and others. Satellite manufacturing and launch services, for instance, have seen a surge in activities and market size, growing from USD 25.15 billion in 2019 to a projected USD 54.17 billion in 2027 (Analysys mason, 2023). This growth is driven by the increasing demand for satellites for various applications such as communication, broadcasting, remote sensing, and navigation. The number of patents with "microgravity" in the title or abstract soared from 21 in 2000 to 155 in 2020, indicating a growing interest in this field (Deloitte, 2023). The satellite manufacturing and launch markets are expected to continue to grow, with a focus on satellites ordered, manufactured, and launched between 2022 and 2032 (Analysys mason, 2023).

Space Exploration and Tourism: Space tourism is a branch of space exploration that enables ordinary individuals to visit space for leisure, economic, or recreational purposes. It includes orbital, suborbital, and lunar space tourism. The industry is expanding at a tremendous growth rate owing to technological innovations coupled with users' inclination toward space adventures. Space exploration and tourism represent another promising area of growth. The global space tourism market was valued at USD 695.1 million in 2022 and is expected to expand at a compound annual growth rate (CAGR) of 40.2% from 2023 to 2030. This growth is fueled by technological innovations and an increasing interest in space adventures (Bushnell, 2021). The estimated revenue of the orbital space tourism market worldwide amounted to roughly 385 million U.S. dollars in 2021, and this figure was forecast to reach 555 million U.S. dollars by 2030 (Statista, 2023). The space tourism market is still young and developing, with adults in the United States believing that private companies focused on space exploration will become profitable in the next ten years.

In-Space Manufacturing and Services: In-space manufacturing and services refer to the transformation of raw or recycled materials into components, products, or infrastructure in space. This also includes the in-space inspection, life extension, repair, or alteration of a spacecraft after its initial launch. The unique environment of space, characterized by its near-vacuum state, microgravity, and higher levels of radiation, offers unique research and manufacturing opportunities. In-space manufacturing and services are also gaining traction. The unique environment of space, characterized by its near-vacuum state, microgravity, and higher levels of radiation, offers unique research and manufacturing opportunities. The number of patents with "microgravity" in the title or abstract soared from 21 in 2000 to 155 in 2020, indicating a growing interest in this field (McKinsey , 2023). The idea of manufacturing in space is not that far out. Earthly advances in manufacturing automation and smart, "lights out" factories will be right at home when transplanted into outer space.

In the realm of space exploration, a pertinent question arises: "Do we observe a divergence in technological innovations within space agencies from their historical precedents, and how do these compare with the advancements in the new space economy?" This inquiry is particularly relevant when considering the technological taxonomies of established organizations such as NASA. Our intention is to address this question through a comprehensive analysis of patents, thereby scrutinizing the technological portfolios of various space agencies. This approach will allow us to discern patterns, trends, and shifts in innovation, providing valuable insights into the evolution of space technology.

3. Patents and search strategies

3.1 Introduction on intellectual property and Patents

Intellectual Property (IP) is a critical concept in the modern world that refers to unique creations of the mind. These creations can encompass a wide range of areas, including inventions, literary and artistic works, designs, symbols, names, and images used in commerce. The law protects these creations through various mechanisms such as patents, copyright, trademarks, and trade secrets. These protections provide creators with exclusive rights over their creations, allowing them to earn recognition or financial benefit. The IP system is designed to balance the interests of innovators and the public, fostering an environment conducive to creativity and innovation. As we move further into the knowledge-based economy, the importance of IP continues to grow. It provides a framework that encourages the development of new products and services, offering companies the confidence to invest in research and development, knowing they will have control over the use of their creations. This, in turn, drives economic growth and increases competitiveness.

3.1.1 Patents

Patents, as a form of Intellectual Property (IP), are pivotal in fostering technological progress and economic growth worldwide. They serve as a conduit for the propagation of innovation by providing a comprehensive public disclosure of a novel invention. This disclosure confers upon the patent holder a time-bound monopoly, typically spanning 20 years from the filing date, on the utilization of the invention. This monopoly, however, is not absolute. It is contingent upon the patent holder actively endeavouring to bring the invention into public use. Failure to adequately exploit the invention may lead to compulsory licensing or even revocation of the patent.

The ambit of the patent is delineated by the claims, which must be lucid and precise to apprise the public of the patent's boundaries. Patents encompass new and useful aspects of 'machines, manufactured products, industrial processes, and chemical compositions.' The patent system is fundamentally designed to stimulate innovation and technological advancement. By granting inventors exclusive rights to use and profit from their inventions, the patent system incentivizes research and development. The patent system strikes a balance between the interests of inventors, who are rewarded with a temporary monopoly, and the public, which benefits from the disclosure of the invention and the eventual entry of the invention into the public domain. It promotes the dissemination of technological information and catalyzes further innovation.

It's crucial to note that patent laws are not universal; they vary by jurisdiction. This implies that the procedures for applying for a patent, processing applications, deposit requests, and even the criteria for what is deemed patentable or unpatentable, differ and should be evaluated based on the jurisdiction. For instance, Italian legislation stipulates that inventions in any technological field that are new, involve an inventive step, and are capable of industrial application can be patented. This underscores the concept of innovativeness, a key requirement for an invention to qualify for patent protection. To be patentable, the invention must be novel, meaning it has not been disclosed anywhere in the world before the filing date. In addition to novelty, there are other requirements that an invention must meet to be eligible for patent protection.

The **assignee** is the entity that has the property right of the patent. The assignee can be a person, company, or entity that the inventor assigns the patent rights to. The assignee has the right to exclude others from making, using, selling, offering for sale, or importing the patented invention.

To be patentable, an invention must meet several criteria:

- **Novelty**: The invention must be new, meaning it must differ from all previously known things in one or more of its constituent elements or the combination thereof. This means the invention has not been publicly disclosed in any form, anywhere in the world.
- **Inventive Step (Non-obviousness)**: The invention must involve an inventive step, meaning it would not be obvious to a person skilled in the relevant field of technology. This requirement ensures that trivial or incremental improvements over existing products or processes are not awarded patent protection.
- **Industrial Applicability (Usefulness)**: The invention must be capable of industrial application, meaning it can be made or used in some form of industry. This includes agriculture, fisheries, handicrafts, services, and other industries.

Key Components of a Patent

The process of obtaining a patent involves several steps, including preparing a detailed description of the invention (patent specification), filing a patent application with a patent office, and navigating the examination process, where the patent office determines whether the invention meets the requirements for patentability.

A patent document, often referred to as a patent specification, is a document describing the invention in detail and defining the scope of the invention for which protection is sought or granted. It contains several key components:

- **Title**: The title should accurately reflect the subject matter of the invention as concisely as possible.
- **Abstract**: The abstract provides a summary of the invention, allowing readers to quickly understand the key aspects of the invention.
- **Specification**: The specification is a written description of the invention and the manner and process of making and using the same. It should be so complete

and clear that a person of ordinary skill in the art can make and use the invention without undue experimentation.

- **Claims**: The claims define, in technical terms, the extent of the protection conferred by the patent, or the protection sought in a patent application. The claims are the most important part of a patent, as they define the patent's scope of protection.
- **Drawings**: If necessary, the patent document includes drawings that visually depict the invention. These drawings are not always required but can be instrumental in understanding the invention.

The **Bibliographic Data Section**, typically found on the first page of a patent document, outlines the fundamental elements of the document's technical content. This section is often the focus of statistical analyses, such as patent landscapes. The primary bibliographic data include:

- **Applicant**: This refers to the physical or legal entity that files the patent. If the application is approved, the applicant, now referred to as the assignee, holds the patent rights.
- **Inventor**: This is the individual or group who conceived the invention. It's crucial to note that the inventor does not hold the rights conferred by the grant of intellectual property.
- **Filing Date**: Determined by the patent authority, this date sets the boundary within which the state of the art will be analyzed to ascertain if the invention fulfills the conditions for patentability. It also helps establish the patent's expiry date.
- **Priority Date**: This is the date when an applicant files a patent relating to a previously published patent. Specifically, it's the date when the applicant claims priority from that previous application.
- **Publication Date**: Usually 18 months after the patent application is filed or 18 months after the first priority date, this is the date when the patent is published.

It signifies when the patent comes into effect and begins to provisionally exercise its protective effect, even if it has not yet been granted.

- **Priority Data**: Comprising the patent application number, the date of the application, and the identification of the nation/organization where the applicant made a prior application. It identifies any prior patent applications on which a priority claim is made.
- **Classification**: Introduced by WIPO in 1968, the International Patent Classification (IPC) organizes published patents according to their technological areas.
- **Citations**: These cover the state of the art related to the patent under discussion. Citations can indicate collaborations between inventions and can be useful in identifying which inventions will have the most significant technological impact.

3.1.2 IPC Codes

The **International Patent Classification (IPC)**, instituted under the Strasbourg Agreement in 1971, is a globally unified system for patent classification. Before its inception, each jurisdiction had its distinct classification system, often in its native language, leading to considerable confusion and complexity in accessing patents published abroad. Today, the IPC is adopted by over 100 nations and patent authorities. The classification undergoes periodic updates by a committee of experts, which includes representatives from contracting states and organizations, such as the European Patent Office (EPO). The IPC system encompasses approximately 70,000 distinct codes, each signifying a specific technical area. These codes serve as an effective tool for organizing patents, facilitating patent searches, and enabling the systematic storage of technological information contained in patent documents.

The IPC provides a hierarchical system of codes for classifying and searching patents and utility models. It is also employed for classifying publications, scientific articles, and technical texts in general. In this classification system, inventions are categorized based on their functional characteristics rather than their potential applications. The IPC segregates patentable technologies into eight sections (A - H), each representing a distinct technological field. These sections are further divided into increasingly detailed levels, including subsections, classes, subclasses, groups, and subgroups. Each IPC code is hierarchically structured and typically includes a section symbol, class, subclass, and group. For instance, in the code ‘A01B 1/00’, ‘A’ signifies ‘Human Necessities’, ‘01’ indicates ‘Agriculture’, ‘B’ denotes ‘Soil Working’, and ‘1/00’ refers to ‘Hand Tools’.

The IPC system plays a crucial role in patent landscapes and statistical analyses, as it provides a standardized and systematic approach to classifying patents. This facilitates the retrieval of patent documents, the preparation of industrial property statistics, and the assessment of technological development in various areas.

3.2 Methodology and dataset creation

The primary objective of our research is to conduct a comprehensive analysis of the technology portfolios of various space agencies, with a particular focus on evaluating their research performance. We use patents as a key indicator of technological advancement.

Our approach involves the creation of two distinct patent portfolios. The first portfolio comprises all the patents from companies considered to be operating in the downstream sector of the space industry. The second portfolio, on the other hand, includes all the patents from companies considered to be in the upstream sector. Our aim is to calculate and analyze the distance between these two contrasting portfolios and the individual portfolios of various space agencies. We intend to examine the trend of this distance over time to determine if there is a noticeable shift towards either the upstream or downstream portfolio. This analysis will provide valuable insights into the evolving focus of space agencies' research and development efforts.

3.2.1 Derwent and query execution

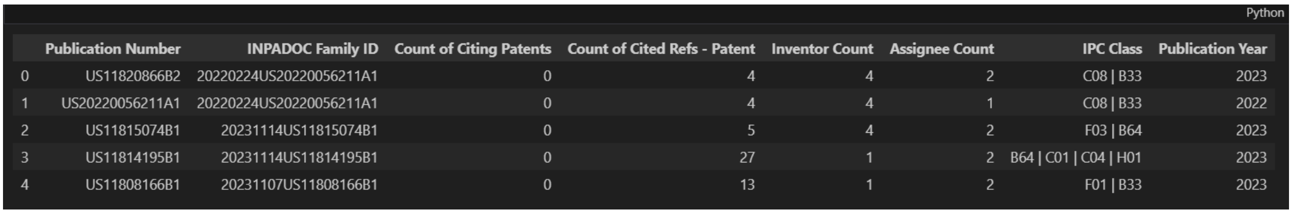
To facilitate this research, we utilize the Derwent platform. This platform allows us to perform targeted queries and extract specific sets of patents. We separately extract patents that are classified as upstream, downstream, and those belonging to various space agencies. This methodical and segmented approach ensures that our analysis is both thorough and precise, providing a robust measure of technological advancement within the space industry. The process involves conducting a search on the Derwent platform, utilizing specific tags to identify companies in the upstream or downstream sectors, as depicted in the accompanying figure. For each space agency, a unique query is executed, incorporating specific filters to ensure the accuracy of the patent search. For instance, a sample query for space agencies could be:

```
PA=(( (Nat* adj Aeronautics) and (Space adj Adm*) ) OR ( NASA ) OR (goddard
adj space) OR (AMES RESEARCH)) NOT ((PA=(("NASA" adj ("KK" OR "CO" OR "CORP"
OR "CASTING")))) OR ((cc=(US) and KI=(S)) OR (cc=(DE) and KI=(U*)) OR (cc=(CN)
and KI=(A8 or A9 or b8 or b9 or c1 or c2 or c3 or c4 or c5 or c6 or c7 or u
or y or u* or y* or s or d or s* or d*))));
```

This query ensures that the search is focused on relevant patents by filtering out unrelated results. It includes specific keywords related to space agencies and excludes certain classifications and kinds of patents based on the country code and kind code.

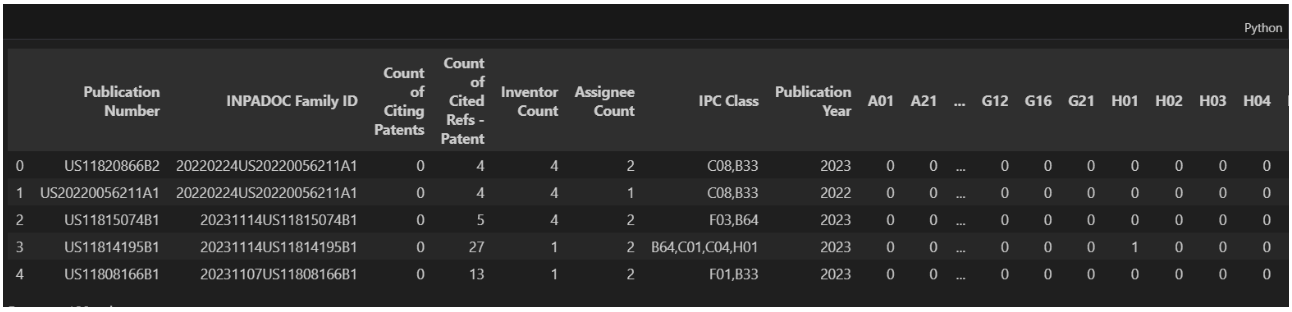
3.2.2 Dataset modelling

Upon extraction of the CSV file, the dataset undergoes a series of transformations to optimize information retrieval and analysis (Figure 1 below). The initial phase involves data cleansing, which includes filtering records with null values, eliminating superfluous spaces, and rectifying incorrectly populated fields. Subsequently, the field containing the International Patent Classification (IPC) codes is split, with each code assigned to a distinct column. These columns are populated with a binary system: '1' indicates the presence of the corresponding IPC code in the patent, and '0' indicates its absence. This can be seen in the figure 2 below that shows the dataset after splitting the IPC codes.



	Publication Number	INPADOC Family ID	Count of Citing Patents	Count of Cited Refs - Patent	Inventor Count	Assignee Count	IPC Class	Publication Year
0	US11820866B2	20220224US20220056211A1	0	4	4	2	C08 | B33	2023
1	US20220056211A1	20220224US20220056211A1	0	4	4	1	C08 | B33	2022
2	US11815074B1	20231114US11815074B1	0	5	4	2	F03 | B64	2023
3	US11814195B1	20231114US11814195B1	0	27	1	2	B64 | C01 | C04 | H01	2023
4	US11808166B1	20231107US11808166B1	0	13	1	2	F01 | B33	2023

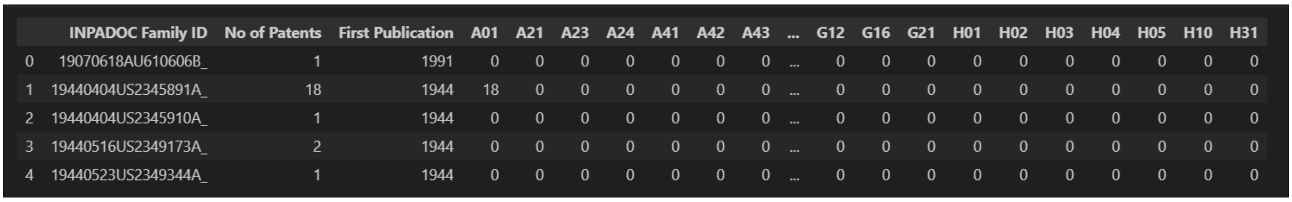
Figure 1 Starting dataset



	Publication Number	INPADOC Family ID	Count of Citing Patents	Count of Cited Refs - Patent	Inventor Count	Assignee Count	IPC Class	Publication Year	A01	A21	...	G12	G16	G21	H01	H02	H03	H04
0	US11820866B2	20220224US20220056211A1	0	4	4	2	C08,B33	2023	0	0	...	0	0	0	0	0	0	0
1	US20220056211A1	20220224US20220056211A1	0	4	4	1	C08,B33	2022	0	0	...	0	0	0	0	0	0	0
2	US11815074B1	20231114US11815074B1	0	5	4	2	F03,B64	2023	0	0	...	0	0	0	0	0	0	0
3	US11814195B1	20231114US11814195B1	0	27	1	2	B64,C01,C04,H01	2023	0	0	...	0	0	0	1	0	0	0
4	US11808166B1	20231107US11808166B1	0	13	1	2	F01,B33	2023	0	0	...	0	0	0	0	0	0	0

Figure 2 Dataset after splitting IPC codes

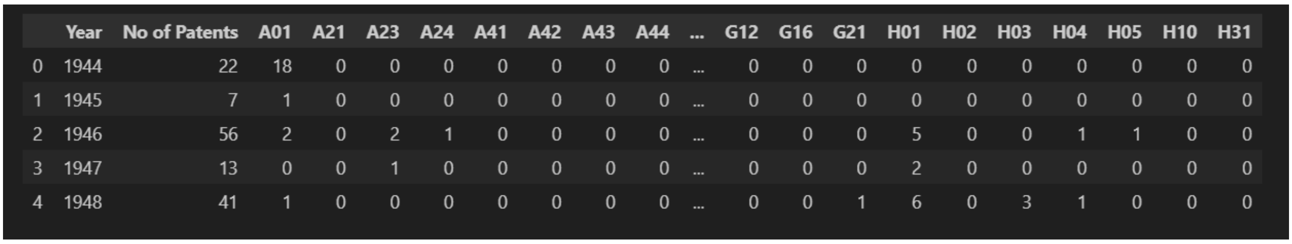
The patents are then aggregated based on their Family ID (Figure 3 below). This approach mitigates issues arising from discrepancies in dates between the proposal record and the acceptance record of a patent. The aggregation results in a single record per Family ID, which encompasses the summation of all IPC codes, the total count of patents, and the earliest publication date among all records within the group.



	INPADOC Family ID	No of Patents	First Publication	A01	A21	A23	A24	A41	A42	A43	...	G12	G16	G21	H01	H02	H03	H04	H05	H10	H31
0	19070618AU610606B_	1	1991	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
1	19440404US2345891A_	18	1944	18	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
2	19440404US2345910A_	1	1944	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
3	19440516US2349173A_	2	1944	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
4	19440523US2349344A_	1	1944	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0

Figure 3 Dataset grouped by Family ID

Further aggregation is performed by segregating the records annually, thereby creating a chronological portfolio for each space company. These annual portfolios can be analysed in terms of percentages by dividing the count of each IPC code by the total number of patents for the corresponding year. This provides a relative measure of the distribution of IPC codes within the patent portfolio of a company for a specific year, as can be seen in the Figure 4 below.



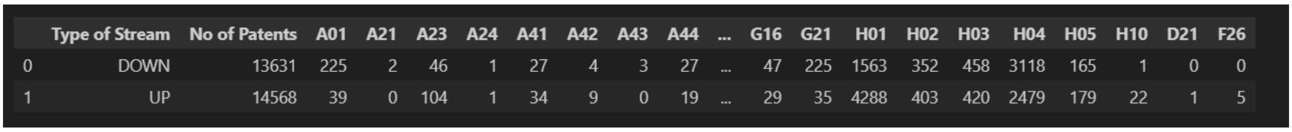
	Year	No of Patents	A01	A21	A23	A24	A41	A42	A43	A44	...	G12	G16	G21	H01	H02	H03	H04	H05	H10	H31
0	1944	22	18	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
1	1945	7	1	0	0	0	0	0	0	0	...	0	0	0	0	0	0	0	0	0	0
2	1946	56	2	0	2	1	0	0	0	0	...	0	0	0	5	0	0	1	1	0	0
3	1947	13	0	0	1	0	0	0	0	0	...	0	0	0	2	0	0	0	0	0	0
4	1948	41	1	0	0	0	0	0	0	0	...	0	0	1	6	0	3	1	0	0	0

Figure 4 Dataset grouped by year

The identical methodology is applied to both the upstream and downstream portfolios. The availability of time-stamped data enables a broader scope for comparisons. Specifically, it allows for the computation of cosine distance to the spatial agencies on a period-by-period basis, thereby enhancing the precision of the trend analysis. An additional benefit is the ability to scrutinize the variation of the primary IPC codes over time, with the objective of identifying those that typify the upstream sector and those that are distinctive of the downstream sector.

An alternative approach that was considered involves the use of a singular portfolio for both upstream and downstream, without year-based differentiation. The advantage of this method is that it consolidates all data into a single record, thereby simplifying computation, as exemplified in Figure 5.

However, we have elected to adopt the first approach. Despite its greater operational complexity, it minimizes information loss and facilitates more accurate period-by-period comparisons.



	Type of Stream	No of Patents	A01	A21	A23	A24	A41	A42	A43	A44	...	G16	G21	H01	H02	H03	H04	H05	H10	D21	F26
0	DOWN	13631	225	2	46	1	27	4	3	27	...	47	225	1563	352	458	3118	165	1	0	0
1	UP	14568	39	0	104	1	34	9	0	19	...	29	35	4288	403	420	2479	179	22	1	5

Figure 5 Database of UPS and DWN

3.3 Distance metrics

During this phase, research was conducted to discern the most effective distance measures applicable to our dataset. Subsequently, all the various metrics will be enumerated and elucidated, along with their respective advantages and disadvantages pertaining to our dataset.

3.3.1 Explanation of distance metrics

Euclidean Distance

Euclidean distance, often referred to as the L2 norm or Euclidean norm, is a measure that calculates the straight-line distance between two points in a space. This measure, derived from the Pythagorean theorem, finds applications in various domains such as physics, computer science, and data science. In a two-dimensional space, the Euclidean distance between two points (x1, y1) and (x2, y2) is calculated as $\sqrt{(x2-x1)^2 + (y2-y1)^2}$. This formula can be extended to higher dimensions. Despite its simplicity and widespread usage, Euclidean distance has a limitation - it can be sensitive to the scale of different dimensions. Therefore, when using Euclidean distance, normalization or standardization of values is often recommended.

Pros:

- Simple and intuitive - it's the straight-line distance between two points.
- Since our data is already normalized, the issue of different scales in different dimensions is not a concern.

Cons:

- Treats all dimensions equally, which might not be desirable if some dimensions are more important than others. In our study all IPC codes have the same weight

- Can be sensitive to outliers. Even though our data is normalized, if there's a large difference in one dimension, it will have a larger impact on the Euclidean distance.

Manhattan Distance (L1 norm)

Manhattan distance, also known as the L1 norm or taxicab distance, is a measure used to calculate the distance between two points in a grid-like path. It is named after the grid layout of the Manhattan streets, which is laid out in a square grid. In a two-dimensional space, the Manhattan distance between two points (x1, y1) and (x2, y2) is calculated as |x2-x1| + |y2-y1|. This formula can be extended to higher dimensions. Unlike Euclidean distance, Manhattan distance is not sensitive to the scale of different dimensions, making it particularly useful in certain contexts such as high-dimensional spaces. However, it does not measure the actual distance, but rather the sum of vertical and horizontal distances, which can be a limitation in some applications.

Pros:

- Simple and intuitive: it's the sum of the absolute differences between corresponding dimensions.
- More robust to outliers than Euclidean distance.
- Can be more appropriate when data is not isotropic (i.e., doesn't have the same properties in all directions).

Cons:

- Treats all dimensions equally, which might not be desirable if some dimensions are more important than others.
- Doesn't consider the correlation between different dimensions.

Cosine Similarity

Cosine similarity is a measure that calculates the cosine of the angle between two vectors. This metric is a judgment of orientation and not magnitude, in the multi-dimensional space. The cosine similarity is advantageous because even if the two similar documents are far apart by the Euclidean distance because of the size (like, the word 'cricket' appeared 50 times in one document and 10 times in another) they could still have a smaller angle between them. Smaller the angle, higher the cosine similarity. Mathematically, it is defined as the dot product of the vectors divided by the product of the vectors' magnitudes, or |A . B| / (||A|| ||B||). The resulting similarity ranges from -1 meaning exactly opposite, to 1 meaning exactly the same, with 0 indicating orthogonality or decorrelation, while in-between values indicate intermediate similarity or dissimilarity. For text matching, the attribute vectors A and B are usually the term frequency vectors of the documents.

Pros:

- Not sensitive to the magnitude of the vectors, only their direction. This can be useful if we're interested in the relationship between the vectors rather than their absolute values.
- Can handle high-dimensional data well.
- Since it measures the angle between vectors, it can identify the similarity between vectors even if they are far apart in terms of Euclidean distance.

Cons:

- Not as intuitive as Euclidean distance. The concept of the angle between two vectors might be harder to understand and interpret.
- Might not be suitable if the magnitude of the vectors is an important factor in the analysis. However, since our data is normalized, this might not be a major concern.

Normalization of distance metrics

To evaluate and compare the various measures, it is imperative to initially transform the cosine similarity into a distance measure. Upon accomplishing this, it is feasible to normalize all the various measures between 0 and 1, thereby facilitating a more precise understanding. This methodical approach ensures a comprehensive and accurate evaluation of the distance measures relative to our dataset.

Euclidean Distance: Normalization is performed by dividing the Euclidean distance by the square root of the number of dimensions (in this case, the number of IPC code columns). This is because in an n-dimensional space, the maximum Euclidean distance between any two points (when all dimensions range from 0 to 1) is the square root of n. So, dividing by the square root of n scales the distance to the range [0, 1].

Manhattan Distance: Normalization is performed by dividing the Manhattan distance by the number of dimensions. This is because in an n-dimensional space, the maximum Manhattan distance between any two points (when all dimensions range from 0 to 1) is n. So, dividing by n scales the distance to the range [0, 1].

Cosine Distance: Normalization is performed by dividing the cosine distance by 2. This is because the cosine distance ranges from 0 to 2 (since it's calculated as 1 minus the cosine similarity, and cosine similarity ranges from -1 to 1). So, dividing by 2 scales the distance to the range [0, 1].

The reason for normalizing these distances is to make them comparable. When distances are normalized to the same scale, you can compare them directly and use them in algorithms that expect input features to be on the same scale. It's a common preprocessing step in many machine learning and data analysis workflows.

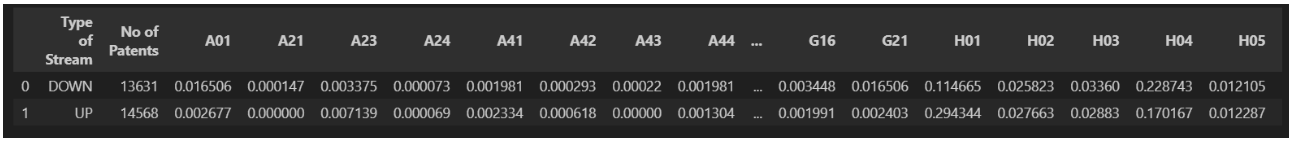
3.3.2 Choice of distance metric

To decide which of the three measures to use, we tested them by calculating the distance between the upstream and downstream portfolios. In this case, we want the distance to be maximum as the two portfolios represent our benchmark for the two different types of activities of space agencies. To execute the task at hand, it is imperative that we align the two datasets such that they share identical column structures. This process, often referred to as dataset alignment, is a critical step in many data analysis tasks.

In the context of our task, the datasets contain IPC (International Patent Classification) codes. These codes are used to categorize patents. However, not all datasets may have the same IPC codes, leading to a discrepancy in their column structures. To rectify this, we introduce a process called column alignment. If one dataset has a column for a certain IPC code and the other doesn't, we add the same column to the second dataset. However, as this IPC code was not originally present in the second dataset, we don't have any corresponding values. To handle this, we populate the entire column with '0'. This alignment of labels across both datasets, now having identical IPC code columns, is a prerequisite for the accurate computation of the distance metric. It ensures that we are comparing like with like, thereby providing meaningful comparison results.

Following the alignment process, we carry out normalization of the datasets. This step ensures that the values within the datasets are adjusted to be independent of the quantity of patents each dataset possesses. This is crucial as it removes any bias that could be introduced by the sheer volume of patents in one dataset compared to the other, thereby facilitating an unbiased comparison.

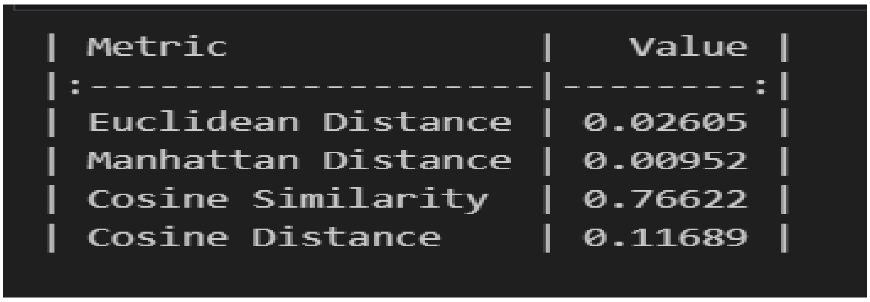
During this stage of testing distance metrics, we employ a more condensed portfolio due to technical considerations, which renders various distance measures more comparable. The normalized dataset is depicted in the subsequent Figure 6. However, when it comes to the actual computation of cosine similarity with prominent space agencies, we will utilize the comprehensive dataset as previously delineated.



	Type of Stream	No of Patents	A01	A21	A23	A24	A41	A42	A43	A44	...	G16	G21	H01	H02	H03	H04	H05
0	DOWN	13631	0.016506	0.000147	0.003375	0.000073	0.001981	0.000293	0.00022	0.001981	...	0.003448	0.016506	0.114665	0.025823	0.03360	0.228743	0.012105
1	UP	14568	0.002677	0.000000	0.007139	0.000069	0.002334	0.000618	0.00000	0.001304	...	0.001991	0.002403	0.294344	0.027663	0.02883	0.170167	0.012287

Figure 6 Normalized dataset

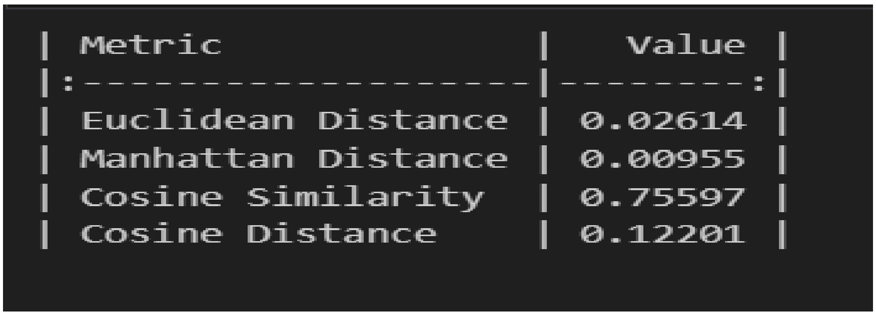
Figure 7, as seen below, presents the initial computation results of the diverse distance metrics between the upstream and downstream portfolios. Upon preliminary observation, the two portfolios exhibit a high degree of similarity, necessitating additional modeling to augment this distance.



```
| Metric             |   Value |
|:-------------------|--------:|
| Euclidean Distance | 0.02605 |
| Manhattan Distance | 0.00952 |
| Cosine Similarity  | 0.76622 |
| Cosine Distance    | 0.11689 |
```

Figure 7 Distances between upstream and downstream portfolios

To increase these values and further differentiate the datasets, we proceed by further modelling the dataset and removing from the upstream and downstream portfolios all those patents that are identical and present in both. In this way, we increase the difference between the two. The results obtained are shown in the figure 8 below. As you can see, there is an improvement in the measures as the values of the distances have now increased.



```
| Metric             |   Value |
|:-------------------|--------:|
| Euclidean Distance | 0.02614 |
| Manhattan Distance | 0.00955 |
| Cosine Similarity  | 0.75597 |
| Cosine Distance    | 0.12201 |
```

Figure 8 Distances calculated on modelled datasets.

We proceed using the cosine similarity. This is because the transformation into cosine distance was practiced only to allow a simpler comparison with the other distance metrics, albeit involving a slight loss of information. Now that we have chosen, it is no longer necessary to modify the value and therefore we keep the value of the similarity to have more complete information.

Our decision to persist with the application of cosine similarity for our analysis is underpinned by its robustness as a metric, particularly in relation to our dataset. Furthermore, it is noteworthy that cosine similarity is widely recognized as a benchmark within the scientific community in this field.

4. Portfolio analysis

4.1 Upstream and Downstream Portfolios

In this segment, we will conduct a comprehensive analysis of the upstream and downstream portfolio compositions. Our focus will be on identifying the primary International Patent Classification (IPC) codes that constitute these portfolios. We aim to discern any prevailing trends within these codes. Specifically, our interest lies in pinpointing areas where these codes are prominently featured. Subsequently, we will examine these variations within the portfolios of space agencies. Our objective is to ascertain whether these agencies are predominantly leaning towards upstream or downstream directions. This will provide us with valuable insights into their strategic orientations.

4.1.1 Upstream Portfolio

We shall commence our discussion by offering a succinct summary of the most prevalent International Patent Classification (IPC) codes present in this portfolio. Specifically, in reference to Figure 9 below, we can trace the progression of the top 10 IPC codes for the Upstream portfolio.

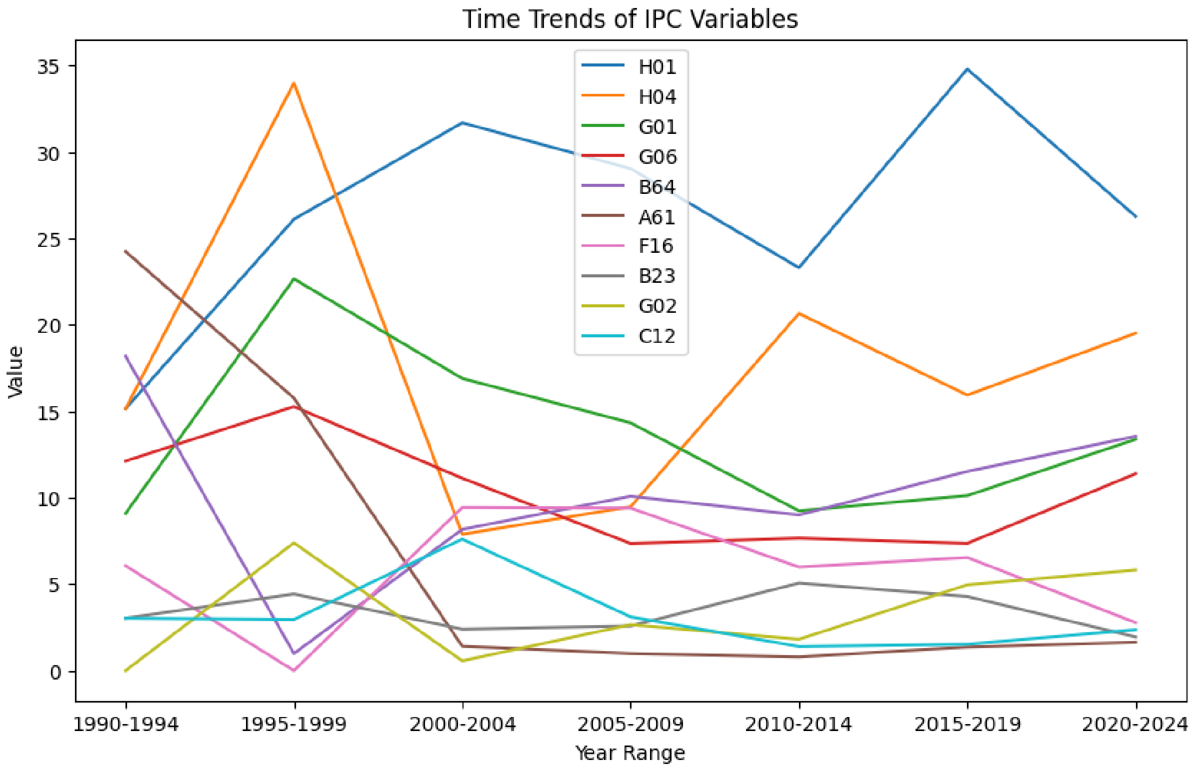


Figure 9: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. Upstream Portfolio.

The following is a concise overview of each International Patent Classification (IPC) code depicted in the chart. This is succeeded by a discussion on the potential utilization of these codes by space agencies and corporations.

H01: This IPC code pertains to basic electric elements. It covers all electric units and the general mechanical structure of apparatus and circuits, including the assembly of various basic elements into what are called printed circuits. In the context of space activities, H01 could be relevant in several ways:

- Power Systems: Spacecraft need electrical power for their operations, which is often generated onboard using solar panels or radioisotope thermoelectric generators.
- Communication Systems: Space missions require robust and reliable communication systems for transmitting and receiving data.

- Electronic Circuits: The electronic circuits used in various spacecraft systems, from navigation to scientific instruments.

H04: This IPC code pertains to the field of electric communication technique. Relevance to Space Activities:

- Communication Systems: The design and operation of communication systems for transmitting and receiving data between spacecraft and ground stations.
- Data Transmission: The techniques for transmitting data, such as images and scientific measurements, from spacecraft to Earth.

G01: This IPC code pertains to measuring and testing. It covers instruments and methods for measuring and testing of various variables such as dimensions, physical conditions like temperature, and qualities like density or colour. In the context of space activities, G01 could be relevant in several ways:

- Environmental Monitoring: Space missions often involve monitoring and measuring various environmental conditions, such as temperature, pressure, and radiation levels.
- Navigation and Positioning: Accurate measurement of position, velocity, and orientation is crucial for navigating spacecraft.
- Scientific Experiments: Many space missions carry scientific experiments that involve measuring various physical or chemical properties.

G06: This IPC code pertains to the field of computing and calculating. It covers various aspects of computing, including data processing equipment. In the context of space activities, G06 could be relevant in several ways:

- Spacecraft Navigation: The complex calculations required for navigating spacecraft.
- Data Processing: The processing and analysis of data collected by spacecraft and satellites.
- Simulation: Simulators which are concerned with the mathematics of computing the existing or anticipated conditions within the real device or system.

B64: This IPC code pertains to aircraft, aviation, and cosmonautics. It covers lighter-than-air aircraft, aeroplanes, helicopters, and vehicles, equipment or the like, which are specially adapted for cosmonautics. In the context of space activities, B64 could be relevant in several ways:

- Spacecraft Design: The design and construction of spacecraft, including both manned and unmanned vehicles.
- Launch Systems: The systems used to launch spacecraft into orbit, including both rockets and other types of launch vehicles.
- Ground Support Equipment: The equipment used to support space missions on the ground, including launch pads, mission control centers, and tracking stations.

A61: This IPC code pertains to the field of medical and veterinary science and hygiene. It covers various aspects of health and life-saving techniques. In the context of space activities, A61 could be relevant in several ways:

- Space Medicine: The development of medical procedures and treatments for astronauts in space.
- Life Support Systems: The design of life support systems for spacecraft.

- Health Monitoring: Devices and methods for monitoring the health of astronauts in space.

F16: This IPC code pertains to engineering elements or units, general measures for producing and maintaining effective functioning of machines or installations, and thermal insulation in general. Possible relevance to Space Activities:

- Spacecraft Construction: Design and construction of spacecraft.
- Thermal Management: The thermal insulation aspects of F16 could be crucial for managing the extreme temperatures encountered in space.
- Machine Maintenance: The measures for maintaining effective functioning of machines could be relevant for the operation and maintenance of spacecraft systems.

B23: This IPC code pertains to machine tools and metal working. It covers the working of metallic materials and non-metallic materials, provided that the methods applied are similar to those used in metal-working and not provided for elsewhere. In the context of the space sector, B23 could be relevant in several ways:

- Spacecraft Manufacturing: The design and construction of spacecraft require precise machining and metal working. This could involve turning, boring, milling, and grinding of various metals used in spacecraft1.
- Launch Systems: The manufacturing of launch systems, such as rockets, also requires extensive metal working. The precision and quality of these operations are critical for the safety and success of space missions.

G02: This IPC code is related to optics, applying not only to visible light but also to ultra-violet or infra-red radiations. In relation to space activities, G02 could be relevant in several ways:

- Telescopes: Space telescopes like the Hubble Space Telescope or the James Webb Space Telescope rely heavily on optical systems to capture and focus light from distant celestial objects.
- Optical Communication: Some space missions are exploring the use of lasers (an area of optics) for communication, which can provide higher data rates than traditional radio systems.
- Remote Sensing: Many Earth observation satellites use optical systems to capture images of the Earth's surface in various wavelengths of light. These images are used for a wide range of applications, from weather forecasting to environmental monitoring.

C12: This IPC code pertains to microorganisms or enzymes; propagating, preserving, or maintaining microorganisms; mutation or genetic engineering; culture media. It could be relevant to the space sector in several ways:

- Life Support Systems: Microorganisms could be used in life support systems on spacecraft for recycling waste, producing food, or generating oxygen.
- Astrobiology: The study of life in space (astrobiology) often involves the use of microorganisms or enzymes. This could include studying how life might survive on other planets or how life on Earth might be affected by conditions in space.
- Space Medicine: Genetic engineering could be used to develop treatments or preventative measures for health issues that astronauts face in the microgravity environment of space, such as muscle atrophy or radiation exposure.

To decipher and comprehend the trends in International Patent Classification (IPC) codes, it is imperative to juxtapose them with the downstream portfolio and ascertain the specific codes that distinctly define each of the two portfolios. Consequently, at this initial phase, we abstain from analyzing the trends in the codes. Having examined the upstream portfolio, we will now proceed to present the downstream portfolio. Following this, a comparative analysis between the two portfolios will be conducted, along with an examination of the trends of the major codes.

4.1.2 Downstream Portfolio

We will now proceed with a similar analysis for the downstream portfolio. Initially, we will present a succinct description of the International Patent Classification (IPC) codes that have not been previously included in the upstream portfolio. This will provide us with a comprehensive understanding of the unique components within the downstream portfolio.

Subsequently, we will conduct a comparative analysis of the two portfolios. This will enable us to discern and comprehend the variances between the upstream and downstream portfolios, thereby providing valuable insights into their respective performance trajectories over time.

In Figure 10 below, the time trend of the top 10 IPC codes in the downstream portfolio is shown.

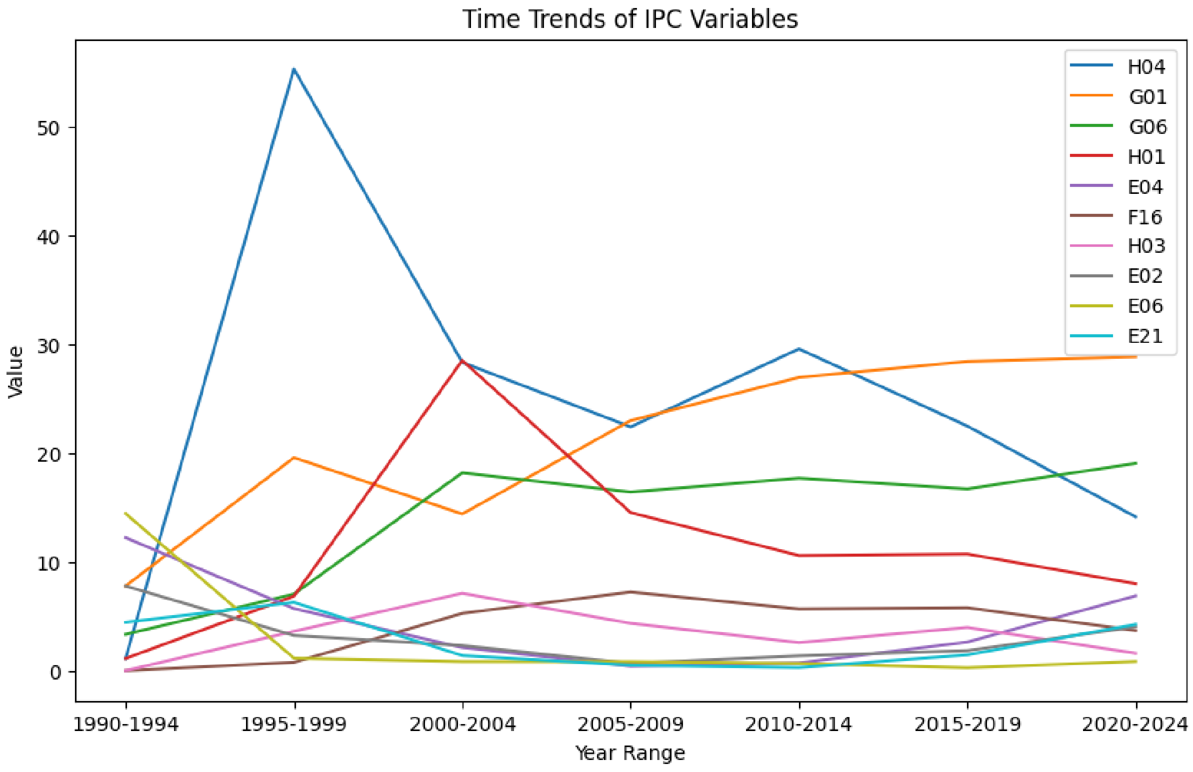


Figure 10: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. Downstream Portfolio.

E04: This IPC code pertains to building, including general building constructions; walls, e.g. partitions; roofs; floors; ceilings; insulation or other protection of buildings. In the context of space activities, E04 could be relevant in several ways:

- Space Infrastructure: The principles of building construction could be applied to the development of infrastructure on other celestial bodies, such as lunar bases or Martian habitats.
- Spacecraft Interior Design: The design of spacecraft interiors, including the arrangement of partitions, floors, and ceilings, could also fall under this code.

H03: This IPC code pertains to basic electronic circuitry, including modulation. In the context of downstream space activities, H03 could be relevant in several ways:

- Satellite Communication Systems: The principles of modulation could be applied to the design of communication systems for satellites3.
- Data Processing: The basic electronic circuitry covered under this code is fundamental to the operation of many systems on a spacecraft, from life support systems to navigation.

E02: This IPC code pertains to hydraulic engineering and foundation constructions. In the context of downstream space activities, E02 could be relevant in several ways:

- Resource Extraction: The principles of hydraulic engineering could be applied to the extraction of resources from other celestial bodies, such as the moon or asteroids.
- Spacecraft Foundations: The principles of foundation construction could inform the design of landing pads or bases for spacecraft on other celestial bodies.

E06: This IPC code pertains to equipment for fitting in or to buildings. In the context of downstream space activities, E06 could be relevant in several ways:

- Space Infrastructure: The principles of building construction could be applied to the development of infrastructure on other celestial bodies, such as lunar bases or Martian habitats.
- Spacecraft Interior Design: The design of spacecraft interiors, including the arrangement of partitions, floors, and ceilings, could also fall under this code.

E21: This IPC code pertains to earth or rock drilling; mining. In the context of downstream space activities, E21 could be relevant in several ways:

- Resource Extraction: The principles of earth drilling and mining could be applied to the extraction of resources from other celestial bodies, such as the moon or asteroids.
- Tunnel Construction: The methods used for making or lining tunnels, galleries, or large underground chambers on Earth could inform the construction of similar structures on other celestial bodies.

4.1.3 Upstream and downstream comparison

We shall now advance to the comparative analysis of the two portfolios, with the specific aim of discerning which International Patent Classification (IPC) codes are more emblematic of one portfolio over the other.

Our examination will particularly utilize Figures 11 and 12, which encapsulate the statistical attributes of the two portfolios. It is crucial to note that these values are intended to be interpreted as percentages. Each value denotes the proportional representation of a particular IPC code within the portfolio. This method of representation facilitates a more intuitive comprehension of the distribution and prevalence of each IPC code within the respective portfolios.

	From year	To year	H01	H04	G01	G06	B64	A61	F16	B23	G02	C12
0	1990	1994	15.152	15.152	9.091	12.121	18.182	24.242	6.061	3.030	0.000	3.030
1	1995	1999	26.108	33.990	22.660	15.271	0.985	15.764	0.000	4.433	7.389	2.956
2	2000	2004	31.690	7.887	16.901	11.127	8.169	1.408	9.437	2.394	0.563	7.606
3	2005	2009	29.037	9.477	14.329	7.354	10.083	0.986	9.401	2.578	2.654	3.108
4	2010	2014	23.305	20.659	9.239	7.660	9.006	0.789	5.989	5.060	1.811	1.393
5	2015	2019	34.799	15.937	10.122	7.360	11.521	1.363	6.542	4.289	4.961	1.526
6	2020	2024	26.273	19.519	13.377	11.388	13.552	1.639	2.776	1.945	5.814	2.361

Figure 11: Percentage of patents in the portfolio that contain each IPC code by period, Upstream.

	From year	To year	H04	G01	G06	H01	E04	F16	H03	E02	E06	E21
0	1990	1994	1.111	7.778	3.333	1.111	12.222	0.000	0.000	7.778	14.444	4.444
1	1995	1999	55.323	19.582	7.034	6.844	5.703	0.760	3.612	3.232	1.141	6.274
2	2000	2004	28.347	14.404	18.190	28.532	2.124	5.263	7.110	2.308	0.831	1.385
3	2005	2009	22.414	22.989	16.420	14.532	0.411	7.225	4.351	0.657	0.821	0.493
4	2010	2014	29.588	26.966	17.697	10.581	0.702	5.665	2.575	1.358	0.655	0.281
5	2015	2019	22.487	28.429	16.707	10.724	2.625	5.779	3.968	1.832	0.265	1.445
6	2020	2024	14.138	28.863	19.056	7.991	6.873	3.688	1.593	4.023	0.838	4.247

Figure 12: : Percentage of patents in the portfolio that contain each IPC code by period, Downstream

For the purpose of this analysis, our focus will be primarily directed towards the most significant disparities between the two portfolios.

Specifically, we observe that the most emblematic International Patent Classification (IPC) codes for the Upstream portfolio are H01 and B64. The former has a representation of 26.27%, a stark contrast to its 7.99% representation in the Downstream portfolio. The latter, B64, accounts for 13.55% of the Upstream portfolio and is notably absent from the top 10 IPC codes in the Downstream portfolio. These values are coherent with the nature of these two IPC codes. H01 pertains to the electrical and circuit components, while B64 is related to the structural aspects of the instruments and transportation means utilized in space. Consequently, they provide an accurate reflection of the Upstream sector.

The Downstream portfolio is primarily characterized by the International Patent Classification (IPC) codes G01 and G06, which hold respective values of 28.86% and 19.05%. In contrast, these codes represent 13.38% and 11.39% in the Upstream portfolio. These percentages pertain to the 2020-2024 period; the disparities were even more significant in earlier periods. These results are comprehensible when considering the nature of the G01 and G06 codes, which are associated with data collection, computation, and testing. These elements constitute the primary assets of downstream companies, as they utilize this information to deliver a product or service to users globally.

In the subsequent stages of comparative analysis involving the portfolios of space corporations, insights derived from these codes will be employed to discern whether there is a pronounced inclination towards either portfolio. Specifically, the trajectories of G01 and G06 will be scrutinized to assess the downstream portfolio, while the codes H01 and B64 will be examined for the upstream portfolio. This constitutes a pragmatic and empirical methodology aimed at acquiring a comprehensive understanding of the strategic intentions of these space enterprises.

4.2 NASA Portfolio

Having gained a comprehensive understanding of the Upstream and Downstream portfolios, we now turn our attention to the analysis of NASA's portfolio. Our objective is to discern any prevailing trends, specifically, to ascertain if there has been a shift in focus from upstream to downstream research. Our initial approach involves examining the temporal trend of the top 10 IPC codes within the portfolio and their distribution. This analysis is visually represented in Figure 13, which displays a line chart of the aforementioned data.

As part of our standard procedure, we will provide succinct descriptions for any IPC codes that have not been previously introduced due to their absence in the previous portfolios.

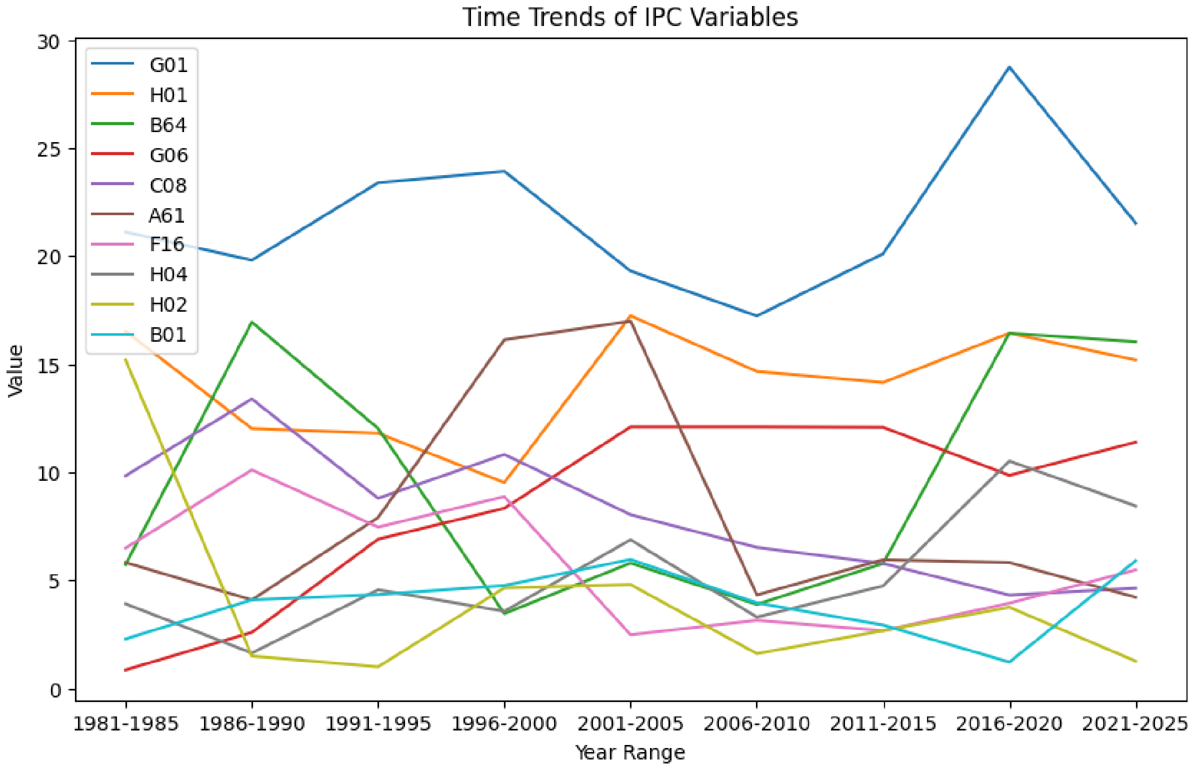


Figure 13: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. NASA Portfolio.

C08: This IPC code pertains to the field of chemistry and covers organic macromolecular compounds and their preparation or chemical working-up. In the context of space activities, C08 could be relevant in several ways:

- Material Science: The development of new materials for use in spacecraft and space suits.
- Fuel Development: The creation of new propellants for rockets.

H02: This IPC code pertains to the generation, conversion, or distribution of electric power. Relevance to Space Activities:

- Power Systems: The generation and distribution of electric power are crucial for spacecraft operations.

- Energy Conversion: The conversion of energy, such as solar energy into electrical energy, is a key aspect of many space missions and could be classified under H02.

B01: This IPC code pertains to physical or chemical processes or apparatus in general. Relevance to Space Activities:

- Life Support Systems: The physical and chemical processes could be used in the design of life support systems for manned space missions.
- Resource Utilization: The techniques for processing materials, such as extracting water from lunar soil.
- Scientific Experiments: Many space missions involve conducting physical or chemical experiments.

Upon initial observation, the IPC codes that were not present in the preceding portfolios appear to be more pertinent to the upstream category. For a more detailed examination, we will employ cosine similarity analysis to compare the NASA portfolio with the upstream and downstream portfolios. This will enable us to gain a more precise understanding of the statistical distribution. Figure 14 below shows the time trend of cosine similarieties between Nasa portfolio and Upstream/Downstream portfolios.

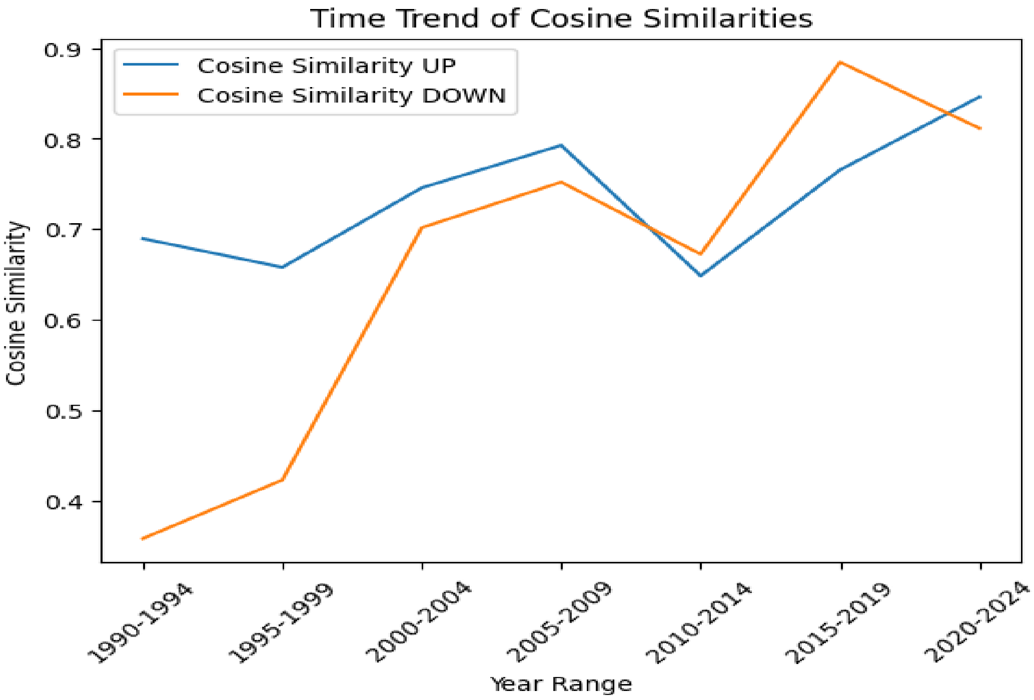


Figure 14: Cosine similarity between the NASA portfolio and the upstream and downstream portfolios

As depicted in Figure 14, it is evident that in the initial phase, there was a significant disparity between upstream and downstream research, with a pronounced concentration in the former. Specifically, the values over the period 1990-1994 are 0.69 and 0.36 for upstream and downstream, respectively.

Substantial investments in downstream research have not only bridged this gap but also surpassed it in the period from 2010 to 2020. To be precise, the cosine similarity values for the period 2015 - 2019 are 0.77 and 0.88 for the upstream and downstream sectors, respectively. However, in the recent period, we observe a minor shift in trend, with the similarity to the upstream sector once again surpassing that of the downstream.

To further our understanding, let's delve into the numerical data of the IPC codes to identify which ones have had the most significant impact. In relation to the primary downstream and upstream codes, we aim to discern any specific trends. Figure 15 below shows period by period all the percentages of the major IPC codes in the NASA portfolio.

	From year	To year	G01	H01	G06	B64	A61	C08	H04	F16	B25	B01
0	1990	1994	21.399	13.674	6.367	11.795	7.829	11.378	3.967	7.829	5.741	3.758
1	1995	1999	25.114	9.247	9.361	4.566	15.525	10.731	4.110	9.475	1.484	5.594
2	2000	2004	20.687	15.933	10.387	5.282	16.109	9.067	7.394	2.817	0.528	5.018
3	2005	2009	15.882	13.727	12.610	4.789	7.103	6.385	3.113	2.474	0.958	5.587
4	2010	2014	18.577	15.581	12.060	4.869	5.693	5.318	3.596	3.071	16.255	2.547
5	2015	2019	29.540	16.942	10.078	14.335	4.865	4.605	10.686	3.910	1.911	1.651
6	2020	2024	21.994	14.663	10.264	17.009	4.985	5.865	7.038	4.692	1.466	4.106

Figure 15: Percentage of patents in the portfolio that contain each IPC code by period, NASA

Considering the IPC codes that typify the upstream portfolio, namely H01 and B64, and those that define the downstream portfolio, specifically G01 and G06, let's scrutinize the principal shifts.

In the upstream domain, we observe a consistent investment in H01. However, the scenario for B64 is distinct: there is a substantial surge in investments in the last two time intervals, with this code escalating from 4.87% in the 2010-2014 period to 17.01% in the 2020-2024 period.

Conversely, in the downstream domain, there is a minor decrease in G06 from 12.06% in 2010-2014 to 10.26% in 2020-2024. The primary factor influencing the balance is the code G01, which experiences a significant drop from 29.54% in 2015-2019 to 21.99% in 2020-2024.

As previously highlighted, NASA does not exhibit a significant bias towards either the upstream or downstream sectors. However, recent trends indicate a subtle shift towards the upstream sector. This is particularly evident in the substantial investments directed towards research associated with the B64 code, which encompasses aircraft, aviation, and cosmonautics.

4.3 ESA Portfolio

In this segment, we will conduct a comprehensive examination of the ESA portfolio. As with our previous portfolio evaluations, we will initially provide a concise introduction to any IPC codes that have not been previously discussed. Subsequently, we will delve into a more detailed analysis.

Figure 16, displayed below, illustrates the proportional representation of IPC codes within the ESA patent portfolio across various time periods.

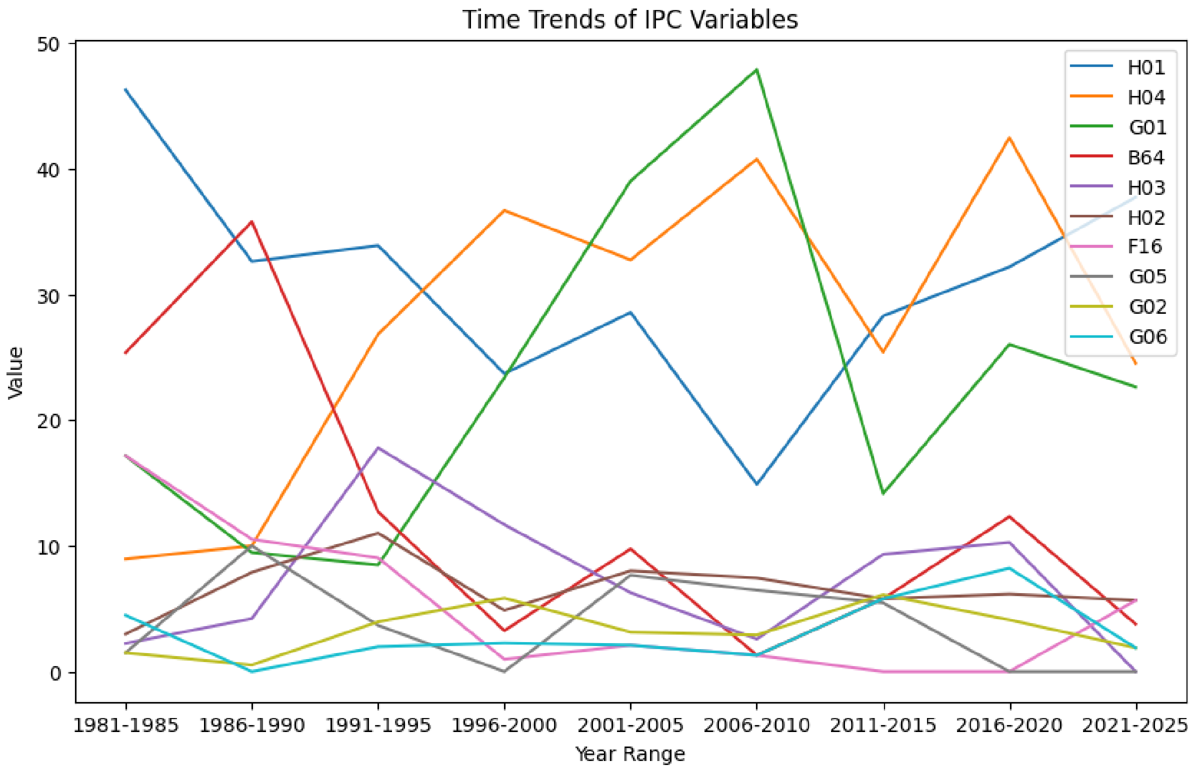


Figure 16: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. ESA Portfolio.

H02: This IPC code pertains to the generation, conversion, or distribution of electric power. Relevance to Space Activities:

- Power Systems: The generation and distribution of electric power are crucial for spacecraft operations.

- Energy Conversion: The conversion of energy, such as solar energy into electrical energy, is a key aspect of many space missions and could be classified under H02.

G05: This IPC code is related to controlling and regulating. It covers methods, systems, and apparatus for controlling, in general. This is particularly relevant to space agencies as it covers areas like control systems which are crucial in space technology. Here are a few examples:

- Attitude Control: Spacecraft use attitude control systems to orient themselves in space. These systems use various sensors and actuators to detect and adjust the spacecraft's orientation.
- Orbit Control: Maintaining a spacecraft's orbit requires careful control of its velocity and direction. This is often achieved using onboard propulsion systems.
- Robotic Systems: Many space missions involve robotic systems, such as the robotic arms on the International Space Station or the Mars rovers. Controlling these systems requires sophisticated control algorithms.

Once again, it seems that the two codes are associated with the upstream sector. For a more lucid understanding, Figure 17 below delineates the cosine similarity between the ESA portfolio and both the upstream and downstream portfolios, segmented by each time range.

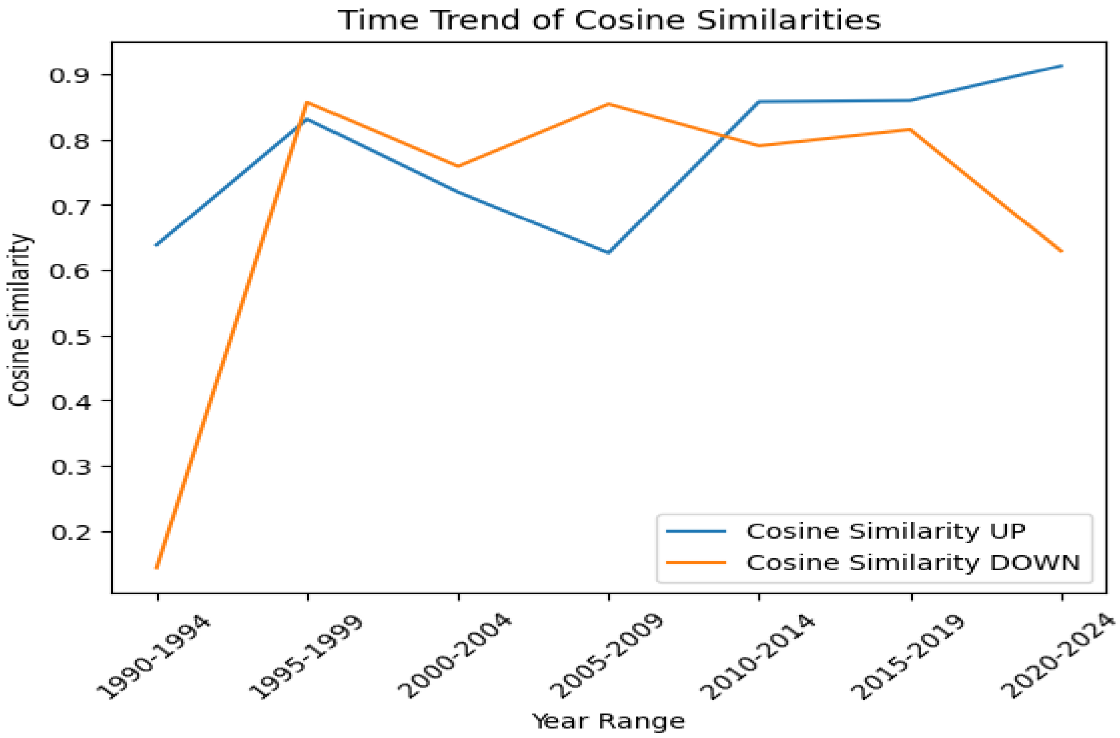
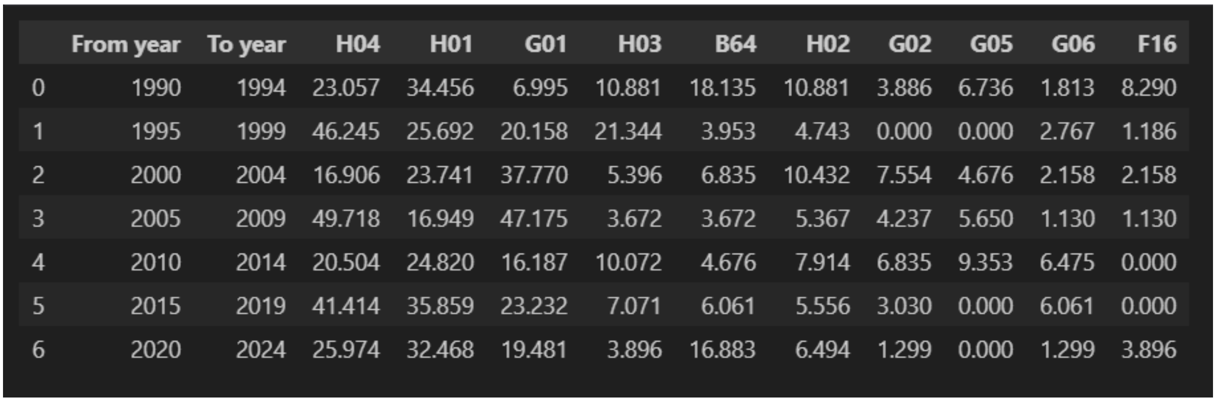


Figure 17: Cosine similarity between the ESA portfolio and the upstream and downstream portfolios

On a macroscopic level, the trajectory appears to closely mirror that of NASA: an initial skew towards the upstream sector, subsequently superseded by the downstream sector, and then a reversion back towards the upstream. Notably, for ESA, there is a more pronounced shift in the most recent period compared to NASA. The similarity with the upstream sector stands at 0.91, while that with the downstream sector is 0.63, indicating a clear trend.

Having established a general understanding of the ESA portfolio's trajectory, let's delve deeper into the primary IPC codes to discern the key drivers of this change. In accordance with our standard procedure, we will undertake a meticulous examination of the values presented in figure 18. These values represent the percentage of patents in which a specific IPC code appears, segmented by various time ranges.



	From year	To year	H04	H01	G01	H03	B64	H02	G02	G05	G06	F16
0	1990	1994	23.057	34.456	6.995	10.881	18.135	10.881	3.886	6.736	1.813	8.290
1	1995	1999	46.245	25.692	20.158	21.344	3.953	4.743	0.000	0.000	2.767	1.186
2	2000	2004	16.906	23.741	37.770	5.396	6.835	10.432	7.554	4.676	2.158	2.158
3	2005	2009	49.718	16.949	47.175	3.672	3.672	5.367	4.237	5.650	1.130	1.130
4	2010	2014	20.504	24.820	16.187	10.072	4.676	7.914	6.835	9.353	6.475	0.000
5	2015	2019	41.414	35.859	23.232	7.071	6.061	5.556	3.030	0.000	6.061	0.000
6	2020	2024	25.974	32.468	19.481	3.896	16.883	6.494	1.299	0.000	1.299	3.896

Figure 18: Percentage of patents in the portfolio that contain each IPC code by period, ESA

Upon examining the data, the dominance of the H04 code is immediately apparent, accounting for a staggering 49.72 percent in the 2005-2009 period. This implies that this IPC code was present in half of ESA's patents during that time frame. Conversely, the G06 code, despite its prevalence in other portfolios, registers a relatively low value. Specifically, it accounts for a mere 1.23 percent over the 2020-2024 period, in stark contrast to the 10.26 percent for NASA, 11.39 percent for the upstream sector, and 19.06 percent for the downstream sector during the same period.

Mirroring the trend observed with NASA, there is a significant upsurge in the B64 code, typically associated with the upstream sector. This code witnessed an increase from 6.06% in the 2015-2019 period to 16.88% in the subsequent period, 2020-2024. As for the other primary upstream code, H01, it maintains a consistently high value, standing at 32.47% in the 2020-2024 period. This aligns with the trend of the last two periods towards the upstream sector, as it was recorded at 24.82% in the 2010-2014 period.

Pertaining to the primary downstream codes, G01 and G06, there is a noticeable downward trend. As previously noted, G06 registers a significantly lower value in comparison to other portfolios, and this value has been on a decline in the recent period. Conversely, G01 maintains a substantial presence, despite a decrease when compared to the preceding period: it accounted for 23.23% in the 2015-2019 period and dropped to 19.48% in the 2020-2024 period, thereby corroborating the shift towards the upstream sector. A similar pattern is observed for the H03 code, which is exclusive to the downstream sector (it does not feature in the top 10 IPC codes for the upstream portfolio), and has been experiencing a decline in recent years. It is crucial to highlight that both IPC codes G01 and G06 are experiencing an upward trend in the downstream portfolio during the identical time frame.

4.4 JAXA Portfolio

This segment will delineate the structure of JAXA's portfolio. In accordance with our standard protocol, Figure 19 below exhibits a line graph depicting the top 10 IPC codes across various periods. It is important to note that the values represent the percentage of patents in which a specific IPC code appears for each time interval. Following the graph, we will introduce any IPC codes that have not been previously discussed.

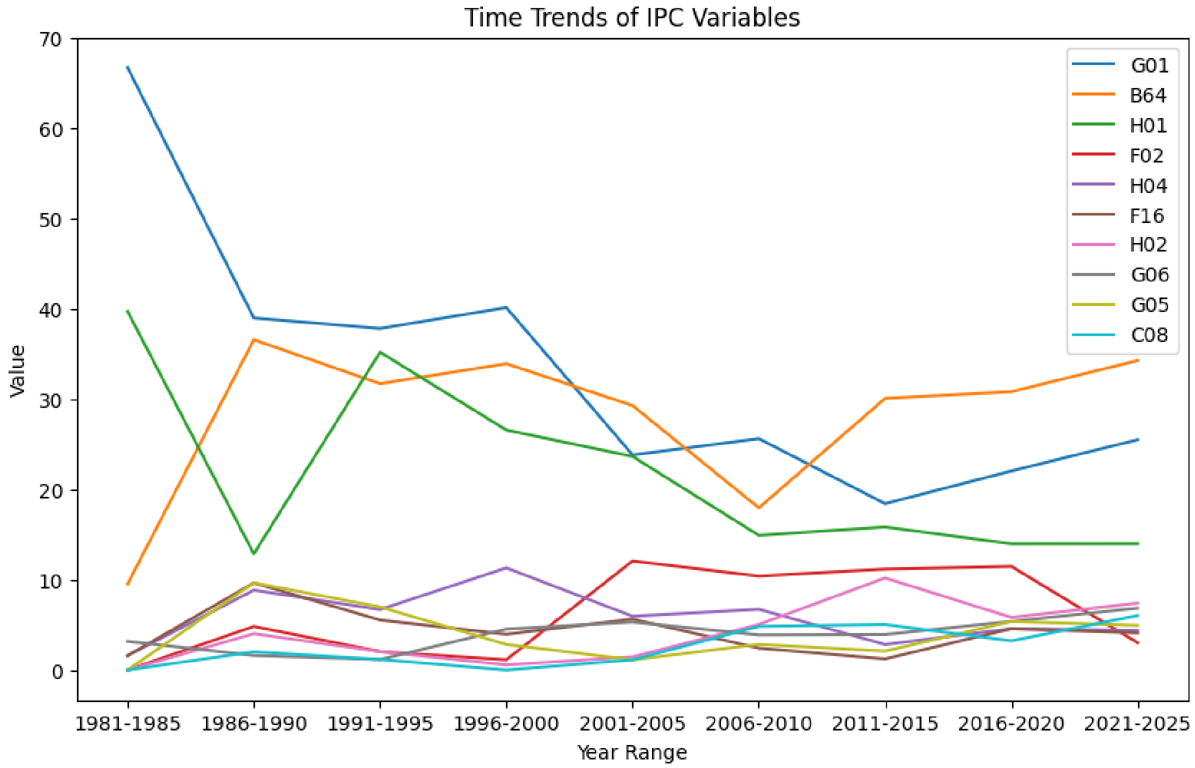


Figure 19: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. JAXA Portfolio.

F02: It covers internal-combustion piston engines, combustion engines in general, and gas-turbine plants. In the context of space activities, F02 could be relevant in several ways:

- Rocket Propulsion: The combustion engines covered under F02 can be used in the design and construction of rocket engines. These engines work on the principle of expelling hot gases generated from combustion to produce thrust.
- Spacecraft Power Systems: Combustion engines and gas-turbine plants can be used to generate power for spacecraft systems. For instance, gas turbines can be used in power generation systems for spacecraft.
- Air-Breathing Propulsion: For vehicles that operate within the Earth's atmosphere, such as space planes, the air intakes for jet-propulsion plants covered under F02 can be relevant.
- Turbochargers: Turbochargers, which are used for augmenting the mechanical power output of internal-combustion piston engines by increasing charge pressure, can be used in the design of high-performance propulsion systems.

Upon initial observation, this appears to be a code related to upstream procurement. To gain further insights into the trend, let's scrutinize the subsequent graph depicted in Figure 20. Similar to the NASA and ESA portfolios, it presents the values of the cosine distance of the JAXA portfolio in relation to the upstream and downstream portfolios.

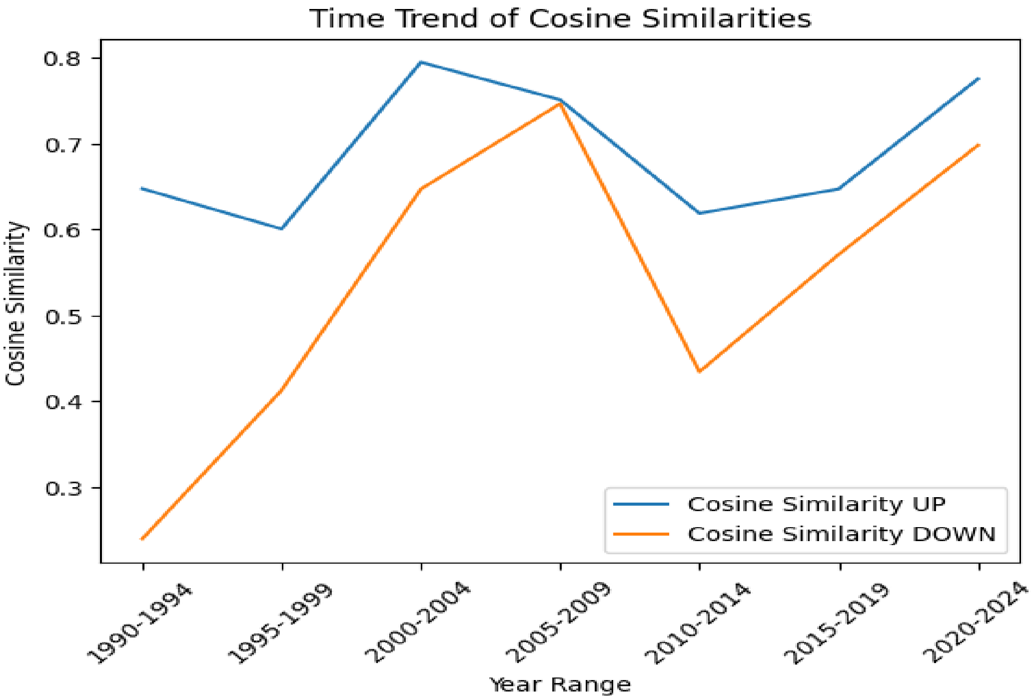


Figure 20: Cosine similarity between the JAXA portfolio and the upstream and downstream portfolios

In the context of JAXA, the overarching trend of the portfolio diverges in recent periods when juxtaposed with NASA and ESA. Initially, it exhibits the customary trajectory, initially leaning towards the upstream sector and subsequently gravitating towards the downstream sector. However, in the last two periods, it demonstrates growth in both compartments. This is in stark contrast to the other two space agencies, which were progressively distancing themselves from the downstream sector and aligning more with the upstream sector.

To articulate this with greater numerical precision, the cosine similarities stand at 0.70 and 0.76 with the downstream and upstream portfolios, respectively. These values, being notably similar, suggest that the current portfolio exhibits a balanced distribution between the two sectors.

To gain a deeper understanding of the factors driving this shift, let's examine the primary IPC codes in greater detail. Consequently, Figure 21 below presents a table showcasing the top 10 IPC codes for JAXA across various time frames.

	From year	To year	B64	G01	H01	F02	H04	H02	F16	G05	G06	C08
0	1990	1994	33.718	34.870	32.277	1.729	6.916	2.882	7.781	8.069	0.576	2.305
1	1995	1999	31.746	41.270	22.222	1.587	7.937	1.587	5.291	5.291	2.646	0.000
2	2000	2004	32.983	26.681	31.723	8.403	5.672	1.891	5.042	0.630	6.092	1.050
3	2005	2009	15.010	27.383	13.590	11.866	8.114	2.840	3.347	3.144	4.564	3.854
4	2010	2014	32.506	16.749	16.998	10.670	2.481	9.553	1.117	0.496	2.854	4.467
5	2015	2019	31.279	20.075	12.512	13.259	3.641	8.217	4.015	4.669	4.762	4.015
6	2020	2024	31.081	26.689	15.878	3.209	5.405	5.068	4.392	7.095	7.432	5.068

Figure 21: Percentage of patents in the portfolio that contain each IPC code by period, JAXA

The primary deviation in this portfolio, as compared to its predecessors, is the pronounced prevalence of the B64 code. This code, which is characteristic of the Upstream sector, constitutes an average of 30 percent of JAXA's portfolio, a figure that is more than twice that of other portfolios. Specifically, in the 2020-2024 period, it comprises 31.08 percent of all patents.

Broadly speaking, the portfolio has remained stable over the past decade, with no significant alterations. There is a marginal growth in both upstream and downstream IPC codes. Notably, both G01 and G06 codes, which are distinctive to the downstream sector, have been escalating in the last two periods, despite their decline in their respective portfolios. This suggests a subtle divergence in JAXA's trajectory as compared to other agencies and downstream companies.

4.5 CNSA Portfolio

Our discourse on the portfolios of space agencies persists, with our focus now shifting to the China National Space Administration (CNSA). As with our prior examinations, we commence by delineating the overarching trend of the top 10 International Patent Classification (IPC) codes, supplementing the introduction of new codes with succinct descriptions. Figure 22 provides a graphical representation of the proportion each IPC code contributes to the portfolio across different periods.

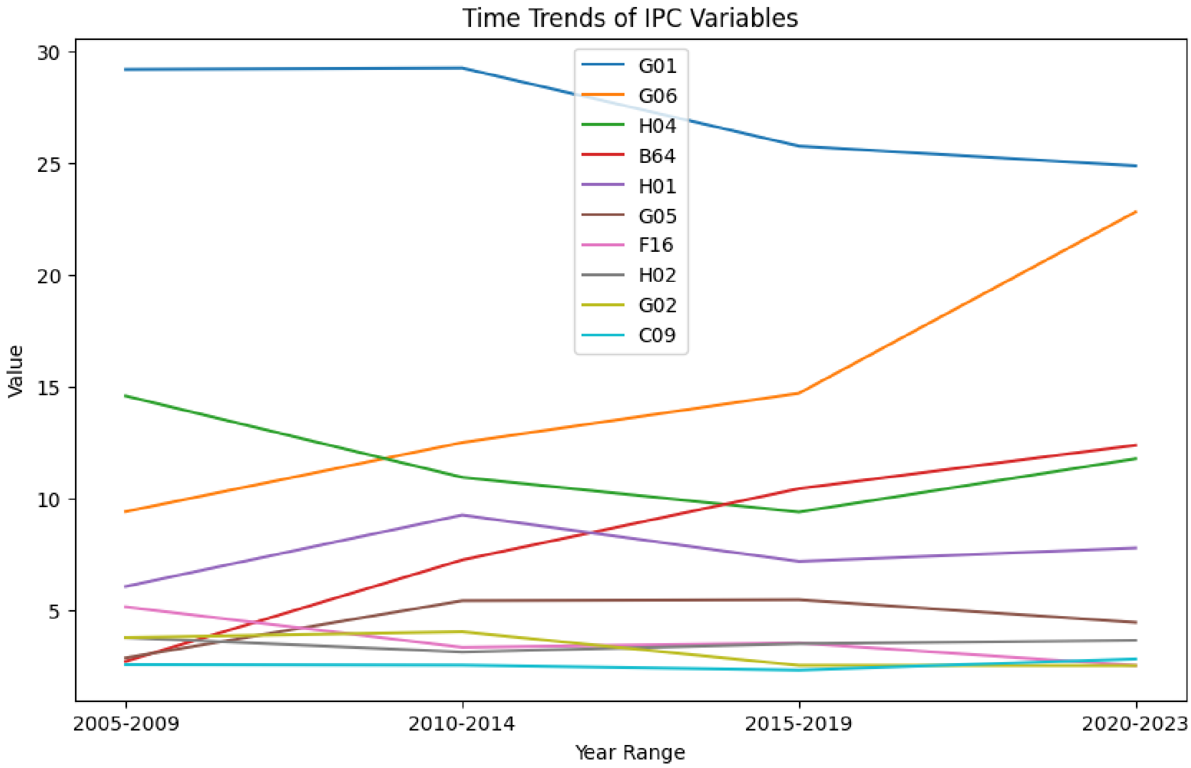


Figure 22: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. CNSA Portfolio.

In this instance, the span of periods under consideration is relatively limited in comparison to prior portfolios. This is primarily due to the insufficiency of data, which could potentially compromise the precision of the analysis. Consequently, the decision was made to focus on a more constricted range of years, thereby ensuring the reliability of the information obtained.

C09: pertains to Chemistry and Metallurgy. It covers a wide range of chemical compounds and their methods of preparation, applied chemistry, certain industries, operations, treatments, and metallurgy. In the context of space activities, C09 could be relevant in several ways:

- Materials for Spacecraft: The chemical compounds covered under C09 can be used in the design and construction of various materials for spacecraft. This includes the development of specialized alloys, ceramics, and plastics that can withstand the harsh conditions of space.
- Energy Generation and Storage: The chemistry of energy generation and storage systems, such as fuel cells and batteries, is covered under C09. This includes the chemistry of electrolytes, electrodes, and other components of these systems.
- Surface Coatings: C09 also covers the chemistry of surface coatings, which can be crucial for spacecraft. These coatings can provide protection against radiation, thermal extremes, and micrometeoroid impacts.

Utilizing the concept of cosine similarity, we conduct an analysis of CNSA's selection patterns in relation to both upstream and downstream portfolios. The graphical representation of this cosine similarity, delineated period by period, is illustrated in Figure 23.

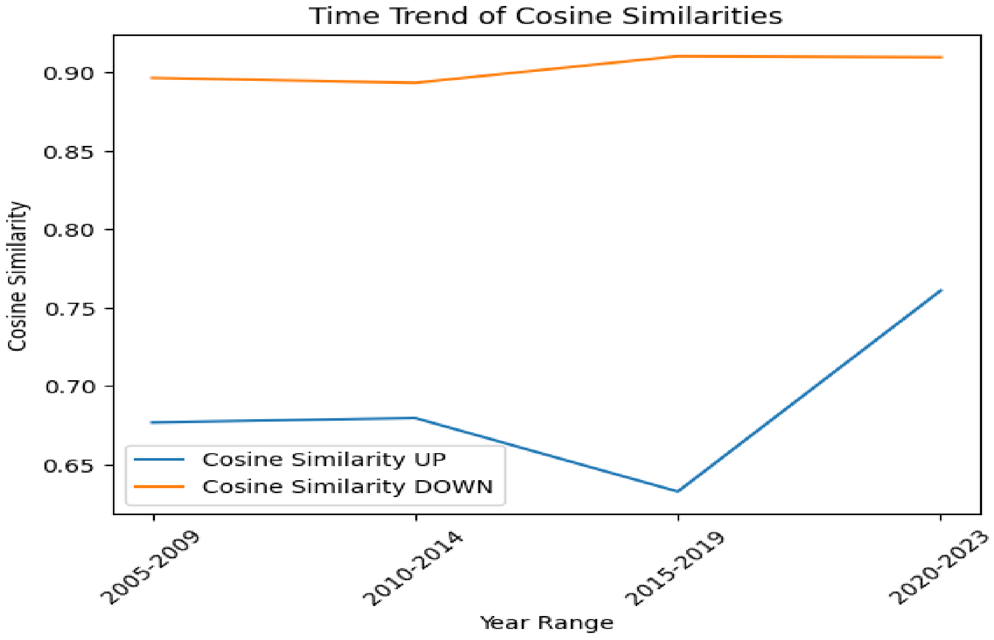


Figure 23: Cosine similarity between the CNSA portfolio and the upstream and downstream portfolios

Upon initial observation, it is apparent that the primary focus of CNSA's portfolio is on the downstream sector. During the 2015 - 2019 period, it achieves a cosine similarity value of 0.91 with the downstream portfolio. Simultaneously, the value relative to the upstream portfolio is 0.63, marking a distinct divergence from the preceding period. Nevertheless, the final period reveals significant growth in the latter sector, exhibiting a similarity of 0.76. On a broader scale, a consistent pattern is observable across other agencies, with the downstream sector demonstrating expansion in the final period. To delve deeper into this trend, we will proceed to scrutinize the principal shifts in the portfolio IPC codes. Figure 24 below presents a table delineating the percentage values of each IPC code for every respective period within the portfolio.

	From year	To year	G01	G06	H04	B64	H01	G05	F16	H02	G02	C09
0	2005	2009	29.179	9.422	14.590	2.736	6.079	2.888	5.167	3.799	3.799	2.584
1	2010	2014	29.239	12.509	10.957	7.265	9.269	5.441	3.361	3.150	4.054	2.562
2	2015	2019	25.754	14.710	9.404	10.450	7.200	5.484	3.554	3.524	2.554	2.346
3	2020	2023	24.869	22.814	11.785	12.391	7.798	4.474	2.548	3.671	2.542	2.843

Figure 24: Percentage of patents in the portfolio that contain each IPC code by period, CNSA

The portfolio exhibits a considerable degree of stability in the most recent periods. It is evident that the codes H04 and B64, which represent the upstream sector, have experienced a modest growth in recent periods, thereby indicating a heightened interest in this sector. Pertaining to the downstream sector, as anticipated, the values are significantly high, underscoring the precedence accorded to this sector by CNSA. Specifically counterbalancing the expansion of the upstream sector is the downstream code G06. This code witnessed an increase from 14.71 percent to 22.81 percent in the final period, thereby maintaining the downstream domain's status quo.

4.6 KARI Portfolio

We shall now advance to the examination of the portfolio belonging to the Korea Aerospace Research Institute (KARI). Figure 25 reproduces the chart featuring the principal IPC codes, supplemented with concise descriptions of those that have not been previously introduced.

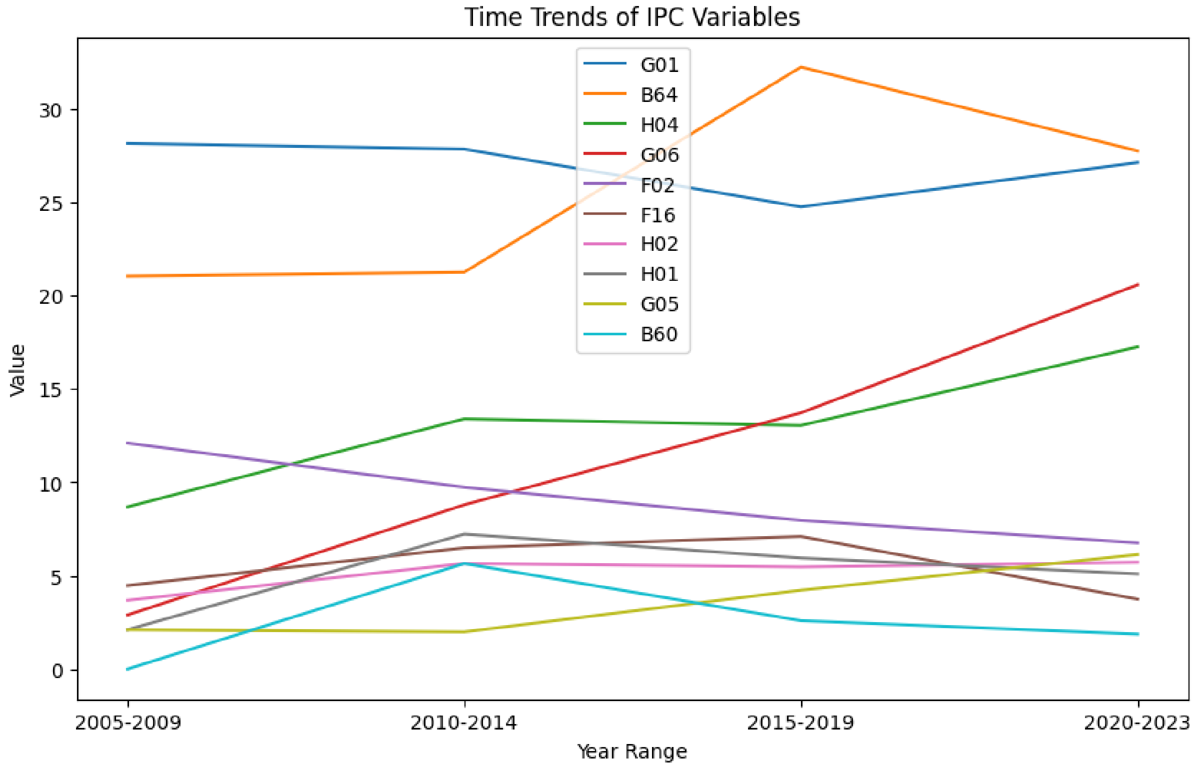


Figure 25: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. KARI Portfolio.

Once again, the time span under consideration is more limited due to a scarcity of data and a deficient quantity of patents in earlier periods. Subsequently, we present IPC code B60, which has not been previously introduced.

B60: pertains to Vehicles in General. It covers a wide range of aspects related to vehicles, including their design, construction, and operation. In the context of space activities, B60 could be relevant in several ways:

- Rover Design: This includes the design of wheels, axles, and other components crucial for rover mobility.
- Brake Systems: B60 covers vehicle brake control systems, which can be relevant for spacecraft that need to decelerate during landing or docking maneuvers.
- Air-Cushion Vehicles: B60 also covers air-cushion vehicles, which can be relevant for the design of vehicles that need to operate in low-gravity environments, such as the lunar surface.

Having established a comprehensive understanding of the IPC codes within the portfolio, we can now observe in Figure 26 the temporal trend of cosine similarities for the KARI agency, juxtaposed with the upstream and downstream portfolios.

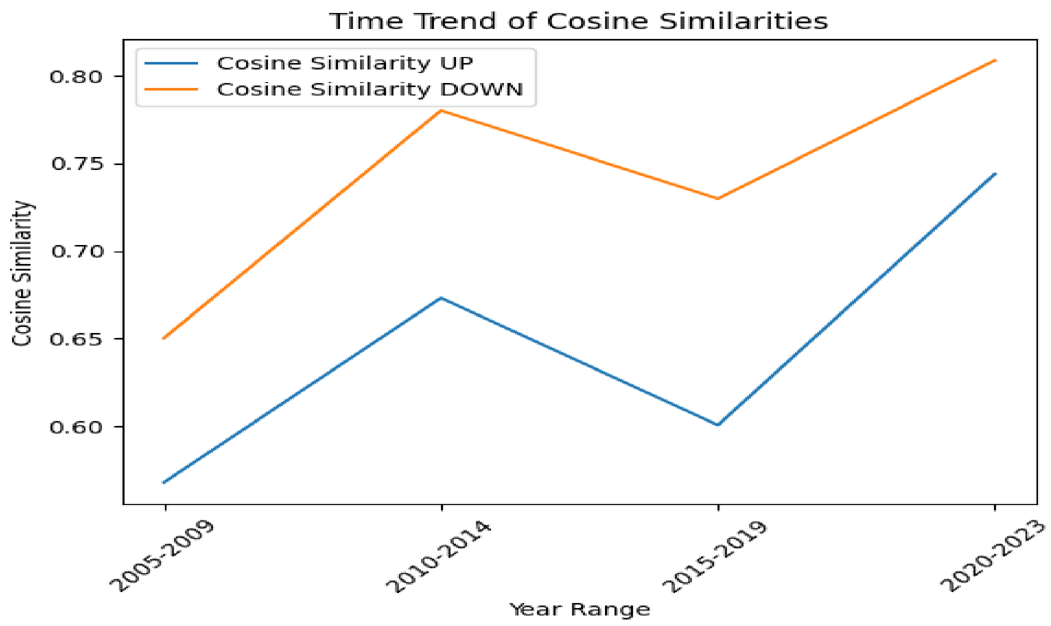


Figure 26: Cosine similarity between the KARI portfolio and the upstream and downstream portfolios

Once again, the portfolio exhibits a stronger emphasis on the downstream sector. However, it is noteworthy that the overall values are more tempered compared to previous agencies, with the initial values even falling below 0.60 for the upstream portfolio. Specifically, for the 2005-2009 period, the cosine similarity with the upstream sector is 0.57, while that with the downstream sector is 0.65 - decidedly modest values. In more recent periods, we observe a pronounced alignment with the benchmark portfolios. Specifically, in the 2020-2023 period, the similarity with the upstream portfolio escalates to 0.74, while the downstream portfolio reaches 0.81. To comprehend these disparities, we shall proceed to a meticulous examination of the IPC codes delineated in the table in Figure 27.

	From year	To year	G01	B64	H04	G06	F02	F16	H02	H01	G05	B60
0	2005	2009	28.158	21.053	8.684	2.895	12.105	4.474	3.684	2.105	2.105	0.000
1	2010	2014	27.853	21.257	13.403	8.796	9.738	6.492	5.654	7.225	1.990	5.654
2	2015	2019	24.760	32.246	13.052	13.724	7.965	7.102	5.470	5.950	4.223	2.591
3	2020	2023	27.131	27.755	17.256	20.582	6.757	3.742	5.717	5.094	6.133	1.871

Figure 27: Percentage of patents in the portfolio that contain each IPC code by period, KARI

The portfolio's initial divergence from the benchmarks becomes increasingly evident. Indeed, as it strikes a balance between upstream and downstream, it is consequently less akin to either of the two specifically. This is particularly true in the early periods, where we observe a significant presence of F02, a code that typically does not exhibit high values and which sees a 50 percent reduction in later periods in favor of other more prevalent codes. In fact, in the subsequent periods, the similarity with benchmark portfolios intensifies. It is noteworthy to mention the remarkable growth of G06 from 13.72% in the 2015-2019 period to 20.58% in the 2020-2023 period. This figure is distinctive in that G06 is a more downstream code, and in the downstream portfolio, there is a decrease in the same over the identical period.

4.7 Roscosmos Portfolio

In this section, we will undertake an analysis of the portfolio belonging to the Russian space corporation, ROSCOSMOS. Given the limited data at our disposal, the periods under scrutiny are the most recent ones. Figure 28 below illustrates the trajectory of the top 10 IPC codes, that is, those codes that recur most frequently in patents for each respective period.

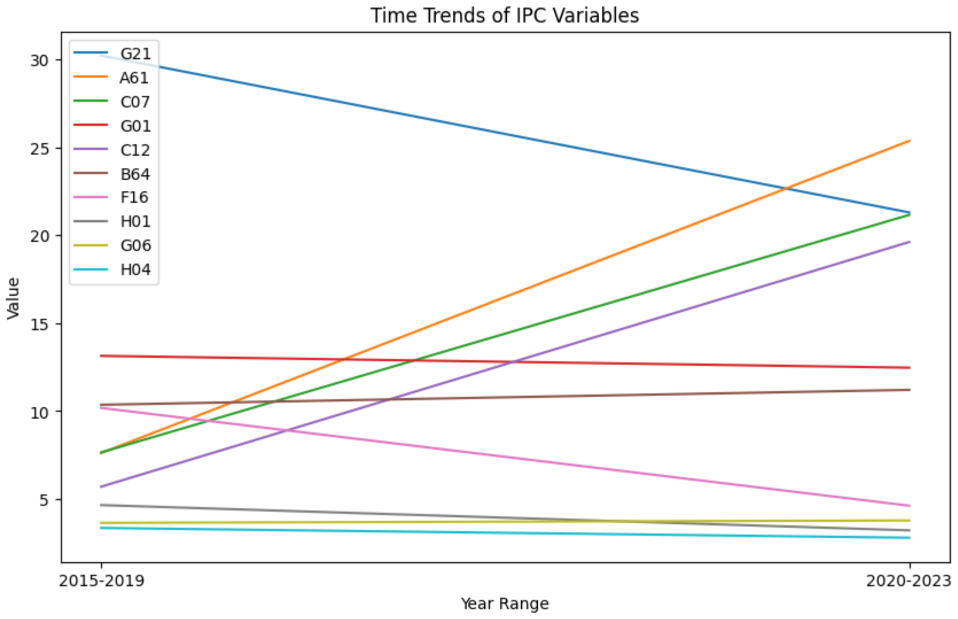


Figure 28: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. ROSCOSMOS Portfolio.

G21: pertains to Nuclear Physics; Nuclear Engineering. It covers a wide range of aspects related to nuclear physics and engineering, including fusion reactors, nuclear reactors, nuclear power plants, and more. In the context of space activities, G21 could be relevant in several ways:

- Nuclear Propulsion: Can be used in the design and construction of nuclear propulsion systems for spacecraft. This includes both fission and fusion-based propulsion systems.
- Power Generation: Nuclear power plants and reactors covered under G21 can be used to generate power for spacecraft systems. This can be particularly useful for long-duration space missions where solar power might not be sufficient or reliable.

- Radiation Shielding: The principles of nuclear physics covered under G21 can be used in the design of radiation shielding for spacecraft. This is crucial for protecting both the spacecraft's electronics and the crew from harmful cosmic radiation.

C07: covers a wide range of aspects related to chemistry and metallurgy, including inorganic compounds, organic compounds, macromolecular compounds, and their methods of preparation. In the context of space activities, C07 could be relevant in several ways:

- Propellant Chemistry: The chemistry of propellants, which are crucial for rocket propulsion, falls under this category. The formulation and optimization of propellants require a deep understanding of the chemical properties and reactions of various compounds.
- Life Support Systems: The chemistry involved in life support systems, such as the production of breathable air and the recycling of waste, can be covered under C07. This includes the chemistry of gases and the processes involved in their purification and management.
- Energy Generation and Storage: The chemistry of energy generation and storage systems, such as fuel cells and batteries, is covered under C07. This includes the chemistry of electrolytes, electrodes, and other components of these systems.

It is particularly intriguing to observe that two of the top three IPC codes in this portfolio (G21 and C07) are codes that have not surfaced in any of the preceding portfolios. The remaining code, A61, is only present in the NASA portfolio, albeit in markedly minimal proportions. These data underscore the distinctiveness of ROSCOSMOS in comparison to the other portfolios. To gain a more lucid understanding, let us examine the cosine similarities in relation to the upstream and downstream benchmark portfolios, as depicted in Figure 29.

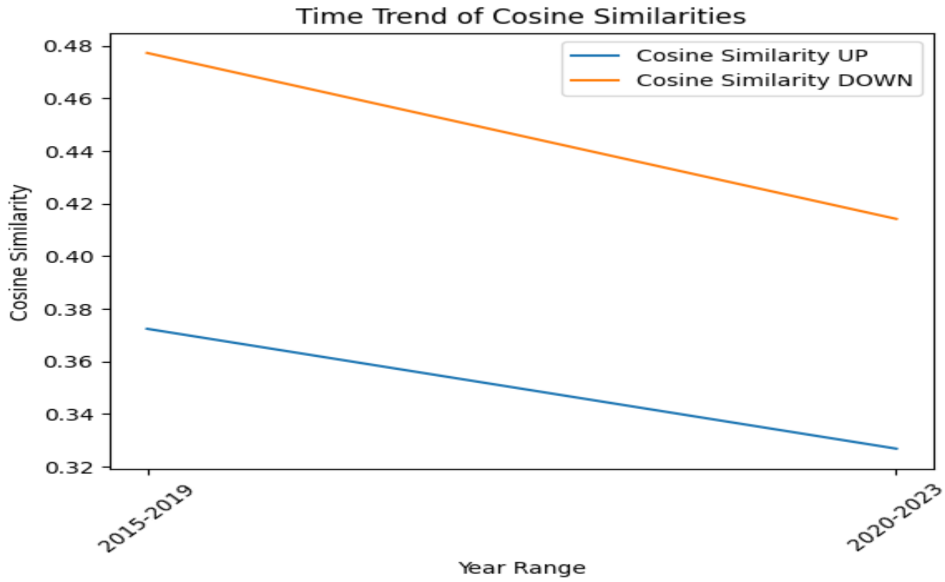


Figure 29: Cosine similarity between the ROSCOSMOS portfolio and the upstream and downstream portfolios

In this scenario, the values are markedly more extreme than those observed for the KARI agency. Given the preceding discussion, we anticipated considerably low values. We still discern a higher similarity with the downstream portfolio, despite both similarities exhibiting a declining trend in the second period. Specifically, the similarity with the upstream portfolio diminishes from 0.37 in the 2015-2019 period to 0.33 in the 2020-2023 period. Conversely, for the downstream, it decreases from 0.47 to 0.41. Let us now delve into a detailed examination of the information pertaining to the main IPC codes, as presented in the table in Figure 30.

	From year	To year	G21	A61	C07	G01	C12	B64	F16	H01	G06	H04
0	2015	2019	30.206	7.615	7.651	13.136	5.702	10.357	10.177	4.655	3.645	3.356
1	2020	2023	21.289	25.350	21.148	12.465	19.608	11.204	4.622	3.221	3.782	2.801

Figure 30: Percentage of patents in the portfolio that contain each IPC code by period, ROSCOSMOS

Upon examining the numerical values, it is immediately evident that codes H01, G06, and H04 do not rank among those with the highest values. Indeed, the majority of the portfolios analyzed thus far predominantly comprise these codes. In contrast, for ROSCOSMOS, all these codes register values of less than 4 percentage points over the 2020-2023 period. Consequently, it becomes challenging to conduct an analysis aimed at discerning the scientific research trend of this agency, as it deviates from the conventional norms. It appears to chart its own unique course, with a significant emphasis on nuclear research, as evidenced by the G21 code, which accounts for 30.21 percent and 21.29 percent in the 2015-2019 and 2020-2023 periods, respectively.

4.8 CNES Portfolio

In this section, we undertake a comprehensive analysis of the French space agency, CNES. Given our prior examination of the European Space Agency (ESA), it presents an opportunity to draw a comparative study between the two entities. Refer to Figure 31 for a visual representation of the temporal trends associated with the top 10 International Patent Classification (IPC) codes.

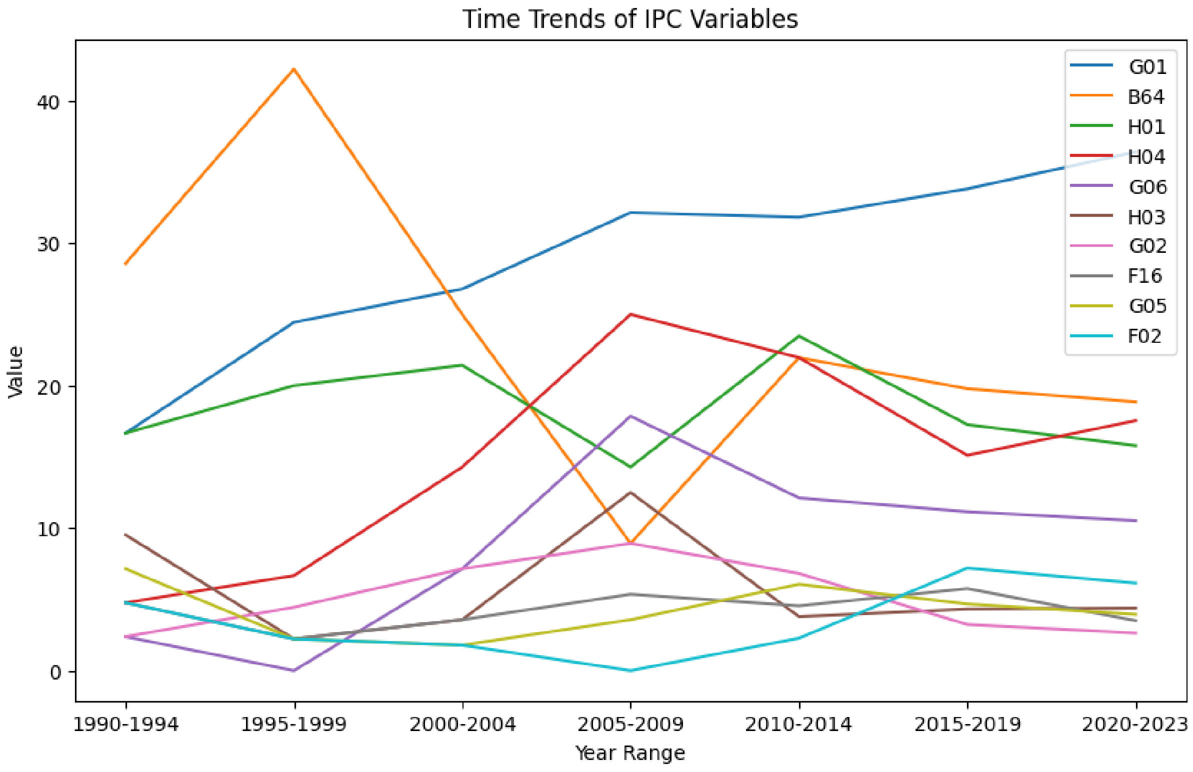


Figure 31: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. CNES Portfolio.

As is our usual practice, we proceed by introducing codes that have not yet been submitted and then do a more in-depth analysis.

F02: covers a wide range of aspects related to combustion engines and hot-gas or combustion-product engine plants, including internal-combustion piston engines. In the context of space activities, F02 could be relevant in several ways:

- Rocket Propulsion: The combustion engines covered under F02 can be used in the design and construction of rocket engines. These engines work on the principle of expelling hot gases generated from combustion to produce thrust.
- Spacecraft Power Systems: Combustion engines and hot-gas or combustion-product engine plants can be used to generate power for spacecraft systems. For instance, gas turbines can be used in power generation systems for spacecraft.
- Air-Breathing Propulsion: For vehicles that operate within the Earth's atmosphere, such as space planes, the air intakes for jet-propulsion plants covered under F02 can be relevant.

As depicted in the graph, the distribution of the primary codes exhibits a pattern that is somewhat reflective of those observed in other space agencies. For a more granular view and numerical correlation, we refer to Figure 32, which illustrates the trend of cosine similarities with the upstream and downstream benchmark portfolios.

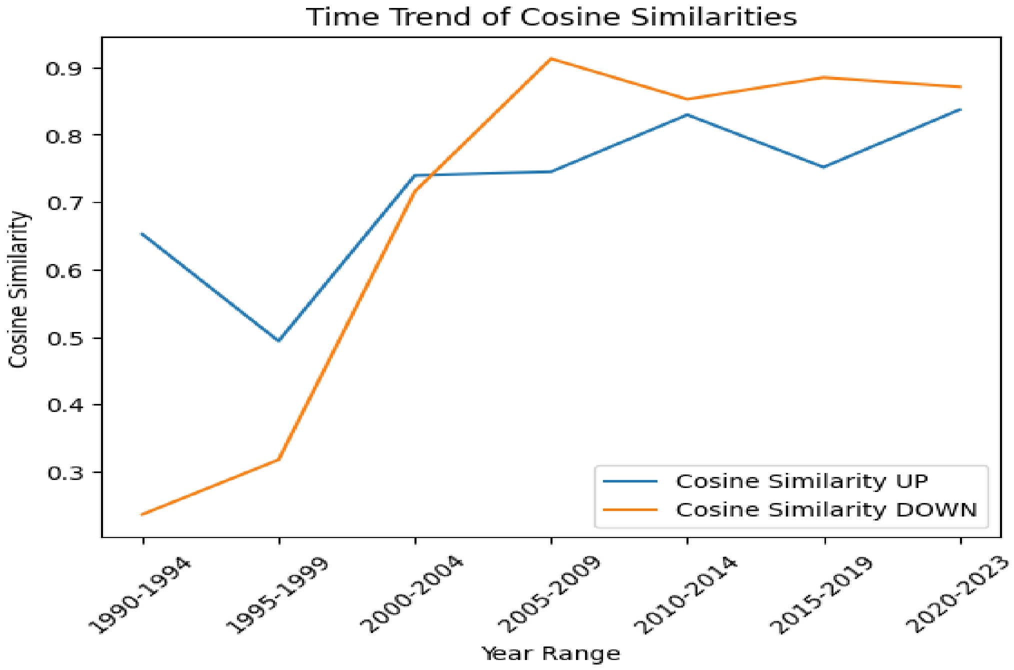


Figure 32: Cosine similarity between the CNES portfolio and the upstream and downstream portfolios

Upon reaching this juncture in our analysis, it becomes apparent that a shared trend emerges across the majority of the agencies. Initially, all agencies exhibit relatively low values in the downstream sector, which subsequently experience significant growth, resulting in a more developed downstream sector compared to the upstream.

To elucidate with specific data, during the 1990 - 1994 period, the similarities for the upstream and downstream sectors were 0.65 and 0.24, respectively. A notable transition is observed in the 2005 - 2009 period, where the downstream sector surpasses the upstream, with similarities of 0.74 and 0.91 for the upstream and downstream sectors, respectively. In the most recent period, 2020 - 2023, there is an observed growth in the upstream sector, while the downstream sector remains stable. Specifically, the similarities are 0.84 and 0.87 for the upstream and downstream sectors, respectively.

To better understand this information with more specific data, the table in Figure 33 below shows the information for each IPC code.

	From year	To year	G01	B64	H01	H04	G06	H03	G02	F16	G05	F02
0	1990	1994	16.667	28.571	16.667	4.762	2.381	9.524	2.381	4.762	7.143	4.762
1	1995	1999	24.444	42.222	20.000	6.667	0.000	2.222	4.444	2.222	2.222	2.222
2	2000	2004	26.786	25.000	21.429	14.286	7.143	3.571	7.143	3.571	1.786	1.786
3	2005	2009	32.143	8.929	14.286	25.000	17.857	12.500	8.929	5.357	3.571	0.000
4	2010	2014	31.818	21.970	23.485	21.970	12.121	3.788	6.818	4.545	6.061	2.273
5	2015	2019	33.813	19.784	17.266	15.108	11.151	4.317	3.237	5.755	4.676	7.194
6	2020	2023	36.404	18.860	15.789	17.544	10.526	4.386	2.632	3.509	3.947	6.140

Figure 33: Percentage of patents in the portfolio that contain each IPC code by period, CNES

From the perspective of International Patent Classification (IPC) codes, the portfolio does not exhibit any outliers or specific noteworthy values. A point of interest arises during the period where the downstream sector surpasses the upstream in terms of similarity. During this time, there is a significant decline in the B64 code, which is inherently an upstream code. Specifically, this code decreases from 25% in the 2000 - 2004 period to 8.93% in the 2005 - 2009 period.

Regarding the other codes, they align with our expectations. In fact, G01, H01, and H04 frequently constitute the majority of patent shares. G06 lags slightly behind at 10.56% over the 2020 - 2023 period. However, it is important to note that historically, CNES has not heavily invested in this area, as evidenced by the fact that from 1990 - 2004, it never exceeds 8%.

4.9 DLR Portfolio

The final agency under scrutiny in this study is the German Aerospace Center, DLR. We once again present the values of the top 10 International Patent Classification (IPC) codes, as depicted in Figure 34.

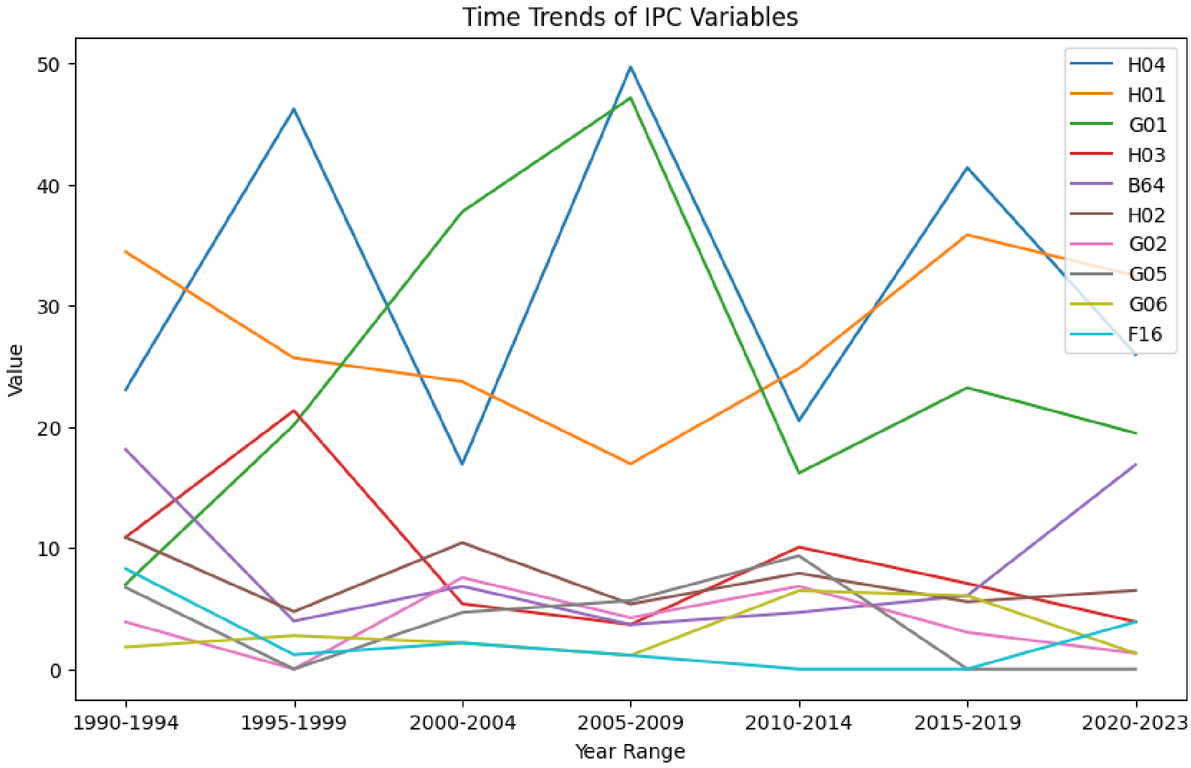


Figure 34: Graph containing the top 10 IPC codes. Y-axis: percentage of patents in the portfolio that contain each IPC code, X-axis: time range. DLR Portfolio.

In this instance, all International Patent Classification (IPC) codes pertinent to the graph have been previously introduced, thus we will advance directly to the analysis.

Even without delving into the specific numerical values, the substantial variability of the primary codes, notably H04 and G01, is readily observable. For a more lucid understanding, we will present in figure 35 the graph illustrating the cosine similarity in relation to the upstream and downstream sectors, thereby facilitating a comprehensive comprehension of the overarching trend.

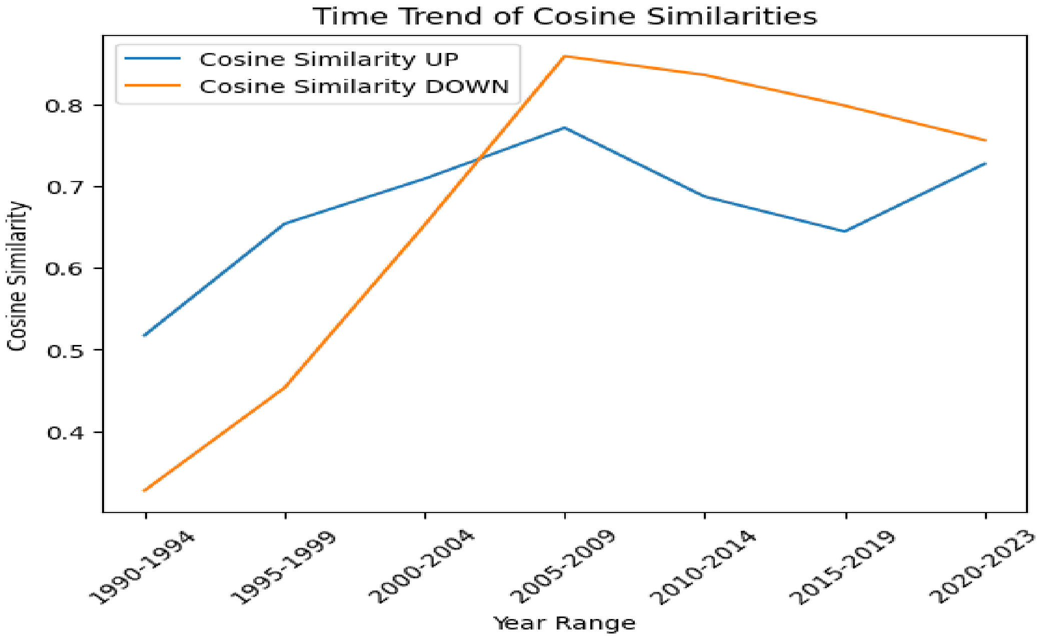
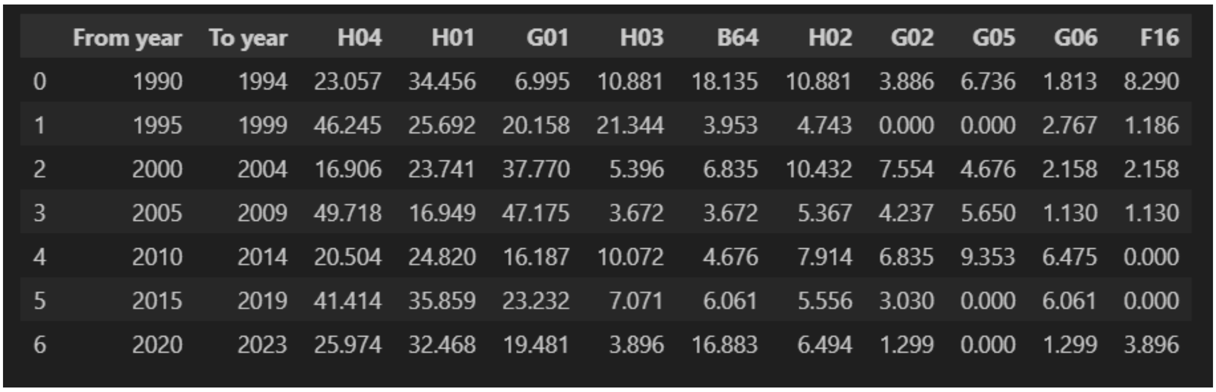


Figure 35: Cosine similarity between the DLR portfolio and the upstream and downstream portfolios

Upon completion of the analysis of the French space agency, the parallels in terms of cosine similarity are readily apparent. This is anticipated, given that both entities are European space agencies. The trend is indeed congruent, albeit the values are proportionally smaller in this case. Specifically, the initial similarities for the 1990 - 1994 period are 0.52 and 0.33 for the upstream and downstream sectors, respectively. The downstream sector surpasses the upstream in the 2005 - 2009 period, with similarity values of 0.77 and 0.86 for the upstream and downstream sectors, respectively. Consistent with the trend observed in most agencies, DLR also experiences growth in the upstream sector in the most recent period, culminating in values of 0.73 and 0.76 for the upstream and downstream sectors, respectively, in the 2020 - 2023 period.

We now proceed to a more detailed examination of each International Patent Classification (IPC) code. Figure 36 presents a table depicting the percentage value for each code, segmented by period.



	From year	To year	H04	H01	G01	H03	B64	H02	G02	G05	G06	F16
0	1990	1994	23.057	34.456	6.995	10.881	18.135	10.881	3.886	6.736	1.813	8.290
1	1995	1999	46.245	25.692	20.158	21.344	3.953	4.743	0.000	0.000	2.767	1.186
2	2000	2004	16.906	23.741	37.770	5.396	6.835	10.432	7.554	4.676	2.158	2.158
3	2005	2009	49.718	16.949	47.175	3.672	3.672	5.367	4.237	5.650	1.130	1.130
4	2010	2014	20.504	24.820	16.187	10.072	4.676	7.914	6.835	9.353	6.475	0.000
5	2015	2019	41.414	35.859	23.232	7.071	6.061	5.556	3.030	0.000	6.061	0.000
6	2020	2023	25.974	32.468	19.481	3.896	16.883	6.494	1.299	0.000	1.299	3.896

Figure 36: Percentage of patents in the portfolio that contain each IPC code by period, DLR

The portfolio of DLR, as depicted in the table, exhibits a pronounced polarization: a few International Patent Classification (IPC) codes register significantly high values, while the remainder are relatively low. Notably, the H04 code demonstrates substantial fluctuation across each period, oscillating from a peak of 49.72% in the 2005 - 2009 period to 20.51% in the subsequent period. This pattern of sharp increase followed by a decrease is a recurring trend.

The other primary codes maintain a degree of stability. It is noteworthy to highlight the significant surge in the B64 code in the most recent period, escalating from 6.06% in the 2015 - 2019 period to 16.88% in the 2020 - 2023 period. This underscores an intensified investment in the upstream sector in recent years. An anomaly is presented by the G06 code, which, despite typically being a dominant code, records extremely low values. In fact, in the most recent period, it registers a value of merely 1.3%.

4.10 Similarities using NASA as benchmark

Having collated data on various space agencies and scrutinized the trends towards the upstream or downstream sectors, it becomes compelling to discern the similarities among them.

Specifically, NASA has been selected as the benchmark agency due to its longstanding reputation as a global leader in space research. Consequently, we computed the cosine similarity between the patent portfolios of the different agencies and that of NASA. We opted to utilize only one period, 2015 - 2019, as it offered the most comprehensive data. As observed earlier, certain portfolios, such as that of ROSCOSMOS, lack sufficient historical data. Moreover, the final period, 2020-2023, is incomplete and would not adequately represent the portfolio over a five-year span.

With these considerations in mind, Figure 37 below presents a table detailing the cosine distance value for each agency in relation to NASA, also specifying the period in which it was calculated.

Agency	From year	To year	Cosine Similarity
CNES	2015	2019	0.9449
CNSA	2015	2019	0.93071
DLR	2015	2019	0.8725
ESA	2015	2019	0.75084
JAXA	2015	2019	0.80577
KARI	2015	2019	0.83952
ROSCOSMOS	2015	2019	0.55106

Figure 37: cosine similarities of different agencies using NASA as a benchmark

Prior to delving into the analysis of the available data, it is beneficial to revisit the cosine similarity values of NASA's portfolio in relation to the upstream and downstream benchmarks for the 2015 - 2019 period. These values are 0.77 and 0.88, respectively, indicating a portfolio that leans more towards the downstream sector.

In the broader context, it is anticipated that various space agencies would exhibit a high degree of similarity, given their shared focus on space exploration. Therefore, our interest lies in discerning the variations in these similarities to glean insights into their respective technological preferences.

Beginning with the two entities demonstrating the highest similarity, CNES's portfolio aligns almost perfectly with that of NASA, as evidenced by a similarity index of 0.95. This suggests a shared focus on identical technological domains. Interestingly, a divergence is observed when compared to ESA, which, excluding ROSCOSMOS, exhibits a more diverse technological focus than NASA, as indicated by a similarity index of 0.75. This could potentially be interpreted as a manifestation of cooperation; the amicable relations between the two agencies could foster a shared vision, thereby leading to a 'division of labor' in the technological domains they operate in, promoting specialization. Concluding the analysis of European agencies, DLR occupies a position intermediate to CNES and ESA, while maintaining a more pronounced downstream-focused profile, and a similarity index with NASA of 0.87.

An intriguing outcome is derived from the similarity computation with the China National Space Administration (CNSA), which reveals a pronounced emphasis on technologies akin to those of NASA, as indicated by a similarity index of 0.93. This underscores the competitive dynamic between China and the United States, as their research into identical technologies places them in direct competition within the same market segment, with both prioritizing the downstream sector. The reliability of these calculations is high, given the substantial number of patents utilized to compute the similarity over the 2015 - 2019 period.

In the context of Russia, we observe its space agency, ROSCOSMOS, diverging significantly from all other agencies, particularly NASA, with a similarity index of 0.55. This highlights a focus on markedly different technological areas compared to the U.S. agency, suggesting that they do not compete at a technological level to specialize in the same areas.

Turning our attention to the Japan Aerospace Exploration Agency (JAXA) and the Korea Aerospace Research Institute (KARI), it is noteworthy to consider the geographical variable. These agencies, representing Japan and South Korea respectively, are geographically proximate. They appear to be pursuing similar technological categories, as evidenced by their close similarity indices with NASA: 0.81 and 0.84 for JAXA and KARI, respectively. Despite their competition and geographical proximity, neither agency competes technologically with China and Russia, which are also located within the same geographical region. Notwithstanding, it is anticipated that KARI will persist in its missile research endeavors, primarily propelled by the ongoing geopolitical strain with North Korea.

Conclusions

The analysis of the temporal and comparative trends of the upstream and downstream portfolios of the space companies leads to the following conclusions. The time trend analysis is primarily based on the data from the recent periods, as the data from the earlier periods (before 2005) is limited and unreliable. However, the earlier data is still used to provide a general overview of the historical trajectories of the space companies.

In the realm of research sectors, it is noteworthy that there was an initial skew towards the upstream sector. However, post-2000, the downstream sector has witnessed an exponential surge, leading to its unequivocal dominance over the former. The majority of the space companies scrutinized in this study demonstrate a higher cosine similarity with the downstream sector. Intriguingly, a shift has been observed in recent years, particularly during the 2020 - 2023 period, with the upstream sector undergoing substantial growth. This trend could be attributed to the proliferation of private space companies that depend on the research and instrumentation support of national and international space agencies. Consequently, this may have incited the latter to bolster the upstream sector to cater to, and hence monetize, the services required by these private entities. It is crucial to highlight that, as of now, the downstream segment serves as the primary revenue generator for space companies, as detailed in the pertinent section of Chapter 2.

When examining the comparison among space agencies, a striking observation is the pronounced resemblance between the portfolios of NASA and CNSA, highlighting the competitive interplay between these two global space powerhouses. Both entities share similar objectives, as they are engaged in the pursuit of bold and proactive strategies in the military and strategic utilization of space. Despite this, there exists a degree of cooperation and data exchange in certain domains, such as Mars exploration and space debris mitigation. The similarity index between Roscosmos and NASA is relatively low, attributable to their divergent technological priorities and strategies in space exploration. Roscosmos places greater emphasis on upstream technologies, including launch vehicles, spacecraft, and ground stations, while NASA is more oriented towards downstream technologies, encompassing Earth observation, navigation, communication, and space science. Furthermore, Roscosmos operates with a more constrained budget and resources compared to NASA, which impacts its capacity to invest in novel and innovative space technologies.

The data at hand reveals a discernible disparity between the portfolios of NASA and ESA, hinting at potential collaboration in the space domain and specialization in distinct technological areas. Consequently, we anticipate a strong alliance in research and project development between these two space agencies.

Broadly speaking, we foresee space companies intensifying their focus on the advancement of upstream technologies and making substantial investments to secure cutting-edge technology. This technology can then be supplied to private companies, which will leverage it to deliver large-scale services for terrestrial populations. This approach allows national agencies to retain technological supremacy in the most critical areas of international balance, without forgoing the prospect of substantial returns.

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