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Privatizing the space economy

A perspective on U.S. government and private sector participation based on patents

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U.S. Patent and Trademark Office

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A perspective on U.S. government and private-sector participation based on patents

Project team:

This analysis was prepared by the United States Patent and Trademark Office's Office of the Chief Economist, in collaboration with the USPTO's Patents Business Unit and Office of Policy and International Affairs.

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Cover art credit: Figure 1 from U.S. Patent No. 4,781,018, "Solar thermal propulsion unit," issued November 1, 1988 to James M. Shoji, Calabasas, California, and assigned to Rockwell International Corp., El Segundo, California.

Key findings

- The number of patent applications disclosing space inventions grew by 144% between 2003 and 2023, which is about four times larger than the growth rate for all patent applications.
- Between 1976 and 2023, individuals and organizations from the United State were granted the largest number of space patents, at 7,895. Owners located in Europe held the second largest, at 1,577, followed by Asia (794), and the rest of the world (204).
- The number of U.S. space patents associated with the U.S. federal government has increased over time, with the National Aeronautics and Space Administration (NASA) as the top source of support. Between 1976 and 2023, NASA was associated with 449 patents, followed by the Department of Defense (410) and the Department of Energy (106).
- Nearly 16% of U.S. space patents issued in 2023 were associated with the U.S. federal government, over seven times larger than the government's involvement in all patent applications.
- Between 1976 and 1993, the share of space patents from the private sector without the support of the government was 65%, rising to nearly 84% in the following 30 years.
- Small companies, universities, and nonprofits are accounting for a growing share, reaching around 40% of all U.S. space patents in 2023.
- The private sector without the support of the government dominates U.S.-based patenting in position, navigation, and timing as well as for satellite communications, whereas the U.S. federal government is more likely to be involved with space transportation and human space habitation inventions.

I. Introduction

Policymakers in the United States have taken a strong interest in the "space economy." According to the Organization for Economic Co-operation and Development, the space economy includes "all activities and resources that contribute to human progress through the exploration, research, understanding, management, and utilisation of space."[1] The space economy is seen as central to the security and prosperity of the United States. The Office of Space Commerce within the Department of Commerce (DOC) is tasked with fostering the conditions for economic growth and technological advancement in the space commerce industry.[2]

Starting in 2020, the DOC's Bureau of Economic Analysis (BEA) established a measurement program to characterize the economic value created by the U.S. space economy and to track its progress. BEA statistics reveal that production of space-related goods and services accounted for $131.8 billion in U.S. gross domestic product (GDP) and 347,000 private sector jobs in 2022. The direct contribution of the government sector—meaning space-related government personnel, operations, and maintenance—is $31.1 billion of that total, or about 24%. The remaining 77% of U.S. GDP is from the private sector, at $100.6 billion.[3]

As the BEA statistics and other studies have made clear, the private sector plays a substantial role in the U.S. space economy.[4] Private companies now routinely manufacture, launch, and operate satellites; bring resources and astronauts to the International Space Station; and provide or use information from space to improve decision-making on Earth. However, BEA statistics do not reveal the technological advancements supported by the U.S. federal government or private sector that fuel innovation in the space economy. Patent documents can provide a view of emerging technologies and can be associated with the U.S. federal government and private sectors. When taxpayer resources help create inventions, recipients are supposed to record government involvement in the specification section of the patent document.[5] This requirement, including the assignment of patent rights to U.S. federal agencies at the time a patent is issued, allows for an analysis of the volume and trends in technologies associated with both sectors.

This report makes three contributions to a technology-based understanding of the space economy. First, we develop a comprehensive taxonomy of space-related technologies for identifying inventions relevant to the space economy. The taxonomy has nine component areas: satellite communications; position, navigation and timing; earth observation; space transportation; human space habitation; space science; space manufacturing and resource development; space operations and logistics; and

1. See Organization for Economic Co-operation and Development, Space Economy, www.oecd.org/en/topics/policy-issues/space-economy.html#context.

2. See National Oceanographic and Atmospheric Administration, Office of Space Commerce, "Legal and Departmental Authorities of the Office of Space Commerce," www.space.commerce.gov/law/office-of-space-commerce/.

3. Highfill et al. (2024).

4. Weinzierl (2018); Jacobson (2021); Kulu (2021).

5. MPEP§310.

general space technologies. Working with United States Patent and Trademark Office (USPTO) examiners, who are experts in their respective areas, we operationalize the taxonomy by developing a set of detailed queries that use technology classifications and keywords.[6] Second, we analyze the collected patent documents to reveal the volume and growth in U.S. patent applications that disclose space inventions. Finally, we complement this overall analysis by using information within the patent documents to provide a perspective on U.S. federal and private-sector participation in U.S. space patenting between 1976 and 2023.

Our analysis shows that the number of patent applications disclosing space inventions increased by 144% between 2002 and 2023. That is about four times greater than the growth in the total number of patent applications. Between 1976 and 1993, the share of U.S. space patents that did not have U.S. federal government involvement was 65%, rising to nearly 84% in the following 30 years. This growth in private-sector patenting without the support of government is driven in part by a large increase in patenting by small companies, universities, and nonprofits. In 2023, nearly 40% of all U.S. space patents were associated with these types of organizations.

Nearly 16% of U.S. space patents in 2023 received some form of support from the U.S. federal government. That percentage is seven times larger than the government's involvement in all patent applications. We find that the U.S. federal government is much more likely to be involved with space transportation and human space habitation inventions, whereas the private sector without the support of government dominates U.S.-based patenting in satellites for position, navigation, and timing as well as for communications. These findings point to a large expansion in private-sector space invention since 1976, with the U.S. federal government continuing to maintain a strong level of support.

II. The space economy: A technology perspective

Existing research on government and private participation in space invention has faced challenges associated with precisely identifying inventions that disclose space-related technologies in patent documents. Space inventions belong to a broad set of technologies, causing researchers to focus on narrower areas, such as satellite communications.[7]

6. The search queries are contained in the supplementary materials. An assessment of the quality of the queries is available in the Appendix A.

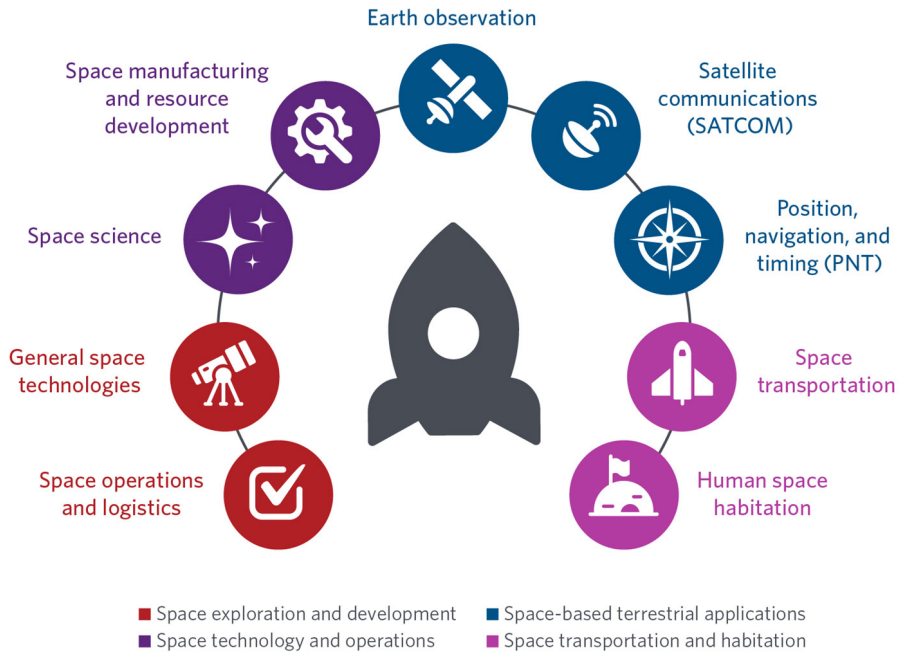
7. OECD (2012); EPO (2021); EPO (2024). One exception is a recent report by the Canadian Intellectual Property Office (CIPO 2018), which uses a broad definition of space technology. However, this report is focused on the Canadian space sector and their approach to identify space patents is not documented well enough to replicate for USPTO patent documents.

The DOC's Office of Space Commerce defines the space industry to include satellites, remote sensing, space transportation, and other entrepreneurial activities related to space.[8] While the DOC's definition contains many of the key aspects of space technology, it is not precise enough to serve as a basis for a patent landscape. The OECD Handbook on Measuring the Space Economy provides a more precise definition of satellite technology, but it is limited to this single area.

By synthesizing various definitions for space technology from policy reports and scientific literature, including the OECD's measurement handbook, and consulting with experts within and outside the USPTO, we constructed a comprehensive and detailed definition of space technologies. Our definition includes nine components that are further grouped into four areas. These areas include space-based terrestrial applications; space transportation and habitation; space exploration and development; and space technology and operations.[9] The nine component technologies include: satellite communications; position, navigation and timing; earth observation; space transportation; human space habitation; space science; space manufacturing and resource development, space operations and logistics; and general space technologies (Figure 1).

The technology areas and their constituent component technologies are defined below, with each component technology definition followed by a USPTO patent that helps illustrate its meaning.

Figure 1: Space technology areas and their component technologies



8. See www.space.commerce.gov/about/mission/.

9. We synthesized the definitions of space technology from OECD (2012), EPO (2021), Yonekura et al. (2022), and Highfill et al. (2022).

A. Space-based terrestrial applications

Activities in space that benefit people on Earth constitute some of the earliest space applications.[10] The space-based terrestrial applications technology area includes the satellite communications; position, navigation and timing; and Earth observation component technologies. These inventions involve passing signals through space or gathering data from space sensors for use in applications on the ground.

- Satellite communications (SATCOM): This component technology includes satellite-related inventions for the purposes of communication—receiving and transmitting signals, such as for telephony, television, or internet data. An example of a satellite communications invention is U.S. Patent No. 11,881,928, issued to Thales SA, which describes a "space communication method for IoT services." This technology controls the communication between Internet of Things (IoT) devices and satellites.

- Position, navigation, and timing (PNT): This component technology involves the use of satellites for navigation, where the satellites provide signals that are used by receivers on the ground (e.g., smartphones) to accurately determine such things as a user's location. For instance, U.S. Patent No. 11,320,540, issued to Honeywell International, describes methods to monitor the integrity of the Global Positioning System (GPS).

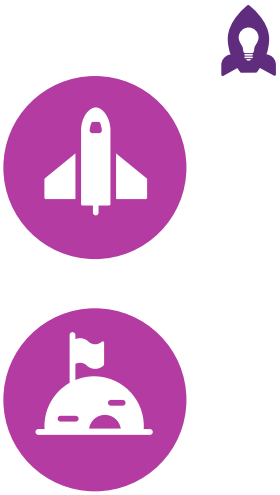
- Earth observation: This component consists of remote sensing and environmental monitoring of Earth using space technologies. An application of remoting sensing is land use utilization, including the monitoring of forests and agricultural fields. Environmental monitoring includes receiving data from the atmosphere for weather prediction. One such Earth observation invention is disclosed in U.S. Patent No 11,820,535, issued to Maxar Space LLC, which uses a constellation of satellites for global surveillance in military and defense applications.

B. Space transportation and habitation

To do anything in space, one must first get to space. The space transportation and habitation technology area includes the space transportation component technology, which contains launch vehicles and space vehicle propulsion. This technology area also includes human space habitation, consisting of crewed space vehicles, space suits, and non-Earth habitats.

10. An example is Project Echo, which launched two passive communications satellites in 1960 and 1964, and which were basically reflective balloons sent into orbit (see https://en.wikipedia.org/wiki/Project_Echo).

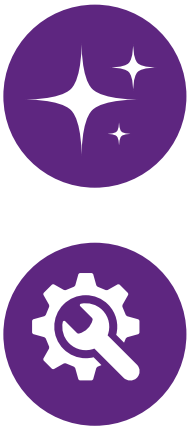
- Space Transportation: The field of space transportation includes space launch vehicles, landing systems, and other means of transport that move satellites, people, and supplies in space. U.S. Patent No. 10,605,204, issued to the U.S. Navy, describes an advanced rocket engine that uses methane as fuel and injects hot helium gas into the combustion chamber to enhance the rocket's performance.
- Human space habitation: Technologies related to human space habitation allow people to survive off Earth and include inventions such as habitats and space suits. An example of a human space habitation patent is U.S. Patent No. 9,302,791, issued to Bigelow Aerospace LLC, which discloses a lander for transporting an astronaut to and from a body such as the moon, an asteroid, or a small planet that has little or no atmosphere.



C. Space exploration and development

The space exploration and development technology area includes the space science and space manufacturing and resource development component technologies. It involves not only more traditional space science and exploration missions—e.g., those conducted by NASA to explore our solar system—but also emerging space activities such as pharmaceutical research and manufacturing in orbit, asteroid mining, and space power beaming.

- Space science: Inventions to measure or monitor space, such as space telescopes and interplanetary probes, fall into the category of space science. This component technology also includes "space weather,"— i.e., how the sun impacts the Earth and on-orbit satellites. U.S. Patent No. 11,479,373, issued to Honeybee Robotics LLC, is an example of a space science patent. The invention consists of a system for collecting soil samples from planets using an interplanetary vehicle.
- Space manufacturing and resource development: This component technology focuses on inventions related to manufacturing and mining in space, as well as developing other space resources such as solar power beaming from space to Earth or to other satellites. In-space manufacturing takes advantage of the low-gravity environment of space (and sometimes the vacuum of space) to develop unique materials and chemicals, such as crystals and pharmaceuticals. An example includes U.S. Patent No. 11,738,891, issued to the National Aeronautics and Space Administration (NASA). This invention involves the use of a spacecraft for mining in low- or zero-gravity environments.



D. Space technology and operations

The space technology and operations technology area captures inventions involved with routine operation of satellites, support activities such as mission planning, and more advanced technologies such as space debris removal. This final area also contains space inventions not covered elsewhere, including subsystems common to spacecraft and satellites.

- Space operations and logistics: This component technology contains inventions for conducting space missions. It includes a wide array of technologies related to satellite control, mission planning, space situational awareness, on-orbit maintenance, and space debris removal. For example, U.S. Patent No. 10,640,239, issued to Airbus Defense and Space Ltd., explains how a vehicle can be used to intercept and remove space debris.

- General space technologies: This component consists of space-related inventions that do not fall into the other component technologies, such as satellite power systems, thermal control, structures, and deployment mechanisms. An example is U.S. Patent No. 12,017,805, issued to the University of Limerick. This patent discloses a structure to deploy satellite solar arrays, antennas, and other objects in space.

III. Findings

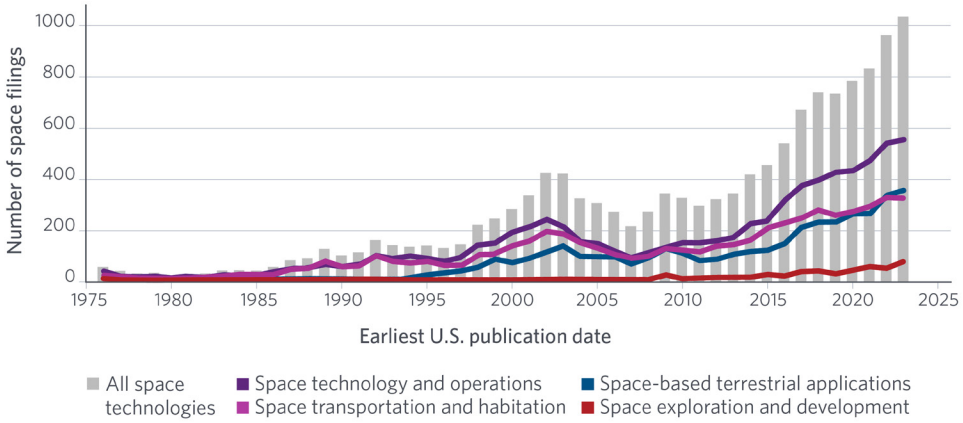
A. Space invention has grown substantially faster than all patent applications

The number of patent applications disclosing space technology is an indicator of commercial potential, reflecting the activity of inventors, companies, universities, and other organizations as they seek to protect their inventions through formal intellectual property (IP) rights. The number of patent applications disclosing space technologies has grown substantially since 1976. Figure 2 shows the number of USPTO patent applications disclosing space inventions by earliest publication year (i.e., the year the application was first published as either a pre-grant publication or patent). Between 1976 and 2003, the number of annual space applications increased from 60 to 425, representing a 608% increase. Between 2003 and 2023, the number of applications grew by 144%, to 1,038 applications.[11] By comparison, the overall number of applications filed at the USPTO between 2003 and 2023 increased by substantially less, at 37%.

11. Between 1977 and 2023, the average annual growth in space applications was 8%.

In addition, Figure 2 separates the number of space applications into the four space technology areas. The largest number of patent applications published in 2023 were in technology and operations (554 applications), which includes space operations and logistics, and general space technologies. Space-based terrestrial applications (including satellite communications; position, navigation, and timing; and Earth observation) and transportation and habitation had the second- and third-largest patent application volumes in 2023, at 353 and 327 applications, respectively. The smallest space technology area in 2023 was space exploration and development (including space science and manufacturing and resource development), at 78 patent applications.

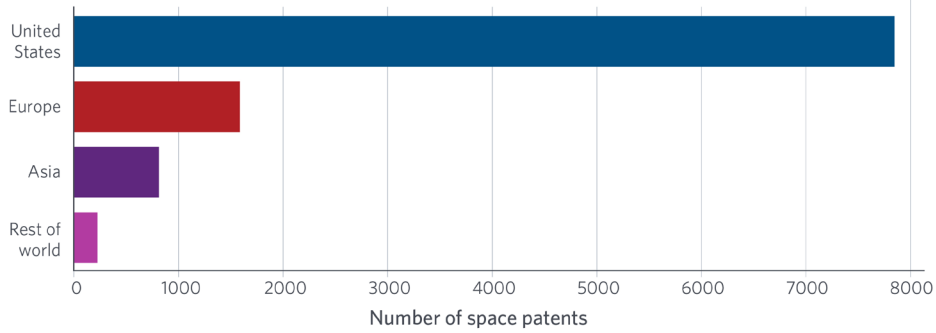
Figure 2: Non-confidential patent applications disclosing space technology, overall and by space technology area, 1976–2023



Notes: The sample includes those patent applications that are non-confidential, meaning they are available to the public. The earliest publication year is from the pre-grant publication (PGPub), if available; otherwise it is from the patent. The space technology area counts do not sum to the overall count since a patent application may be in more than one technology area. The technology and operations area includes the space operations and logistics, and general space component technologies; the space-based terrestrial applications area includes satellite communications (SATCOM) as well as position, navigation, and timing (PNT) and Earth observation; transportation and habitation includes space transportation and human space habitation; and space exploration and development includes space science and space manufacturing and resource development.

Figure 3 shows the number of space patents granted to individuals and organizations located in the United States, Europe, Asia, and the rest of the world. Between 1976 and 2023, U.S. individuals and organizations were granted the largest number of space patents from the USPTO, at 7,895. Owners located in Europe held the second largest, at 1,577, followed by Asia (794), and the rest of the world (204). Figure B1 in Appendix B shows the number of space patents granted to China, Japan, and South Korea over time. Among these countries, Japan has consistently led overall. China did not receive any space patents until the mid-2000s but has seen growth in the last few years, surpassing Japan in 2021. Notably, however, the number of space patents issued each year to owners from these countries is low, reaching a high of 35 granted to China in 2023.

Figure 3: The number of space patents granted to individuals, companies, and other organizations located in the U.S., Europe, Asia, and the rest of the world, 1976–2023



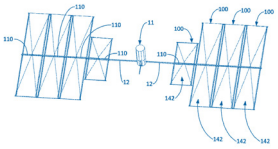
Notes: The locations are first determined by assignees, then applicants, and finally by inventors for patents that do not have assignees or applicants listed at grant. "Rest of world" includes all countries not in Europe or Asia, excluding the United States.

To analyze U.S. federal government and private-sector participation in U.S. space invention, the results from this point forward look specifically at the 75% of space patents with U.S.-based owners (hereby called U.S. space patents). We impose this restriction because most U.S. government funding cannot be obtained by non-U.S. individuals and organizations, and our data does not allow us to track funding by non-U.S. governments.[12]

B. Both the U.S. federal government and the private sector have increased their participation in space invention

The U.S. federal government supports the space economy through both its civil (e.g., NASA) and military (e.g., the Department of Defense, or DOD) missions. Government involvement in space invention can occur at various stages, including by directly supporting basic and applied research, partnering with private organizations to conduct joint research and development, and contracting for specific technologies directly with private companies.[13] Patent documents offer a unique lens with which to examine this process. The Bayh-Dole Act of 1980 requires that patent applications contain a statement of "government interest" when the invention was developed with government support (see Example 1 for a government interest statement denoting support from NASA). We label a patent as having U.S. government involvement if it contains a statement of government interest or has a U.S. government assignee.[14]

Example 1: Government interest statement from a U.S. space patent



U.S. Patent 10,815,012, issued to Analytical Mechanics Associates, Inc., describes "deployable sheet material systems and methods" that have a variety of space applications, including the use in solar arrays to power spacecraft and solar sails for propulsion The patent has U.S. government involvement, stating "The invention was made with Government support under contract No. NAS3-01115 by NASA. The Government has certain rights in the invention." We use data on government interest statements extracted by and made publicly available by PatentsView, a patent data and visualization web platform (https://patentsview.org/government-interest).

12. From a practical perspective, only a few non–U.S.-based individuals and organizations received U.S. federal government support in our data.

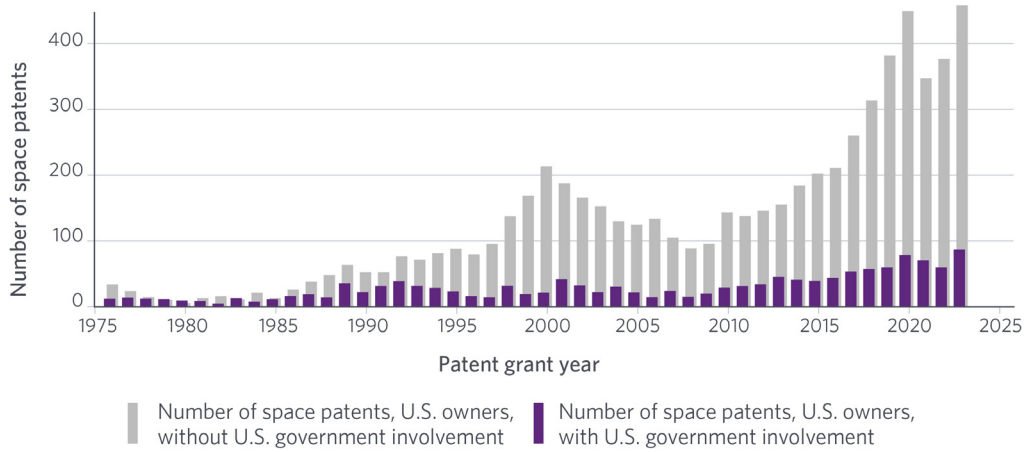
13. NASA (2014); Lambright (2015); Weinzierl (2018).

14. In addition, we also denote a patent as having government involvement if it has a "confirmatory license" transaction with the U.S. government as the licensor. Confirmatory licenses ensure that the U.S. government is granted rights to use inventions for which it provides support.

Figure 4 shows the number of U.S. space patents with U.S. government involvement (purple bars) and without (grey bars) between 1976 and 2023. Consistent with the increase in space patent applications published each year, the number of U.S. space patents with government involvement has also increased, reaching a total of 87 patents granted in 2023.[15] The top U.S. federal government source providing support between 1976 and 2023 was NASA, at 449 patents, followed by the Department of Defense (410 patents) and the Department of Energy (106 patents).

While the number of U.S. space patents with government involvement has increased over time, the number from the private sector without the support of government has increased by even more. Between 1976 and 1993, the share of U.S. space patents that did not have U.S. federal government involvement was 65%, rising to nearly 84% in the following 30 years.[16] While this trend is consistent with greater private-sector activity in space invention, it's important to note that U.S. government involvement continues to be far higher in space than in other technologies. By comparison, the average share of all patents with government support was only 2.2% in 2023. This means that the rate of government involvement in space was over seven times larger in 2023 than it was in all technologies leading to patent applications.

Figure 4: The number of U.S. space patents with and without U.S. federal government involvement, 1976–2023

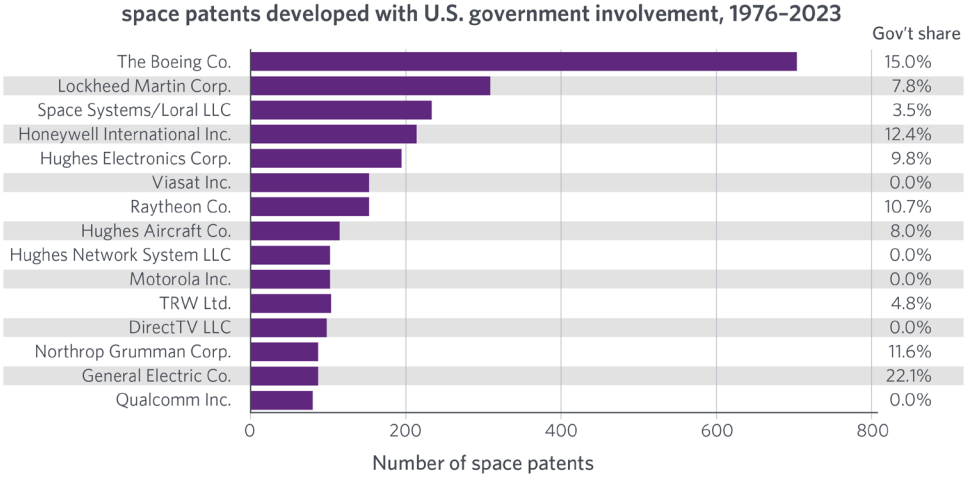


Notes: A patent is classified as having U.S. government involvement if it contains a government interest statement, has a U.S. government assignee, or has a confirmatory license transaction in the patent assignments data. The sample includes all space patents owned at grant by individuals and organizations located in the United States.

15. On an annual basis, the number of space patents with government involvement increased by 11 percent on average each year between 1977 and 2023.

16. We compare the share of space patents without government involvement between the periods 1976–1993 and 1993–2023 since the share began to significantly rise in the early 1990s.

Figure 5: Leading non-government owners of U.S. space patents and the share of their space patents developed with U.S. government involvement, 1976–2023



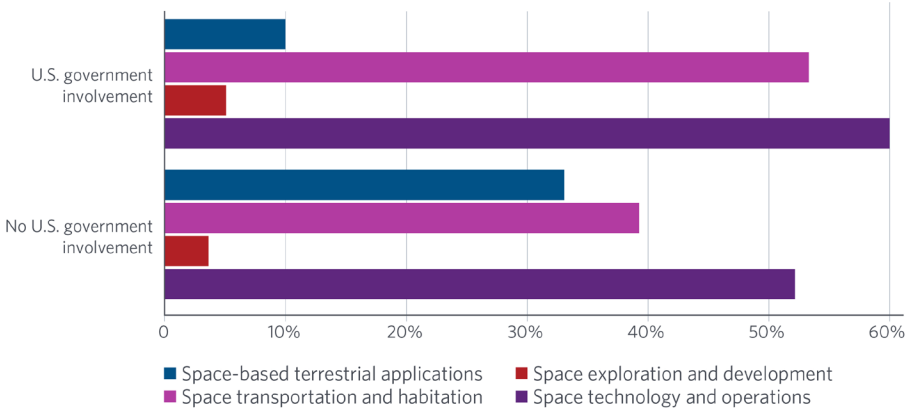
Notes: A patent is classified as having U.S. federal government involvement if it contains a government interest statement, has a U.S. government assignee, or has a confirmatory license transaction in the patent assignments data. The sample includes all patents owned at grant by individuals and organizations located in the U.S.

Figure 5 shows the top 15 non-U.S. federal government owners of U.S. space patents issued between 1976 and 2023, along with the share of their patents developed with government involvement. The leading organization is The Boeing Company, with 694 space patents, followed by Lockheed Martin Corporation (306), Space Systems/Lorel LLC (231), Honeywell International Inc. (210), and Hughes Electronics Corporation (193). These companies have relied on U.S. federal government support for space invention to varying degrees, ranging from a high of 15% of space patents granted to The Boeing Company to a low of 3.5% for Space Systems/Lorel LLC. Five of the top 15 patent owners included in Figure 5 did not rely directly on U.S. federal government support at all in developing their patented space inventions.

C. The U.S. federal government is more involved with space transportation and habitation inventions, whereas the private sector without the support of government dominates patenting in satellite communications and Earth observation

Figure 6 shows the percentage of U.S. space patents with U.S. federal government involvement and those without involvement for each of the four space technology areas. For example, the blue bar at the top shows that 10% of the space patents with U.S. government involvement are in space-based terrestrial applications. For each group (both U.S. government involvement and non-involvement), the bars do not add up to 100%. This is because a space patent may be counted in more than one technology area.

Figure 6: The percentage of U.S. space patents with and without U.S. federal government involvement, by space technology area, 1976–2023

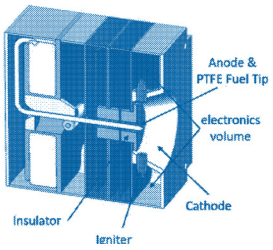


Notes: The bars indicate the percentage of space patents within a group (either those with U.S. federal government involvement or without involvement) from the specified technology area. The space technology area shares for each group (both U.S. government involvement and non-involvement) do not add up to 100% because a patent may be in more than one technology area. A patent is classified as having U.S. government involvement if it contains a government interest statement, has a U.S. government assignee, or has a confirmatory license transaction in the patent assignments data. The technology and operations area includes the space operations and logistics and general space component technologies; space-based terrestrial applications include satellite communications (SATCOM), position, navigation, and timing (PNT), and Earth observation; transportation and habitation includes space transportation and human space habitation; and space exploration and development includes space science and space manufacturing and resource development. The sample consists of all space patents with at least one U.S. assignee at grant.

Notably, Figure 6 indicates that the government is much more likely to be associated with patents in space transportation and habitation (a difference of around 14 percentage points compared to the share of non-government patents in this area), and slightly more likely in space technology and operations (a difference of 8 percentage points). Just over 53% of U.S. space patents that are associated with the U.S. government are in transportation and habitation. These inventions include space launch vehicles, propulsion systems, extraterrestrial habitats, and space suits. For example, one invention disclosing an electric thruster for very small satellites was developed with support from NASA (see Example 2). The U.S. government has a long history of supporting invention in space transportation,[17] including the Apollo and Space Shuttle programs. It continues to provide a substantial degree of its support in this area.[18]

Alternatively, private-sector inventions developed without government support are much more likely to disclose space-based terrestrial applications, a 23-percentage point difference relative to the share of government-supported patents in this area. Around 33% of private-sector space patents are in this area. These inventions include broadband communications, PNT satellites and unique components, remote sensing, and environmental monitoring (terrestrial, atmospheric, and oceanic).

Example 2: U.S. space patent in the transportation and habitation technology area issued with the support of NASA



U.S. Patent 11,242,844 was issued to CU Aerospace LLC and was developed with U.S. federal government support from NASA. The invention is a fiber-fed pulsed plasma thruster providing improved propulsion capabilities for very small satellites such as CubeSats. Propulsion inventions are contained in the transportation and habitation technology area, an area that the U.S. federal government provides a substantial amount of its support.

17. For a history of NASA's involvement in space transportation, see NASA, "Human Spaceflight," www.nasa.gov/specials/60counting/spaceflight.html.

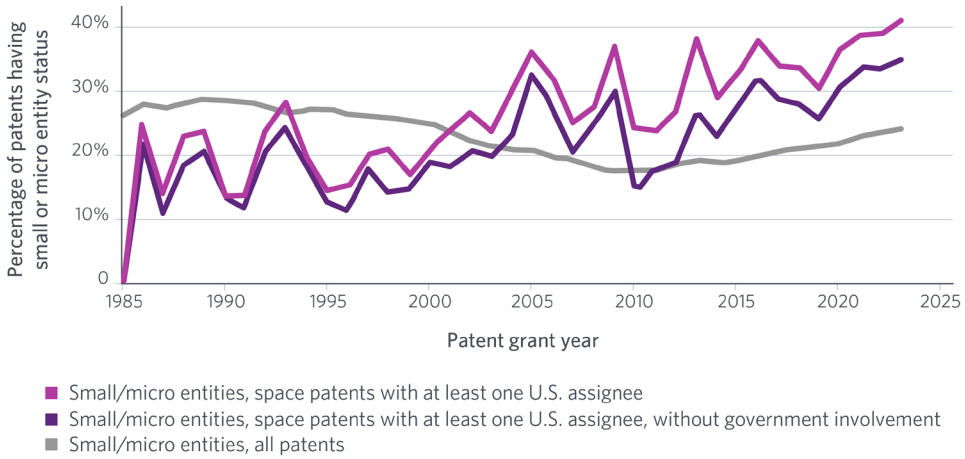
18. Reproducing Figure 5 (which focuses on patents granted in the last 30 years, from 1993–2023) with data from just the last 10 years (2013–2023) shows similar concentrations across the space technology areas for those patents with and without U.S. government involvement.

D. The contribution of small companies, universities, and nonprofits to U.S. space invention has substantially increased

Patent applications filed by small businesses, universities, and nonprofits qualify for lower patent application filing and examination fees at the USPTO. These applicants are called small and micro entities.[19] For example, TerraClear Inc. is a small, venture-backed company that is classified as a small entity. One of its inventions is in the space-based terrestrial applications technology area (see Example 3). For each U.S. space patent, we record whether the applicant paid small or micro entity fees and calculate the share of patents issued to these applicants in each year.

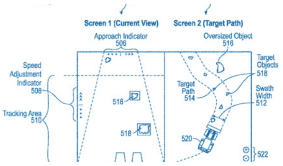
Figure 7 shows that the share of U.S. space patents associated with small and micro entities has generally increased over time, beginning at 20% between 1986 and 1993, and ending at just over 40% in 2023 (magenta line). The grey line shows the small/micro entity share for all patents, which fluctuates between 17% and 29% over the 40-year period. Beginning in the early 2000s, the small/micro entity share in space technologies surpassed the overall share and exceeded it by 71% in 2023.

Figure 7: The percentage of U.S. space patents associated with small and micro entities, 1985–2023



Notes: Patents associated with small and micro entities are those with applicants that paid small and micro entity fees at the USPTO. The figure starts at 1985 because small entity fees were first introduced in 1982. See "Study of Alternative Fee Structures," 65 Fed. Reg. 58746, www.federalregister.gov/documents/2000/10/02/00-25225/study-of-alternative-fee-structures. A patent is classified as having U.S. government involvement if it contains a government interest statement, has a U.S. government assignee, or has a confirmatory license transaction in the patent assignments data. The sample consists of all space patents with at least one U.S. assignee at grant.

Example 3: Private-sector patent in the space-based terrestrial applications technology area, issued to a small entity without the support of government



U.S. Patent 11,710,255, issued in 2023 to TerraClear Inc., describes an "object collection system" that can use satellite imagery to autonomously identify and remove rocks and other debris from a field on Earth, potentially increasing agricultural productivity (see Fig. 5 from the patent). TerraClear, Inc. is a venture- backed company founded in 2017 in Bellevue, Washington, and Grangeville, Idaho.[20]

19. Small businesses are defined as those with fewer than 500 employees. More information on which applicants qualify for small and micro entity fee status is available at https://www.uspto.gov/patents/apply/save-on-fees.

20. See https://www.terraclear.com/company/.

The purple line in Figure 7 shows the contribution to the small/micro entity share of U.S. space patents from those patents without government support, revealing that a majority of the increase in patents from small and micro entities is from this group. The commercialization of new launch systems and small satellites in the last few decades, led by an increase in the use of venture-capital funding and debt financing,[21] may be one reason for this finding. Prior research has revealed the importance of patenting for start-up companies, as receiving a patent is a strong signal for the underlying viability of a company's technology, facilitating venture capital investment and faster sales and employment growth.[22]

E. Discussion and limitations

There has been an increase in both U.S. federal government and private-sector participation in space invention in the United States over the last 50 years. In 2023, the share of U.S. space patents with U.S. government involvement was 16%, over seven times larger than its involvement in all patent applications. We found that small companies, universities, and nonprofits are accounting for a growing share—reaching around 40% of all U.S. space patents in 2023. There is evidence of increasing reliance on venture capital in this sector over the last two decades.[23] Patenting helps start-ups obtain this funding, leading to faster sales and employment growth than otherwise possible.[24]

Utilizing government interest statements and the assignment of patent rights to U.S. federal agencies, our study casts new light on U.S. federal government and private-sector participation in patented space technology over a nearly 50-year time period. As with any study, however, our findings are subject to limitations. First, our landscaping approach sought to maximize precision (i.e., the probability that a patent document retrieved by the approach was actually associated with space), which potentially reduced recall (i.e., the probability that a given space patent document is retrieved). This implies that our counts of non-confidential space applications and patents are potentially lower than their actual values.[25] Second, there is some evidence that patent applicants may not always record statements of government interest.[26] Moreover, U.S. government purchases of space products and services, such as launch services to place satellites into orbit, may provide the incentives for commercial firms to invent. However, our data would not capture this indirect form of support. These factors could potentially lead us to undercount the U.S. federal government's

21. CRS (2016); Weinzierl (2018); Heracleous et al. (2019); Christensen et al. (2023).

22. Gaule (2018); Farre-Mensa et al. (2020).

23. CRS (2016); Weinzierl (2018); Heracleous et al. (2019); Christensen et al. (2023).

24. Gaule (2018); Farre-Mensa (2020).

25. Toole et al. (2019).

26. Kwon (2024).

contribution to U.S. space invention. Additionally, our data is limited to patents. Individuals and organizations in the space sector may elect to protect their inventions via other means, such as trade secrets.

Despite these limitations, our findings reveal a substantial increase in private sector space invention, sustained in part by robust support from the U.S. federal government. As it has for decades, the interplay between the federal and private sectors will continue to shape space invention as this industry moves into the future.

Appendix A

Definition of space technology

Table A1 provides more information on our definition of space technology. Each of the nine component technologies in the second column are linked to one of four broader technology areas in the first column. For each component technology, examples are provided that help illustrate what the component includes and excludes (these examples are not comprehensive).

Table A1. Definition of space technology

Area	Component technology	Includes	Excludes
Space-based terrestrial applications	Satellite communications (SATCOM)	• SATCOM satellites and comm payloads • Broadband communications • Inter-satellite links • Non-geosynchronous SATCOM • Consumer ground terminals and satellite phones	• Tangential applications, e.g., the use of SATCOM as one option for a communications network or application using a network
	Position, navigation, and timing (PNT)	• PNT satellites and unique components	• Tangential applications, e.g., smartphones using the Global Positioning System (GPS) • Locating satellites (i.e., satellite control) • Receivers in general • Cooperating elements; i.e., "additional elements or subsystems, including receivers of other users, which interact or communicate with the receiver" to assist in acquisition or position determination.[27]
	Earth observation	• Remote sensing (passive and active) • Environmental monitoring (terrestrial, atmospheric, and oceanic weather/ observation)	• Space weather (see space science technology component)

27. See the note for Cooperative Patent Classification (CPC) G01S19/03 in the CPC's scheme, found at https://www.uspto.gov/web/patents/classification/cpc/html/cpc-G01S.html.

Area	Component technology	Includes	Excludes
Space transportation and habitation	Space transportation	• Space launch vehicles and components • On-orbit transfer, maneuver, and station-keeping • Interplanetary transfer • Liquid engines, solid rocket motors, and electric thrusters • Non-conventional propulsion, such as solar sails and tethers, to affect orbit change • Ground systems dedicated to space launch • Separation and docking systems between launch vehicles and payloads • Landing systems and aerobraking	• Maintenance satellites • Crewed vehicles and habitation • Orbits and trajectories • Parachutes • Debris clearance
	Human space habitation	• Crewed habitats and vehicles • Extraterrestrial habitats • Space suits • Crew accommodation and protection	• General purpose technology
Space exploration and development	**Space science**	• Space telescopes • Interplanetary probes • Space weather	• Ground-based telescopes
	Space manufacturing and resource development	• In-space manufacturing (e.g., assembling large structures and microgravity drug manufacturing) • Extraterrestrial mining • Power beaming	
Space technology and operations	**Space operations and logistics**	• Satellite data, tracking, and control networks • Mission planning and constellation architectures • Space situational awareness • Rendezvous and proximity operations • Satellite maintenance, repair, and replenishment • Space debris removal	• Space weather • Launch vehicle ground operations
	General space technologies	• Satellite bus technology (e.g., power and data systems) • Other space technologies not covered in other areas	• Specialized mission payloads • Propulsion • Space operations, logistics, manufacturing, and resource management

Evaluation of the space component technology search queries

For each component technology, we created a Cooperative Patent Classification (CPC)/keyword search query to identify patent documents in that component. The search queries are provided in the supplementary materials to this report.

To evaluate the quality of each component technology search query, we randomly sampled 75 documents returned by each query and had two annotators manually label whether each document belonged in the component technology designated by the query. For example, if a patent document was returned by the SATCOM query, the annotator would label whether or not the invention belonged to the SATCOM component technology. Table A2 provides the share of the 75 documents for each component technology that were labeled by the annotators as being in that component (called "precision").

Precision ranges from a high of 0.85 in SATCOM to a low of 0.47 in Earth observation. Even though precision was low for some components, when evaluating whether each of the 675 documents (75 drawn from each component) contained at least one space component technology (including the components for which it was not specifically drawn), precision was 0.85. This shows that precision was much higher than the individual component technology values when aggregated to the overall space level.

Table A2. Precision for each space component technology search query and whether the document contains at least one component

Space component technology	Precision
Satellite communications (SATCOM)	0.85
Position, navigation, and timing (PNT)	0.84
Earth observation	0.47
Space transportation	0.77
Human space habitation	0.63
Space science	0.55
Space manufacturing and resource development	0.55
Space operations and logistics	0.57
General space technologies	0.71
At least one space component technology	0.85

Notes: 75 randomly sampled documents returned by each component technology query were annotated for that component. For the "at least one space technology" annotation, all 675 patent documents (75 from each query) were annotated for whether they contained at least one space component technology. Precision is the share of patent documents that were labeled as being in the component technology.

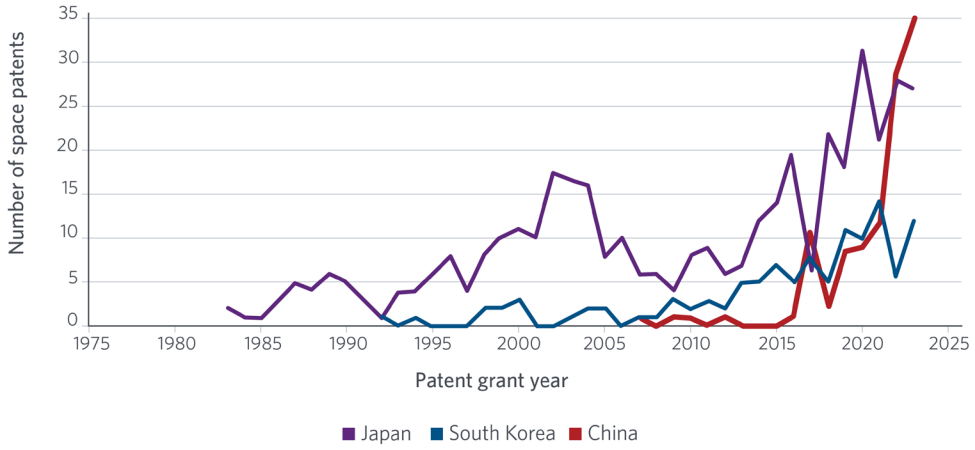
It is difficult to estimate recall (i.e., the probability that a randomly selected space patent document is in our landscape) without a representative sample of space patent documents. But we are able to estimate it for a subset of space technology. The Derwent World Patent Index contains a classification for "space/cosmonautic vehicles and equipment" (Q25-S).[28] Since we did not use this classification explicitly in our search queries, the percentage of these documents that are contained in our landscape is an estimate of recall for the space transportation component technology query. We find that 83% of the Derwent patent documents in Q25-S are in our landscape, which, when combined with precision in this component of 0.77, suggests that the space transportation query was reasonably well designed. Unfortunately, Derwent does not have classifications that align with the other space component technologies. Therefore, we cannot estimate recall for these other components.

28. See https://clarivate.com/intellectual-property/patent-intelligence/derwent-world-patents-index/ and the Derwent World Patent Index Classification guide found at https://clarivate.com/intellectual-property/wp-content/uploads/sites/5/dlm_uploads/DWPI-Classification-Guide-2024.pdf.

Appendix B

Figure B1 shows the number of space patents granted to owners located in China (red line), Japan (purple line), and South Korea (blue line) over time. The figure illustrates that China did not have any U.S. space patents until the mid-2000. But since 2022, the volume of U.S. space patents originating from China surpassed both Japan and South Korea. Notably, the number of space patents issued to these countries each year is low, reaching a high of 35 patents granted to China in 2023.

Figure B1: The number of space patents granted to Japan, South Korea, and China, 1976–2023



Notes: The locations are first determined by assignees, then applicants, and finally inventors for patents that do not have assignees or applicants listed at grant. If a patent was not granted to a country in a given year, then the line for that year drops to zero.

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