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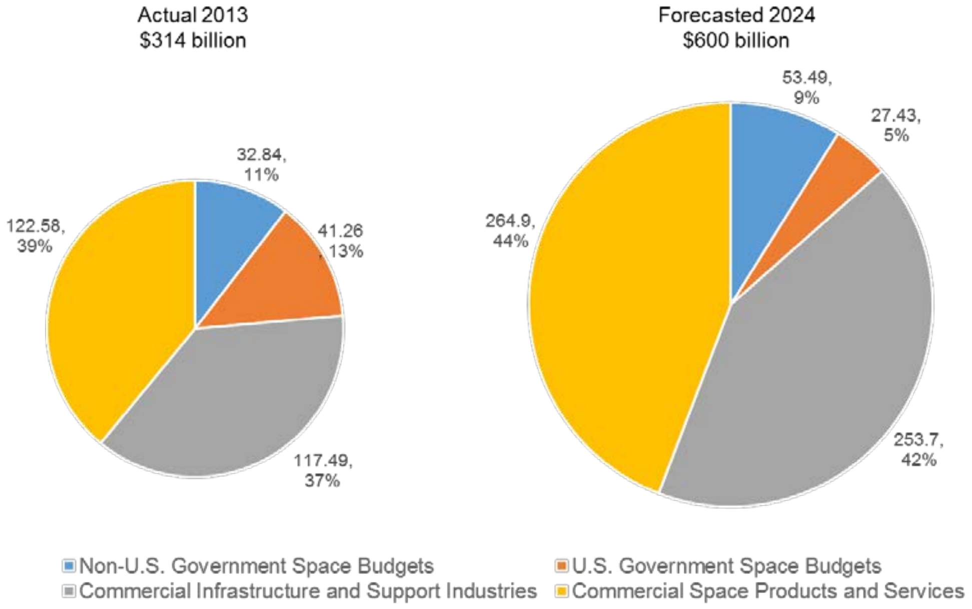
Executive Summary

Fifty years ago, the United States and Soviet Union were the only significant national space programs, and only a small number of commercial entities were involved in substantial space activities. Today, U.S. Government space programs make up barely a quarter of global space budgets. In the next 10 years, even as global space spending is expected to double, government budgets, according to some experts, will make up less than a seventh of the total pie, with the U.S. Government contributing only 5 percent of the total.



Source: Published and unpublished data from the Space Foundation.

Contributions to the U.S. Government Space Budget (Current and Forecasted by the Space Foundation)

The implications of these emergent and dynamic changes are still not well understood. At the behest of sponsors in the Federal Government, the IDA Science and Technology Policy Institute (STPI) undertook a task to explore, synthesize, and summarize global trends relevant to the commercial and civil space sectors, focusing not only on the activities of the major global space faring nations but also on those of the less well-known ones.

Sectoral Observations and Trends

Because the space sector is not uniformly monolithic, it is not feasible to identify trends that apply to the entirety of space-based activities. At one end of the spectrum, for example, is space-based telecommunications—a mature subsector that is largely commercial with extensive global markets and an international value and supply chain. At the other end is space-based position, navigation, and timing, where upstream activities (satellite design, launch, and operations) are government- and military-owned and require large, long-term investment, but downstream services are offered in a competitive commercial market. Most other subsectors reside somewhere between these two poles.

Due to these differences, using both primary and secondary data sources and interviews, STPI researchers explored trends in seven subsectors, which can be summarized as follows:

- **Earth observation (EO)**. Improvements in the performance of satellite-based and other instruments as well as the falling cost of data collection, processing, storage, and analysis is leading to growing demand for imagery and imagery-based intelligence products worldwide. As a result, an increasing number of governments and newly created private firms around the globe has begun participating in EO activity. The technology-enabled breakup of functions makes it easier for new entities to enter the sector, and specialize in one or more aspects of the data cycle. It is important to note, though, that while commercial EO is growing rapidly, its ultimate role and size will be driven by national policies.
- **Communication satellite services**. Since communication satellites are a more mature space-based application, advances in the sector have tended to be incremental. However, a host of new entrants are proposing novel technologies for services like satellite-based Internet via satellites in low or medium Earth orbits, and they are finding interest in the venture community. Revenues in this sector are expected to be driven by growing demand by new consumers and enterprises in the emerging world.
- **Space science and technology (S&T) and exploration.** Space S&T and exploration used to be a domain of the wealthier major space-faring nations. In recent years, countries with smaller space budgets and private nonprofit groups are engaging in space science. Interest in exploration with smaller satellites, including CubeSats (a class of nano-satellites), is also growing. International collaborations in space S&T and exploration are increasing, as are publications by developing countries.
- **Launch and access to space**. With improving technological capabilities worldwide, and with few countries other than those with ballistic missile programs intending to develop significant launch capabilities, global

competition in the launch sector is intensifying in a subset of countries with the necessary infrastructure. Some newer entrants offer different characteristics in their launch services, like India not only providing lower cost launches than traditional launch providers but also minimizing other hurdles (such as requirements related to intellectual property). Together, these developments and others (such as development of smaller launchers for small satellites) will likely create a more commoditized and international launch service for all but the most sophisticated payloads. New approaches to launching are also more cost-conscious than performance-driven. Innovations in small satellite launch and suborbital launch, led by the private sector, are likely to support this trend. Not all countries interested in space-based activities aim to develop launch capabilities. Encouraged by the trend towards standardized and commoditized launch, some prefer to invest in other aspects of space activities.

- **Position, navigation, and timing (PNT).** PNT was an activity once limited to the United States and Russia. However, the sector is opening up with Europe, China, Japan, and India investing in full and partial space-based PNT systems. While upstream activities remain in the hands of the military, downstream activities are in the civil sector, with the growth and consumerism of location-based services. The demand for redundancy and improved accuracy is also driving investments for the development of alternatives to, and augmentations for, space-based PNT systems.
- **Human space flight.** Given the high cost of human space flight, only a small number of countries that are driven by goals related to national prestige and global leadership will be developing indigenous human space flight capabilities. With the International Space Station approaching the end of its life, there is increasing interest in the Chinese space station as well as in private sector-owned space stations that will cater to both government and private customers.
- **Space situational awareness (SSA)**. Alternatives to government SSA data sources, sensors, and services are emerging in the form of private and commercial off-the-shelf (COTS) alternatives. As a result, both civilian and non-governmental entities will be able to provide SSA services, effectively ending the U.S. Department of Defense’s monopoly on SSA. This change will make it more difficult in the future for military organizations and national governments to exclusively control SSA.

Overarching Drivers

To better understand the trends above and their evolution over time, we examined what drives these trends. A driver in this report is defined as a factor that is causing, or might cause, changes to the “who, what, when, why, and how” of space activities. Drivers of trends in space that are also driving trends in other sectors (e.g., globalization and growth in emerging markets) were not explicitly addressed but are assumed to influence the space sector in ways similar to those that are influencing other sectors like information technology (IT).

We identified three space-specific categories of drivers:

- **Growing perception of the usefulness of space.** Space activity has traditionally been a tool to gain geopolitical advantage and build national pride and prestige. In more recent years, it has begun to be viewed as an instrument of public good enabling the provision of services such as weather prediction, distance education, and telemedicine. Its role as an agent of economic growth and development that creates high-value jobs has grown as well. This perception of the growing usefulness of space is driving government, private, and nonprofit actors to invest in space-based activities.
- **Increasing maturity and falling cost of technology.** One of the most critical developments driving activities in space is the increasing availability of commercial-off-the-shelf (COTS) hardware components, and simultaneous advances in miniaturization and IT infrastructure. Other technology drivers include emerging capabilities in IT, especially those related to cloud computing and big data analytics, 3D printing, automation, and robotics.

  One particular technology platform, that of small satellites (satellites that are under 100 kilograms), is being seen as an important driver of future activities especially in Earth observation, communication, and space S&T and exploration sectors. Lower cost combined with increased functionality of these satellites is spurring interest from governments, universities and private actors worldwide. Experts see small satellites as a disruptive force, and the study team drew parallels with the evolution of computing from mainframes to personal computers to personal assistant devices.
- **Changing national policies.** Government funding and policies heavily influence space activity, especially that in the private sector. This is demonstrated by increasing inclusion of commercial solutions to meet government needs, liberalization of technology export controls to promote domestic industry, and the lowering of regulatory barriers.

Overarching Trends

In this report, we define a trend as a development or change related to space activities that affect many countries, including space technologies and space applications. Trends are influenced by drivers in the categories identified above. Synthesizing data from interviews, the literature, and our own analysis using primary sources, the STPI research team identified six distinct but inter-related categories of trends.

- **Leveraging advances in technology**. Technology is both a driver of trends in space and a trend itself. The confluence and acceleration of technological developments, many related to IT and availability of COTS products, are improving performance, reducing size, enabling diverse approaches, and lowering costs in the realm of space.
- **Growing participation and expenditures**. As a result of the falling cost of entering the space sector, more actors—both government and private entities—are investing in, pursuing, and expecting to benefit from space activities. There are eighty countries with activities in space, up from just twenty in 1975. As the number of actors proliferates, the United States is becoming a declining fraction of international activities and partnerships.
- **Structural changes in civil space.** Countries that are developing new or additional space capabilities are not necessarily following the same development pathways followed by traditional space-faring countries. There is also not a common development blueprint across these new entrants. Some countries are focusing on developing indigenous capabilities, and others prefer to be users of space-based data and leverage collaborations with international government and private sector actors to acquire capabilities. Many countries are also blurring the boundaries between military, commercial, and civilian space enterprises, making their progress more difficult to track.
- **Diversity of approaches in the private sector**. New entrants in the space sector are bringing previously unused approaches to the sector—for example, innovations that focus on cost control rather than performance improvement. They are also “spinning in” technologies from other sectors—for example, use of inertial measurement units from video games. Reflecting the culture of Silicon Valley, many of the emerging companies have an entrepreneurial bend, and position themselves as globally oriented IT or media companies rather than aerospace companies offering data services for consumers and enterprises, with space merely as one point in the supply chain.
- **Growing space-based services industry.** Increasing demand for space-based data, as well as applications built on this data, is resulting in a growing space-based service industry (business intelligence, data and mapping applications) for both consumers and enterprises. Governments are also beginning to consider buying services rather than building or acquiring technology or products.
- **Complex global governance**. An increase in the number of actors and types of activities in space is leading to more physical and electromagnetic congestion,

which, among other things, has increased the complexity of domestic and global space governance. As with other strategic sectors such as advanced manufacturing and high performance computing, there is growing tension in this area between globalization and protectionism.

Overarching Implications for the Future

The trends observed above have important implications for the future:

- **Distribution and acceleration of innovation**. As a result of the changes discussed above, innovation in the space sector will become more ubiquitous across the world and especially in the private sector. The sheer number of actors and diversity of approaches in the sector will also ensure that the pace of this innovation will accelerate.
- **Continued ascendancy of consumer/commercial interests**. There will likely be structural changes in many of the subsectors of space. Sectors like Earth Observation, for example, currently managed within governments will begin to bifurcate. After some churn, the higher-end, inherently governmental functions relating to societal well-being will likely remain within the government, but more consumer-driven functions will migrate to the private sector. The consumer sector would then behave as a competitive free market, as has happened in other sectors like IT. As more subsectors of space become more mainstream, there will be growing numbers of global enterprises, supply chains, partnerships, and competition.
- **Difficult to manage the space sector top-down**. COTS hardware, software, and the satellite manufacturing industries are developing globally, and the private space sector is growing. This will make it more difficult for most governments, not just in the United States, to manage the space sector.
- **Difficult to predict developments**. With countries following varying pathways to developing their space capabilities, common metrics used for assessing capabilities of a country, such as investment in developing indigenous capabilities, may lose some meaning. As a result, it will be more difficult than it is today to predict national capabilities.
- **Waning asymmetric control for traditional leaders**. With more countries and private sector firms operating in space and seeking to take on additional roles by participating in international space organizations, both the domestic and global governance landscapes are becoming more complex. As a result, not only will the United States and other traditional space-faring countries have diminishing control of global decisions related to space activities, but there will likely be

greater pressure on them to accommodate the needs of the private sector and emerging space countries.

Technology Disruptions and Other Wildcards

The trends and implications discussed above emerged from extrapolating from current activities and plans. It will, however, be useful to consider developments or “wildcards” that might overturn these trends. Identified wildcards clustered in three categories:

- **Technology developments.** One technology-based wildcard would be a dramatic reduction in the cost of launch emerging from some breakthrough like the ability to re-use multiple stages of rocket engines or the development of specialized carbon nanofibers that make technologies such as space elevators feasible. Other wildcards include technologies that reduce dependence on space (e.g., sub-orbital or atmosphere-based intelligence, surveillance, and reconnaissance), or technologies that would allow utilization of space-based resources (e.g., asteroid mining, space-based solar power).
- **Geopolitical developments**. Unexpected actions from countries would be an important wildcard that disrupts the trends above. Examples include drastic changes or responses to the Outer Space Treaty or other international rules governing space, or weaponization of space (e.g., if China were to place military bases on the moon).
- **Other developments**. Other developments could make extrapolating from current trends moot. Examples include a large, debilitating space weather disaster or cyber-event that cripples space-based services for an extended period, or a space debris cascading event that degrades use of space.

Conclusion

The space sector is undergoing a transformation, as it gradually “breaks free” from the confines of the military/government sector in a few space-faring countries. A demand pull is emerging along two dimensions—from governments worldwide as more countries act on their space aspirations by participating in space activities in different ways, as well as from the private sector (a globalized private sector, even if mostly centered in the United States) wanting and providing more space-based products and services. As the number of actors increase, the space sector will likely see increased competition and overcrowding, both literally and metaphorically, which, in turn, serve as a driver for more products, services and governance structures that can support the needs of a growing sector.

Contents

1. Introduction

A. Background

The Cold War sparked an unprecedented space race between the two major superpowers, the United States and the Soviet Union. Space research during that time contributed in part to the development of technologies ranging from microelectronics, solar panels, integrated circuits, and real-time embedded computers and operating systems.

Since then, the space sector has grown to include more countries and diversified to integrate technologies and innovations from other sectors. Private funding for space-based ventures has increased dramatically over the past decade, along with the growth of a private sector. Hardware and information technology (IT) infrastructure have progressed to a point where technology developed for terrestrial uses is slowly being extended to space-based applications. There is growing demand among governments, private companies, and individual consumers for geospatial data.

The implications of some of these emergent and dynamic changes in the sector are still not well understood. To better understand the global space landscape, the IDA Science and Technology Policy Institute (STPI) undertook a study to explore, synthesize, and summarize global trends relevant to the civil and commercial space sectors.

B. Goal and Scope

The goal of this study was twofold. The first goal of was to understand the factors that are driving recent changes in the space sector changes, and the second goal was to identify trends in the space sector. This report provides a comprehensive perspective of the global civil and commercial space landscape by:

- Identifying critical drivers of global civil and commercial space trends;
- Identifying trends and assessing implications of non-U.S. civil and commercial participation, partnerships, and collaborative activities;
- Identifying trends in specific subsectors of space, and assessing implications of on-orbit operational capabilities, space-based applications, space-based services, and launch services;
- Synthesizing drivers and trends to identify cross-cutting global implications;
- Examining the validity of trends discussed in the space community;
- Identifying potential disruptive or wildcard events; and

- Providing “big picture takeaways” relevant to strategic thinking about the future of space.

With respect to scope, this report does not focus on trends in military space applications. As a result, there was less emphasis on countries like China and Russia that have military-oriented and dual-use space programs.

C. Methodology

This study was organized into four distinct phases. During the first phase, an initial literature review was conducted to identify areas relevant to global trends in civil and commercial space. During the second phase, semi-structured interviews were conducted and resulting data analyzed. During the third phase, additional literature was reviewed to contextualize interview findings. During the fourth phase, quantitative data was identified and analyzed to test premises and validate findings. In addition, members of the study team attended a number of conferences and symposia on topics that informed this report.

Our overall findings are presented in this report, which is divided into two volumes. Volume 1 summarizes overarching drivers and trends in the government and the private space sector. Volume 2 elaborates on trends in seven subsectors, and provides details on trends related to the fast-evolving small satellite platform. It also explores “wildcards” or technological, geopolitical, and other unexpected developments that could disrupt current trends.

The literature review was conducted using a variety of proprietary reports (e.g., from Euroconsult and the Space Foundation), and other web-accessible, open-source and subscription journals and periodicals (e.g., *Space Policy*). Interviews were conducted with about fifty experts in U.S. and foreign governments, international organizations, academia, and the private and nonprofit sectors. A list of interviewees is in Appendix A, which is included in Volume 2 of this report. Primary data were collected from Thomson Reuters’ Web of Science and Elsevier’s Scopus databases, as well as attendance statistics at international conferences (e.g., International Astronautical Congress and Utah Small Satellite Conference). Data were analyzed using content analysis methods and social network analyses tools such as Gephi.

Altogether, the analyses revealed about thirty drivers, over a hundred trends, and about thirty implications, which were grouped and organized for discussion in this report. Appendix B, also in Volume 2, contains complete lists of the initial drivers, trends, and implications as synthesized from the raw data.

D. Limitations

To ensure rigor in our analyses, STPI researchers attempted to find and use quantitative data when validating interview findings. In many cases, there were no data available. For example, we could not find an authoritative catalog of the number of new companies in the space sector or an inventory of global partnerships. Even when data were available, quality sometimes was questionable because of the opacity of their source. A particular limitation was the lack of comparable data on civilian space expenditures, both across countries (available data were not adjusted for purchasing power parity) and years (available data were in current rather than constant dollars). Civil budgets were especially difficult to compare across countries. For example, in the United States, expenditures on human space flight are listed as a civilian expense, whereas in China they are listed as defense (Euroconsult 2014a, 43–44).

To compensate for the lack of reliable data in the space sector, we combined insights from qualitative and quantitative sources, collected and analyzed primary information, and provided caveats when necessary.

2. Overarching Drivers of Trends in Space

To better understand global trends in space, it is useful to contextualize them within a broader ecosystem of drivers. In this study, a driver is defined as an external factor that is causing, or might cause, changes to the “who, what, when, why, and how” of space activities. These drivers are, by definition, wide-ranging and long-term.

Our analysis identified close to thirty drivers that fall into four high-level categories. (A full list is available in Appendix B.) This chapter discusses these categories, which in aggregate can be seen as driving governmental and private interest and investment in space.

A. Globalization

The *Financial Times* defines globalization as involving the integration of economies, industries, markets, cultures and policymaking around the world. In this usage, the term describes processes by which national and regional economies, societies, and cultures have become integrated through the global network of trade, communications, immigration, and transportation.[1] Technological globalization involves the diffusion of technical understanding, research and development, invention, and advanced manufacturing capabilities globally. The extent to which countries (and firms, universities, and other organizations within states) are engaged varies considerably.

Some aspects of globalization are available globally if users have some minimum level of financial resources to pay for products and services (e.g., access to cloud-based IT and communications storage and services). Other aspects of globalization are available to only actors with more significant financial resources and financially enabled technological capabilities. These generalizations apply to the space launch and space systems sectors. Some earth observation data is available to anyone with enough money to pay for it (subject, for U.S. service providers, to U.S. Government regulations). Other capabilities (e.g., development of space launchers capable of lifting significant payloads to orbit) have been developed only by a small number of organizations and, due to cost and limits of market demand, are unlikely to become as widespread as the technologies that are integral to advances in many satellite and satellite-based service capabilities.

Countries are often the referents in discussions of globalization (e.g., statements about China being integral to the global supply chain for personal computers and other products).

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[1] “Definition of globalization,” Financial Times Lexicon, http://lexicon.ft.com/Term?term=globalisation.

Such statements are correct but incomplete. The global diffusion of technological and manufacturing competencies involves firms (necessarily located within countries) as well as governments. Such firms differ in a number of respects. Some are competitive corporation similar to those found within the U.S. private sector. Others have varying relationships with governments (e.g., entities that are state-owned, have a state as their only significant customer, or have special access to credit), or might be regarded as "too big to fail" or as "national champions."

Interrelationships between firms and the countries within which they have staff, facilities, or legal presence can be complex. One major element of globalization is the shifting of the economic fulcrum to the East.[2] According to Apple, its iPhones are manufactured in China by Hon Hai Precision Industry Co. LTD (Foxconn Technology Group).[3] This firm has manufacturing facilities in multiple countries; it is the largest exporter in China and the second largest in the Czech Republic.[4] Its corporate headquarters is in Taiwan and its stock trades on the Taiwan stock exchange.[5] It also has a headquarters within China. In different contexts, it is accurate to refer to it as a Taiwanese, Chinese, or Czech firm. Furthermore, some firms are attempting to become more transnational or multinational, with implications for the diffusion of innovation globally. See Appendix C in Volume 2 of this report for an in-depth discussion of globalization and China.

B. Growing Perception of the Usefulness of Space

With roots in the Cold War, space-based activities are still seen by many as an instrument of security and strategic importance. Governments traditionally viewed space technologies as strategic technologies, with unique dual-use (civilian and military) capabilities. For some countries, such as Iran, civilian activities legitimize military ambition. As space-based capabilities have increased, costs have decreased, and technology has become more ubiquitous, the benefits of space activities have become increasingly visible and attainable (OECD 2014).

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[2] According to some experts, by 2025, emerging markets will have been the world's prime growth engine for more than 15 years, China will be home to more large companies than either the United States or Europe, and more than 45 percent of the companies on Fortune's Global 500 list of major international players will hail from emerging markets—versus just 5 percent in the year 2000 (Dobbs, Ramaswamy, Stephenson, and Viguerie 2014).

[3] Apple, Supplier Responsibility, A detailed list of our suppliers and final assembly facilities, https://www.apple.com/supplier-responsibility/our-suppliers.

[4] Hon Hai website, Group Profile, http://www.foxconn.com/GroupProfile_En/GroupProfile.html.

[5] Bloomberg website, Foxconn Technology Co Ltd, http://www.bloomberg.com/research/stocks/snapshot/snapshot.asp?ticker=2354:TT.

One set of factors that is driving space investment is the growing perception—both by governments and others—that operating in space has societal benefits, promotes economic growth and development, enhances a nation's prestige and geopolitical advantage, and provides profit potential.

1. Societal Benefits

Space-based services—Earth observations, satellite based telephony and broadband services, telemedicine, tele-education, among others—provide well-documented benefits.[6] Many developing countries, especially in Southeast Asia, design their space programs for Earth observation applications. Space-based weather monitoring, for example, enabled India to evacuate millions of people in anticipation of the Phailin Cyclone of 2013. In 1999, a far less powerful cyclone had killed more than 10,000 people. For some countries like Azerbaijan and Venezuela (Selding 2013c; Euroconsult 2014a), interest is in satellite communications to connect remote areas of their countries.

Countries see additional indirect benefits from participating in space-based activities. For some countries like Bolivia and Brazil, space activities are a way to expand partnerships with other countries (Euroconsult 2014a). Other countries like United Arab Emirates and Saudi Arabia view investment in space as a way to shift from an economy based on natural-resources to one based in knowledge. Indeed, a joint United Kingdom Government and space industry group discusses space as providing environmental benefit, stating that "Space can deliver many of these benefits, including rural broadband and the bulk of TV and radio entertainment with the key advantage over terrestrial alternatives *that it produces virtually no carbon here on Earth*" [emphasis added] (*Space IGS* n.d.).

2. Agent of Economic Growth and Development

Investments in space are also being driven by governments eager to produce high-value-added industrial sectors, as the following examples illustrate:

- The United Kingdom (UK) recently established a space agency and set a challenge to grow its share of the global space market to 10 percent (from 6.5 percent) over the next 20 years (*Space IGS* n.d.) and 100,000 high-paying jobs to the economy.
- The space policy of Japan states that "the Government will place the space industry among strategic industries in the 21st Century and enhance

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[6] See https://www.earthobservations.org/geoss.php. Also see *National Strategy for Civil Earth Observations,* available at https://www.whitehouse.gov/sites/default/files/microsites/ostp/nstc_2013_earthobsstrategy.pdf, and *National Plan for Civil Earth Observations,* available at https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/national_plan_for_civil_earth_observations_-_july_2014.pdf.

competitiveness by promoting space machinery smaller, serialized, communized and standardized.… It is important to strengthen the international competitiveness by developing Japan's space industry into a strategic industry for the twenty-first century after the electric and electronic industries and automobile industry" (Gibbs 2012).

- The Korean space vision is "to boost the national economy," and one of its goals is to "raise the national standard of living through space applications" (Space Development Promotion Act 2005)."
- Economic development is central enough to the Australian space enterprise that its Space Coordination Office is placed within the Department of Innovation, Industry, Science and Research (Australian Government 2013).
- Mexico's strategic planning calls for it to expand its aerospace sector, eventually expecting to be a 1-percent participant in the global space industry (Mexican Space Agency 2013).
- Israel's changing space objective is focusing on civil and scientific applications "that would allow Israel to develop a greater industrial scale and competitive edge in the growing, global space market" (Israel Space Agency 2013).

3. National Prestige and Geopolitical Advantage

Using space-based products and services are important to sovereign states. However, the benefits of space-based activities extend into more nebulous territory too, namely national prestige. Self-esteem, the good opinion of others, and reinforcing national identity and sense of purpose have always driven space activities but they are becoming increasingly overt justifications for space programs (de Montluc 2009). There is particularly high status imparted to countries with complex indigenous space programs. In September 2014, for example, when India became the first Asian country to reach Mars orbit, news sources reported that "national pride soared," school children celebrated the space agency, and the Indian Prime Minister wore a red vest, symbolizing prowess and victory (Lakshmi 2014). The United Arab Emirates, with growing space budgets and ambitions, aims to be a leader within the Middle East space enterprise. Status consciousness is not limited to emerging space nations. Upon landing of the Philae probe on comet 67P, ESA Director General Dordain tweeted, "We are the first to have done that, and that will stay forever."[7]

The sentiment has led to the emergence of government-subsidized "pride sats," which are launched by countries more for national prestige than for societal benefit or revenue

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[7] See https://twitter.com/esa/status/532576903282958336.

generation (Arnould 2014). Examples of countries that have launched such satellites include Nigeria, Azerbaijan, and Argentina.[8]

Related to the prestige that comes with accomplishments in space is the geopolitical standing investment in space brings (de Montluc 2009). As illustrations, in their efforts to gain regional geopolitical influence, China and Japan are working with competing regional space organizations, with Beijing leading the Asia-Pacific Space Cooperation Organization (APSCO) and Tokyo leading the Asia-Pacific Regional Space Agency Forum (APRSAF), with India not far behind (Kingwell 2014). In a speech at the launch of four satellites in June 2014, the Indian Prime Minister showed evidence of his diplomatic intentions in the South Asian region, and called on Indian scientists to use their expertise in satellite technology to help countries in the South Asian Association of Regional Cooperation (SAARC).

> Today, I ask our space community, to take up the challenge, of developing a SAARC satellite—that we can dedicate to our neighborhood, as a gift from India. A satellite, that provides a full range of applications and services, to all our neighbor. (Kingwell 2014).

Geopolitics is also evident in bilateral space activities. Japan has been developing strategic cooperation with Vietnam through the investment and provision of Vietnamese remote sensing satellites (Kallender-Umezu 2011). India has a number of agreements with Thailand to cooperate on civil space Earth observation activities.[9] China has civil and commercial space cooperation efforts with countries aligned to its interests in obtaining and having influence over strategic natural resources (e.g., Pakistan, Venezuela, Nigeria, Brazil, and Bolivia).[10] Russia, too, is supporting the design of a family of next-generation rockets in Brazil and creating five new launch pads as part of its Southern Cross Project (United Kingdom, Foreign and Commonwealth Office 2015).

4. Potential for Profitability

It is not just governments that see space as an avenue for growth and development. Capital markets, venture capitalists, and individual companies also see potential near- and far-term payoffs from space-based activities (Al-Ekabi, Baranes, Hulsroj, and Lahcen 2015). In the near-term, expectations are especially high in the remote sensing and Earth observation sectors, where high-resolution, frequently updated geospatial imagery can provide information on the location and movement of people and objects. The potential for

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[8] See http://www.intelsatgeneral.com/blog/talking-hts-nsr-analysts-prashant-butani-and-blaine-curcio.

[9] See http://www.indianembassy.in.th/relationpages.php?id=188888891.

[10] China launched a $250 million Earth Resources Satellite in November 2014 jointly with Brazil, with another launch due 2017 (BBC News 2013; Clark 2011; Clark 2014; Selding 2014b; Fazl-e-Haider 2007).

profitability emerges not just from the sale of imagery or data from space to commercial entities, but also its fusion with other data sources, to sell intelligence and business analytic products.

In the far-term, profitability is expected from activities like asteroid mining and in-situ resource extraction, and proponents project trillions of dollars in revenues (Diamandis and Kotler 2015). Only time will tell whether these projections are true, but they are compelling enough for both interest and investment in the private space sector to increase dramatically (discussed in Chapter 5).

C. Increasing Maturity and Falling Cost of Technology

As new concepts in IT emerge (e.g., low-cost sensors, low-power processors, scalable cloud computing, and ubiquitous wireless connectivity), they are enabling new applications, and adding economic and social value in a range of sectors, including energy, transportation, health care, and others.

Technical advances driving space are not limited to IT alone; they include communications, miniaturization, advanced manufacturing, and more. In fact, technological advancement is so integral to space developments that we consider it both a driver and a trend. This section describes a sampling of technology-based developments, and discusses how they are driving activities in space.

1. Information and Communications Technology/IT

IT advances along multiple fronts, including components, computing infrastructure, and software, are bringing structural changes to the space sector. Three developments in particular are worth showcasing—commercial hardware, software, and cloud computing.

a. Commercial Off-the-Shelf (COTS) Hardware Components

Digital COTS technologies have reliably followed Moore's Law and other exponential laws governing miniaturization and improving performance.[11] Driven by the commercial electronics industry, digital COTS components are now bringing multiple benefits to other sectors. These benefits range from increased functionality (such as incorporation of communication and sensing components directly on processor platforms) to more powerful capabilities (from miniaturization) at a smaller price.

As more COTS hardware is integrated into space systems, all forms of data collection, storage, processing, and transmission can be expected to improve across all parts of the

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[11] Examples include Kryder's Law, which describes the exponential growth of hard disk drive volume, and Hendy's Law, which observes the exponential growth in imaging technology.

space sector.[12] Two areas where COTS technology has become an especially strong driver are processors and storage devices.

Processors. Commercial processor technologies follow exponential laws that have resulted in the scaling down of transistor devices, which is the equivalent of adding more components per chip. Scaling has the property of improving their performance and power, resulting in a constant doubling of computing performance at near constant cost every two years (approximately 40-percent improvement in information processing capability per annum), a faster rate of improvement than seen in custom processors (Figure 2-1).[13] These commercial processors are increasingly integrated into small satellites, allowing for rapid improvements in the processing capability.

Storage devices. Commercial storage (disk drive) capacity has increased at a faster pace than Moore's Law, at an approximate annual growth rate of 62 percent, at roughly the same mass, power, and volume (Walter 2005).[14] Improvements in storage capacity are driving advances in multiple areas such as cloud-based storage. Improving storage capacity not only helps data processing on satellites and other space platforms, it also aids in the collection and archiving of large imagery files such as Earth observation imagery.

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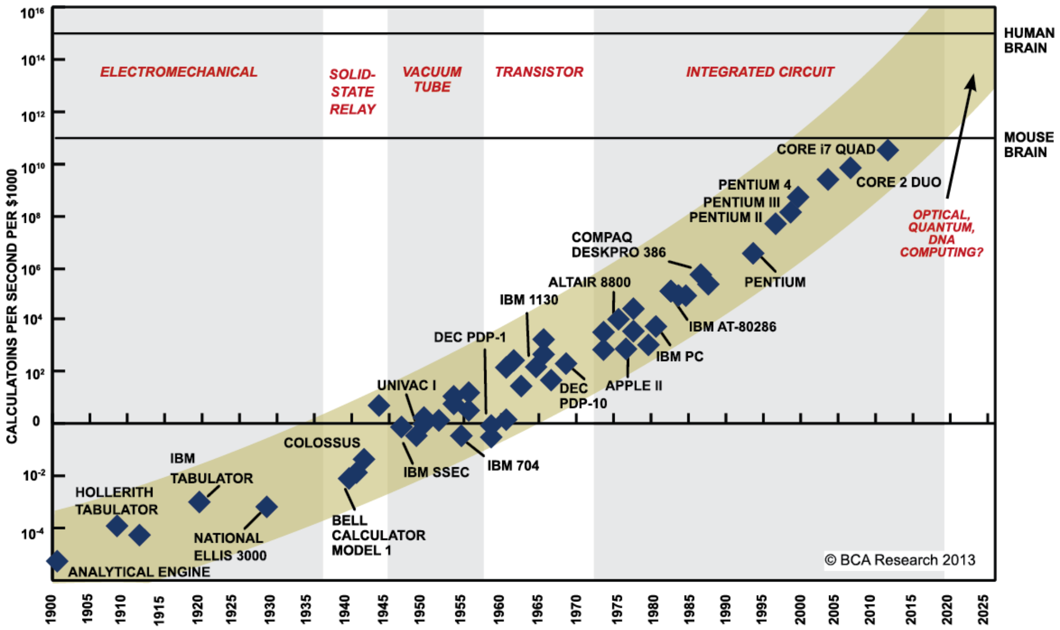
[12] One tradeoff with many COTS components is that while they are often more capable than traditional space hardware, their reliability in the space environment must be proven through ground testing or flight heritage. Otherwise COTS components derived from commercial electronics remain a substantial risk for any mission that depends on them.

[13] Moore's Law projects a doubling of transistors on an integrated circuit every 18 months, an increase in complexity which is achieved by scaling down circuit components (miniaturization) with each successive technology generation. In fact, Moore's Law is not so much a Law in the true sense of the word, as an articulation of a business proposition, based on the fact that cost to manufacture simple chips was found to be nearly independent of the number of components on the chip. In other words, the cost per component was nearly inversely proportional to the number of components; therefore, as electronic circuits have progressively miniaturized by adding more components per chip, the cost of manufacturing per component has dropped even as computing power has grown (Tuomi 2002).

[14] This optimism has been somewhat tempered in recent times (Mellor 2014; Rosenthal 2014).



SOURCE: RAY KURZWEIL, "THE SINGULARITY IS NEAR: WHEN HUMANS TRANSCEND BIOLOGY", P.67, *THE VIKING PRESS*, 2006. DATAPOINTS BETWEEN 2000 AND 2012 REPRESENT BCA ESTIMATES.

Source: Available from http://blog.bcaresearch.com/wp-content/uploads/2013/10/Chart-III-8-Moores-Law-Over-199-Years-And-Going-Strong.png.

Figure 2-1. Increasing Performance and Decreasing Cost of Devices

b. Software Advances in Image Recognition and Analysis

Advances in software are enhancing capabilities of optical imaging systems, as can be seen in smartphone cameras, astronomy, and microscopy tools. Advances in image processing are coming not just from better optics, but from more sophisticated software for processing imagery data.

Looking to the future with the expectation of processing large volumes of geospatial and other imagery data, large data companies in the global commercial sector, such as Google, Facebook, Apple, Microsoft, and Baidu, are pushing automated image recognition capabilities that are based in machine learning and will eventually be used to process larger volumes of data faster. Currently much commercial machine vision technology is done by having humans “supervise” the learning process by labeling specific features. Google and others are building in-house programs for computer vision research and machine learning for image recognition with the goal that the machine is given no help in identifying features (Markoff 2012; Szegedy 2014).

c. Cloud Computing and Big Data Analytics

Advances in cloud-based data analytics is gradually minimizing the need for onboard data processing by allowing most of the image processing and analysis to be done on the ground. Such advances can enable companies to deploy proprietary image processing software on cloud-enabled infrastructure and services combined with large-scale distributed search infrastructure. This enables real-time storage, processing, and analysis of large volumes of data, which has the potential to transform access, usage, and economic exploitation of space-based data.

2. Other Technological Advances

Space-based applications have benefited from continually advancing technology. A comparison of two French satellites launched ten years apart (SPOT-5, launched in 2002, and SPOT-6, launched in 2012) illustrates the impact. SPOT-6 weighs a fourth as much as SPOT-5, but has double the lifetime and double the data acquisition capability.[15] These improvements have come from advances in areas such as miniaturization, power system improvements, advanced materials, 3D printing, and sensors, among others. Miniaturization is a critical driver of recent trends in the small satellite platform, and discussed in Chapter 9 in Volume 2. Here we discuss two specific areas relevant to coming changes in the space sector: power systems and 3D printing.

a. Power Systems

Improvements in power systems, which typically account for 20 to 30 percent of the total spacecraft mass (Yeh and Revay 2014), have the potential to significantly affect space technology (Figure 2-2). The efficiency of perovskite solar cells, for example, has increased from 4 percent to almost 20 percent in only 5 years (Service 2014). Researchers are currently developing ultra-low-power electronic systems that exploit quantum mechanics for operating at voltages as much as five times lower than those of the current standard mobile phone circuit (Barraud 2014). Mobile device components will likely be the first to use such optimized electronics, which minimize thermal dissipation, but the possibility remains for more robust aerospace applications, such as extending the battery life of satellites.

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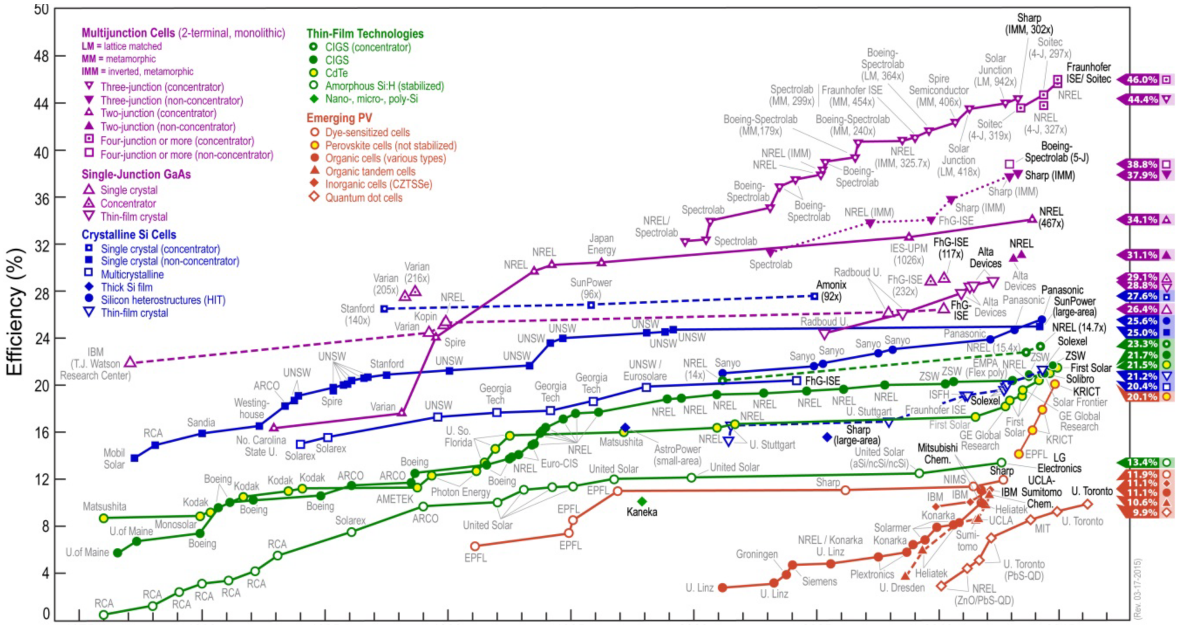
[15] From http://www.satimagingcorp.com/satellite-sensors/other-satellite-sensors/spot-5.



Source: National Renewable Energy Laboratory, National Center for Photovoltaics, http://www.nrel.gov/ncpv/images/efficiency_chart.jpg.

Figure 2-2. Advances in Solar Cell Efficiency by Cell Type

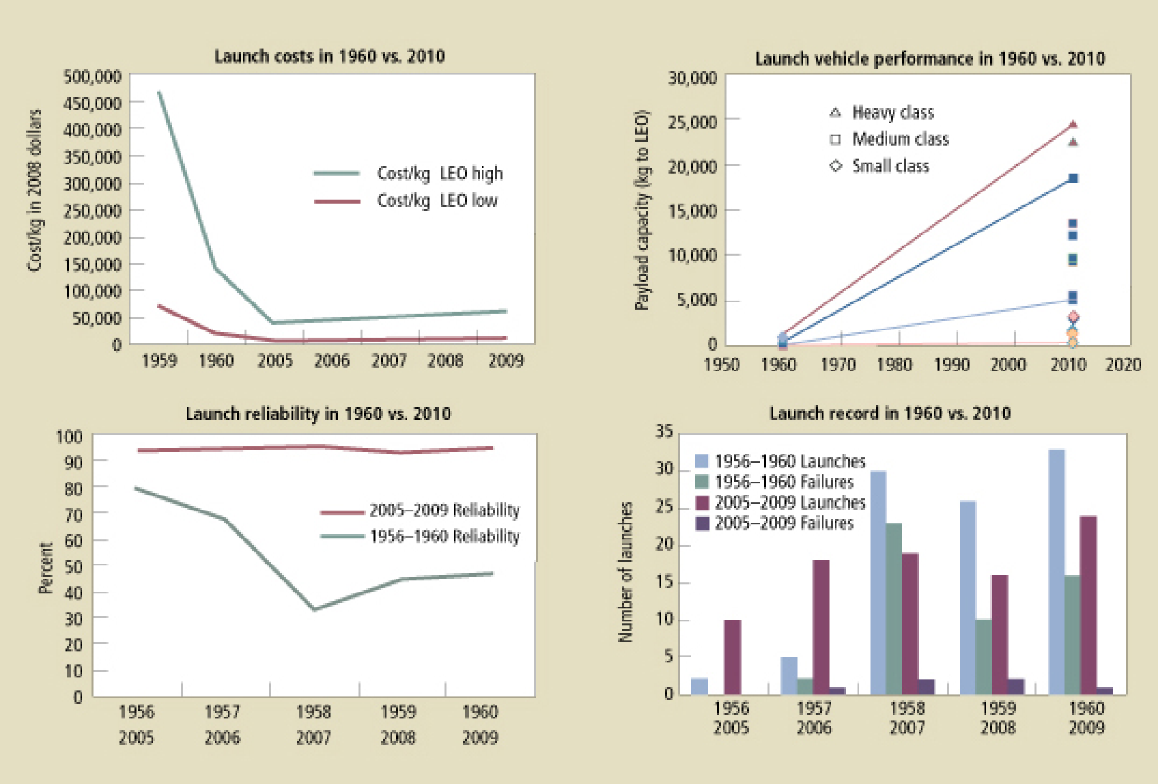
b. 3D Printing

Because it offers the ability for rapid prototyping, rapid tooling, direct digital manufacturing, and easy maintenance and repair, 3D printing can dramatically reduce cost of space hardware and enable a complete reconceptualization of space architectures (Shipp, Gupta, Lal, et al. 2012). Experiments are underway to explore the potential for aerospace applications. In 2013, for example, Aerojet Rocketdyne used laser-sintered fusing of a metallic powder bed to create the center-core section of a full-scale injector that would represent a liquid oxygen hydrogen RL10 engine. The component was built in 8 weeks (traditionally, forge, weld, braze, and five-axis mill 100s of parts to make one, takes over a year) and reduced cost several orders of magnitude by using 33 times less material (Thorne, Ambroso, Lal, et al. Forthcoming). In the same year, Lockheed Martin and its contractor RedEye manufactured fuel propulsion tanks to test a new satellite design, by printing polycarbonate pieces and bonding them together. The process took approximately three months, half the time Lockheed Martin anticipated for traditional space manufacturing techniques, at only one-fifth the price (OECD 2014).

3D printing has been recognized as an important driver of space applications (National Research Council (NRC) n.d.) and all major space-faring nations have invested in the technology (Shipp, Gupta, Lal, et al. 2012).

3. Falling Cost

Improvement in performance is an important driver of developments in space. An equally important driver is the rapidly falling cost of technology for the same or better performance.[16] Indeed, one reason developing countries and the private sector have become more interested in space is that past investment has reduced risks of technology to a level that new entrants can enter the market at not too high a cost. Figure 2-3 illustrates the dramatic drop in launch costs between 1960 and 2010 (top left graph) while increasing the vehicle's payload capacity (top right graph) and reliability (bottom two graphs).



Source: Kendall and Portanova (2010).

Figure 2-3. Comparisons of Launch Costs, Vehicle Performance, Reliability, and Success and Failure Records

D. Changing National Policies

Government funding and policies heavily influence space-based activities, especially private space activity, and government agencies around the world are under pressure to re-

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[16] Lower costs result from other more process- or business-related decisions as well. For example, non-radiation-hardened microprocessors or memory chips cost two or three orders of magnitude less than radiation-hardened ones (Fichtenbaum 2015), and using them instead of radiation-hardened chips is a tradeoff between cost and reliability that firms like Planet Labs and others have made.

examine policies restricting the commercial development and sale of space goods and services (Gibbs 2012, 279). There is also pressure on agencies to begin to view and regulate space as a mainstream economic endeavor, and not see it *solely* as a strategic national security-relevant sector. This shift in emphasis is especially evident in the United States and Europe, where commercial solutions are increasingly used to meet government needs, technology export controls are being liberalized, and regulations are being relaxed to provide higher resolution imagery.

1. Export Controls

Export controls are laws and implementing regulations that govern the distribution to foreign nationals and foreign countries goods (including software and technology) and services. Export controls exist within a broader export control system consisting of international and domestic laws. In the field of space technologies, export controls can dictate who has legal access to space technologies, creating incentives for indigenous technology development for countries unable to import technology, and affecting the commercial competitiveness of domestic firms trading internationally.

While virtually all states with launch technologies and satellite technologies have export control systems, U.S. export controls have historically had the most significant impact globally on the trade in space technologies. This is largely because U.S. indigenous technologies have been integrated into almost all advanced Western commercial telecommunication satellites and, as such, the satellites are subject to U.S. export controls through the application of extraterritorial jurisdiction.[17] In recent years, these controls have acted as drivers for foreign development of indigenous space technologies and launch services.

a. Driving the Development of Indigenous Technology

Whether or not a country or company decides to invest and develop an indigenous space technology depends in part on the calculation of the effect of procuring and relying upon foreign technology on national security and commercial interests. In the space sector, the United States has been a key supplier to the global space industrial base. For certain high-quality, space-qualified parts and components (e.g., radiation-hardened chips), the United States has maintained a practical monopoly. But partly because of U.S. export controls, particularly the International Trafficking in Arms Regulations (ITAR), other countries and their companies have actively sought independence from U.S. technologies through the development of indigenous technologies that allow them to compete with the United States (NRC 2009; Van Atta, Bittmann, Collopy, et al. 2008).

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[17] For more information on the extraterritorial jurisdiction of U.S. export controls, see Mineiro (2012).

Both traditional and non-traditional space powers have developed indigenous space technologies, in part as a response to U.S. export controls. For example, the European Union (EU), concerned that U.S. export control restrictions on certain strategic components integrated into European products, including space related components, were inhibiting EU' nations' ability to act independent of U.S. approval, established a policy "for the development of strategic [space] components concentrating on selected critical components, for which dependency of European industry on international suppliers should be avoided, in order to achieve the optimum balance between technological independence, strategic cooperation with international partners and reliance on market forces" (Council of the European Union 2007). Our interviews and the literature revealed this to be a broader trend. For example, a significant part of Turkey's commercial business is derived from companies seeking ITAR-free technologies.[18]

b. Driving the Development of Launch Services

In addition to driving the development of indigenous technologies, U.S. export controls are also a driver of the launch sector, influencing the ability of customers to procure launch service from certain providers on the global market. For example, since 1998, the United States has maintained a de facto international launch embargo of high-quality telecommunication satellites against Chinese commercial space launch services. This embargo was implemented by prohibiting the re-export of U.S. space technologies integrated into foreign commercial communication satellites to China for launch (Mineiro 2011, 220). As a result, customers with U.S.-origin technology have not been able to access China's launch services, effectively limiting the global competitive market. In part, to gain access to Chinese launch and other foreign launch services, foreign competitors have developed and actively market ITAR-free satellites that can be launched from China (or other countries) without permission of the U.S. Government.

2. Policies to Promote Domestic Industry

As section A.2 of this chapter describes, government policies actively guide the development of indigenous space sectors with vision documents, directed funding, and other mechanisms. An illustration of a government policy driving the space sector is in the areas of commercial imaging.

For security reasons, many countries, including the United States, India, and countries in Europe, have consistently restricted the size and quality of imagery resolution that can be sold. These resolution restrictions have consequences similar to those of export controls, including providing incentives for foreign indigenous development of space-based imaging

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[18] From http://www.gumush.com.tr/. GUMUSH Aerospace & Defense Ltd. is the first pico-, nano-, and microsatellite design and manufacturing company in Turkey and the Middle East.

capabilities equivalent to or superior to restricted capabilities and of non-space-based remote sensing solutions. In recent years, under pressure from the firms, countries have relaxed their restrictions as competing foreign commercial imagery providers approach or surpass a limit. For example, DigitalGlobe, a U.S.-based company, was not allowed to sell imagery with resolution greater than 50 centimeters to customers outside the United States. However, in June 2014, the Department of Commerce granted DigitalGlobe permission to sell its new highest resolution imagery (with 31-centimeter resolution) to all customers. This policy change will affect the competitiveness of U.S. firms. Other government policies, such as those related to whether imaging data should be available free of charge, similarly drive commercial development.

3. Increasing Civil Participation in Space

Now that we have identified the principal overarching drivers of global space trends, we turn to the trends themselves. The first major trend is the increase in the numbers of participants in space-based activities. While increases in participation are illustrated in various ways throughout this report, this chapter focuses on the basic numerical data on participation—number of countries, budget expenditure, and activities.

A. Number of Countries

About 80 countries engage in space-based activities in one form or another (Euroconsult 2014a). This number has grown from 2 in the 1950s and 20 in 1975. Of these, 68 have launched satellites[19] (as have 7 organizations[20]), although as many as 170 countries hold financial interest in satellites (Department of the Air Force 2014). Developments have been especially rapid in recent years; between 2000 and 2009, the number of countries with space agencies grew from 40 to 55 (Selding 2010).

Increasing participation in space-based activities is also evident in the number of new entities that have joined international organizations such as the International Astronautical Federation (IAF), a space advocacy organization with over 280 institutional members from 64 countries across the world. The rise in IAF membership stems, in part, from representation from new countries, as shown in Figures 3-1 and 3-2.[21]

The numbers narrative also masks the rise of certain countries more than others. In terms of space capabilities, some of them are no longer "rising" nations; China and India, for example, have risen; both are significant space-faring nations (Table 3-1).

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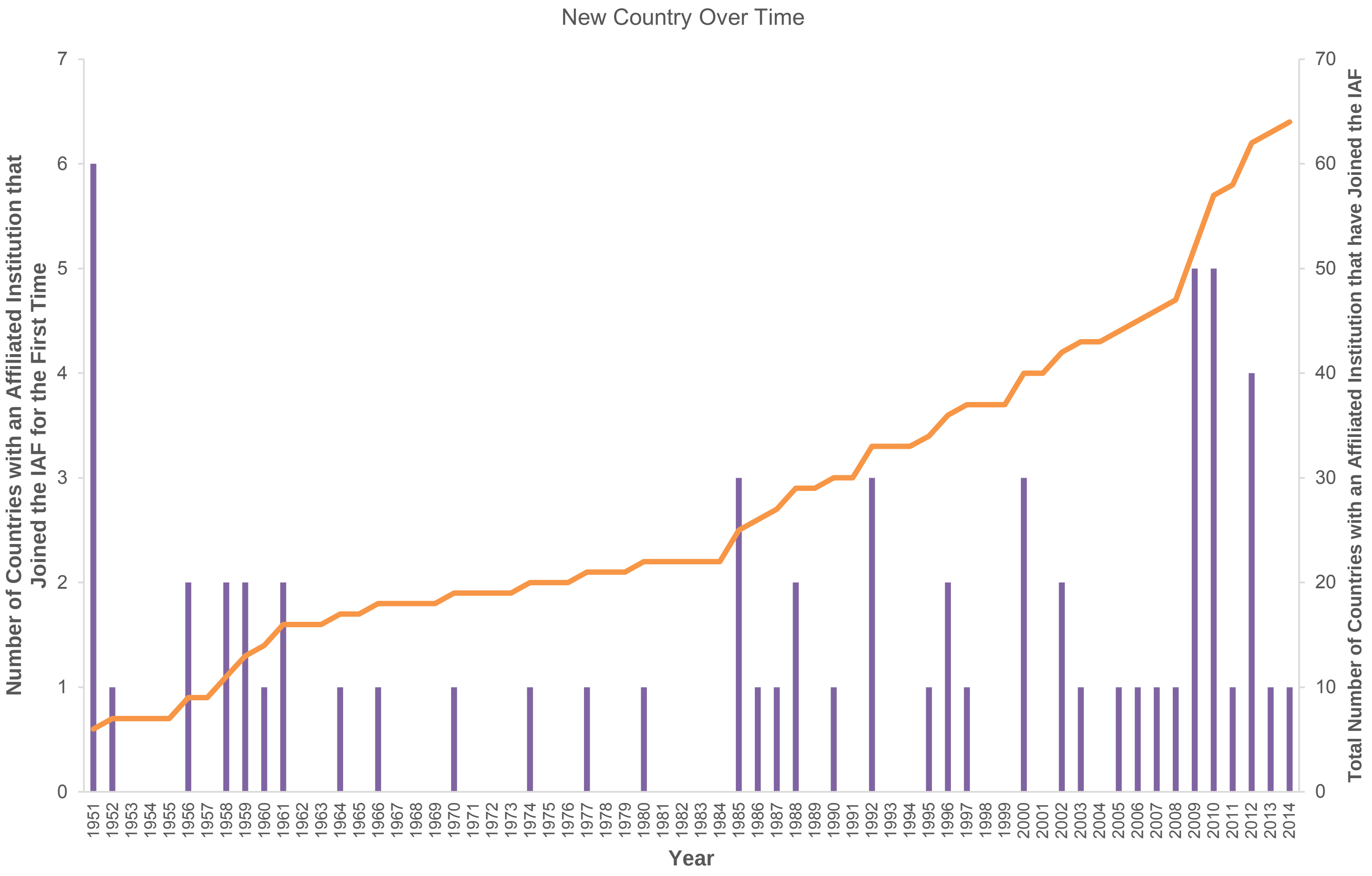
[19] J. McDowell's Space Website, http://planet4589.org/space/log/stats.html.

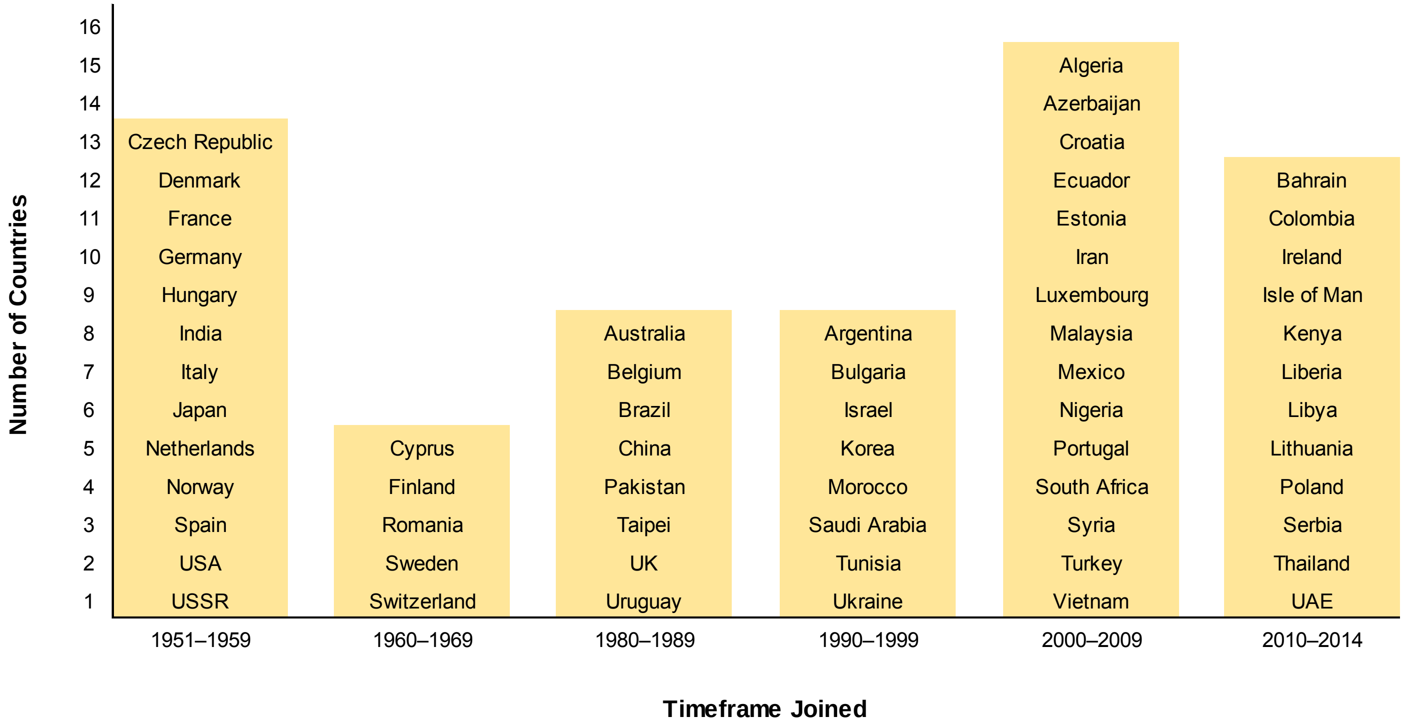
[20] The organizations are European Space Agency (ESA), Regional African Satellite Communications System (RASCOM), Intelsat, International Maritime Satellite Organization (INMARSAT), European Telecommunications Satellite Organization (EUTELSAT), European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and European Union (EU).

[21] Figure 5-5 in Chapter 5 of this volume highlights an important trend identified in the report. By breaking down IAF members by sector—government, industry and universities—we see that participation by universities and industry has gone up in recent years, confirming findings from other sources that governments are not the only participants in the space sector, and space, as a sector, is becoming more democratized.



Source: STPI synthesis of IAF data.

Figure 3-1. Number of Countries with Members in the International Astronautical Federation, by Year Joined



Source: STPI synthesis of IAF data.

Figure 3-2. Countries with Members in the International Astronautical Federation by Time Joined

Table 3-1. Examples of Chinese and Indian Space Launchers and Space Systems

Capabilities/Systems	China	India
Space launch to low earth orbit	Long March 4 series of launchers	Polar Satellite Launch Vehicle (PSLV)
Space launch to geosynchronous orbit	Long March 3 series of launchers	Geosynchronous Satellite Launch Vehicle (GSLV)
Positioning, Navigation & Timing (PNT) satellites	BeiDou	Indian Regional Navigation Satellite System (RNSS)
Communications satellites	Chinasat communications satellites	Indian National Satellite (INSAT) system of 9 communications satellites
Earth observation satellites	GF-1 multispectral earth observation satellite	Radar Satellite-1 (RISAT-1) microwave remote sensing satellite
Weather satellites	Fengyun meteorological satellites	INSAT-3D meteorological satellite
Space science missions	Tiangong-1 space station	Mars Orbiter Mission

B. Civilian Expenditures in Space

There is vast disparity with respect to space expenditures, with a small number of countries dominating space activities, in both the civilian and defense sectors. A 2014 snapshot shows the extreme dominance of the United States followed by those of Russia and Europe (Figures 3-3 and 3-4).

More important than the absolute size of the expenditures is its growth. In 2014, 60 countries invested $10 million or more in space-related applications and technologies (and 21 more had plans for investment), twice as many as in 2004.[22] On the whole, civil expenditures have increased by roughly 6 percent a year for the last 10 years (Figure 3-5, Euroconsult 2014a, 3).[23] But this comparatively mild increase has not been uniform across all countries. Figure 3-6 plots the compound annual increase in expenditures for each of the countries in Euroconsult showing increases from 60 percent (Saudi Arabia) to decreases of almost 100 percent (Egypt). The global increase also masks the fact that expenditures have been decreasing in North America, principally the United States (Figure 3-7), and increasing dramatically in some other countries, principally Russia (Figure 3-8).

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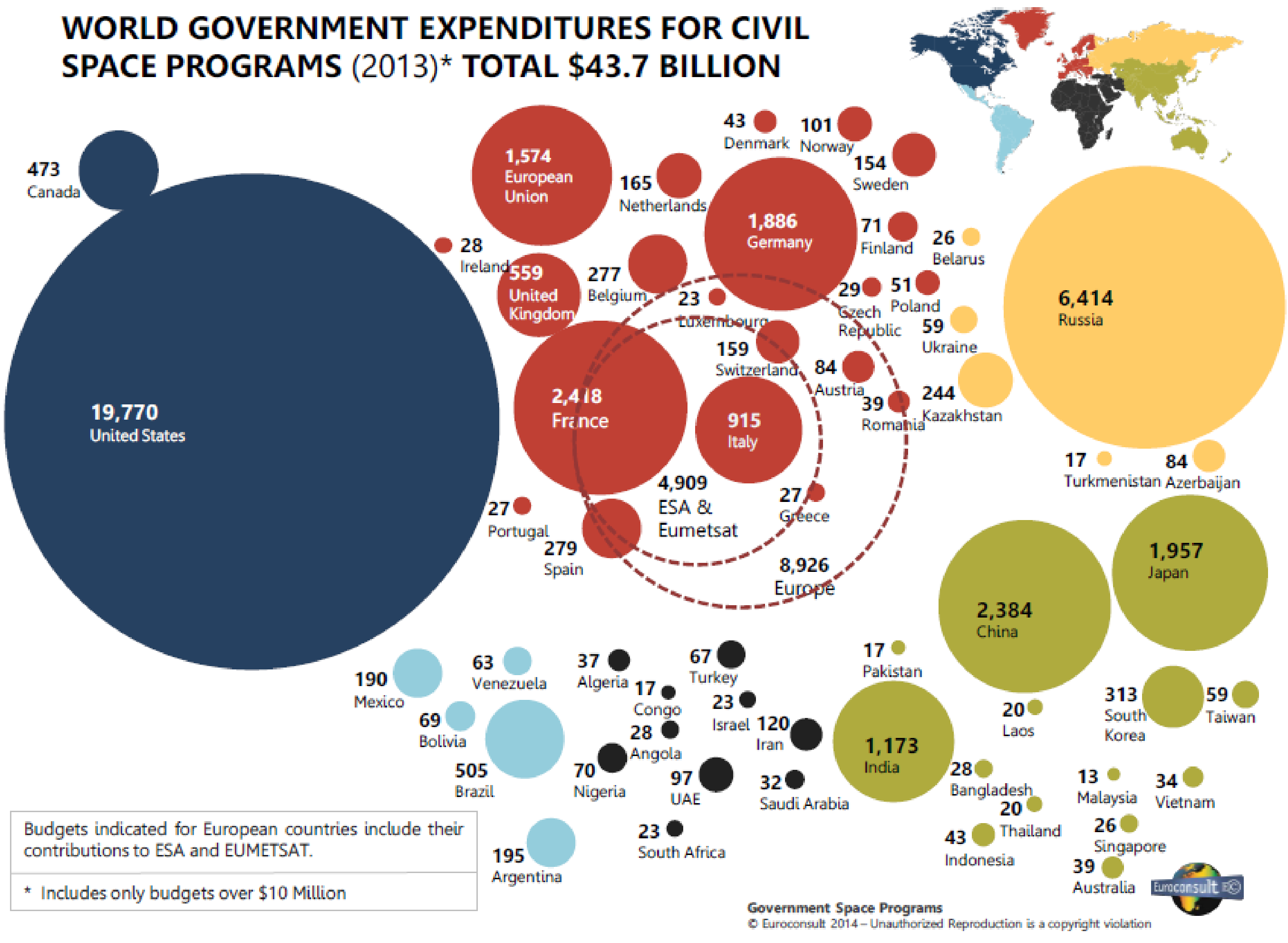
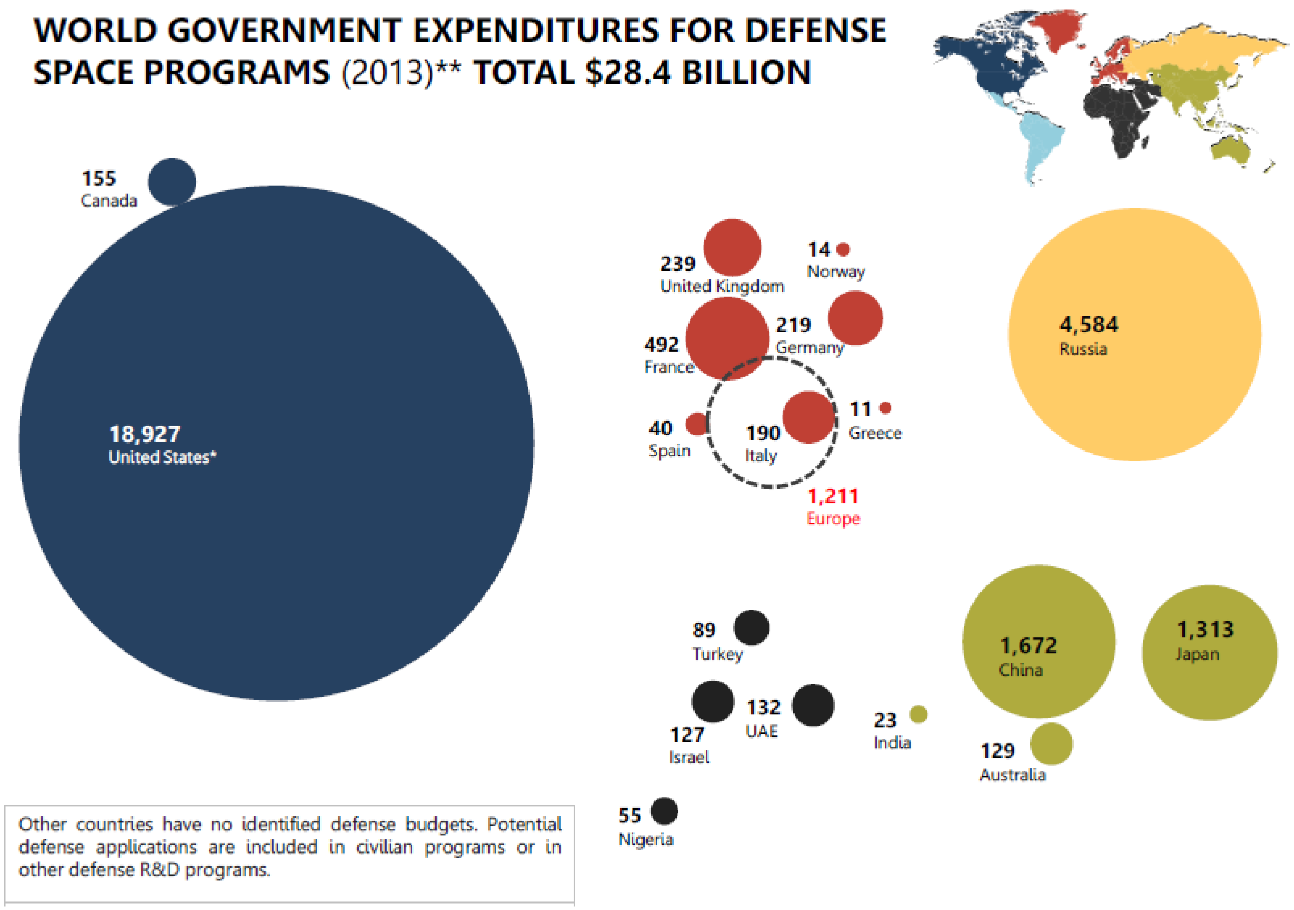
[22] From http://www.euroconsult-ec.com/13_May_2015.

[23] According to the Euroconsult report (2014a), government spending among countries other than the United States and Russia actually increased by 8 percent in 2014. It is important to note that Euroconsult numbers are not adjusted for purchasing power parity and are provided in current rather than constant dollars.



Source: Euroconsult (2014a).

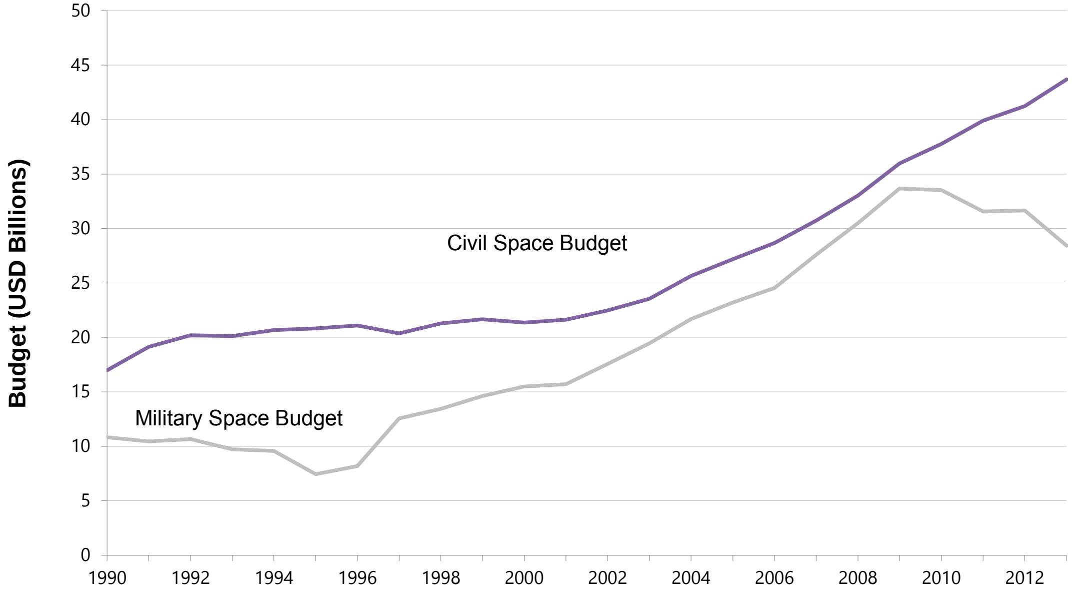
Figure 3-3. Expenditures for Civil Space Programs, 2013



Other countries have no identified defense budgets. Potential defense applications are included in civilian programs or in other defense R&D programs.

Source: Euroconsult (2014a).

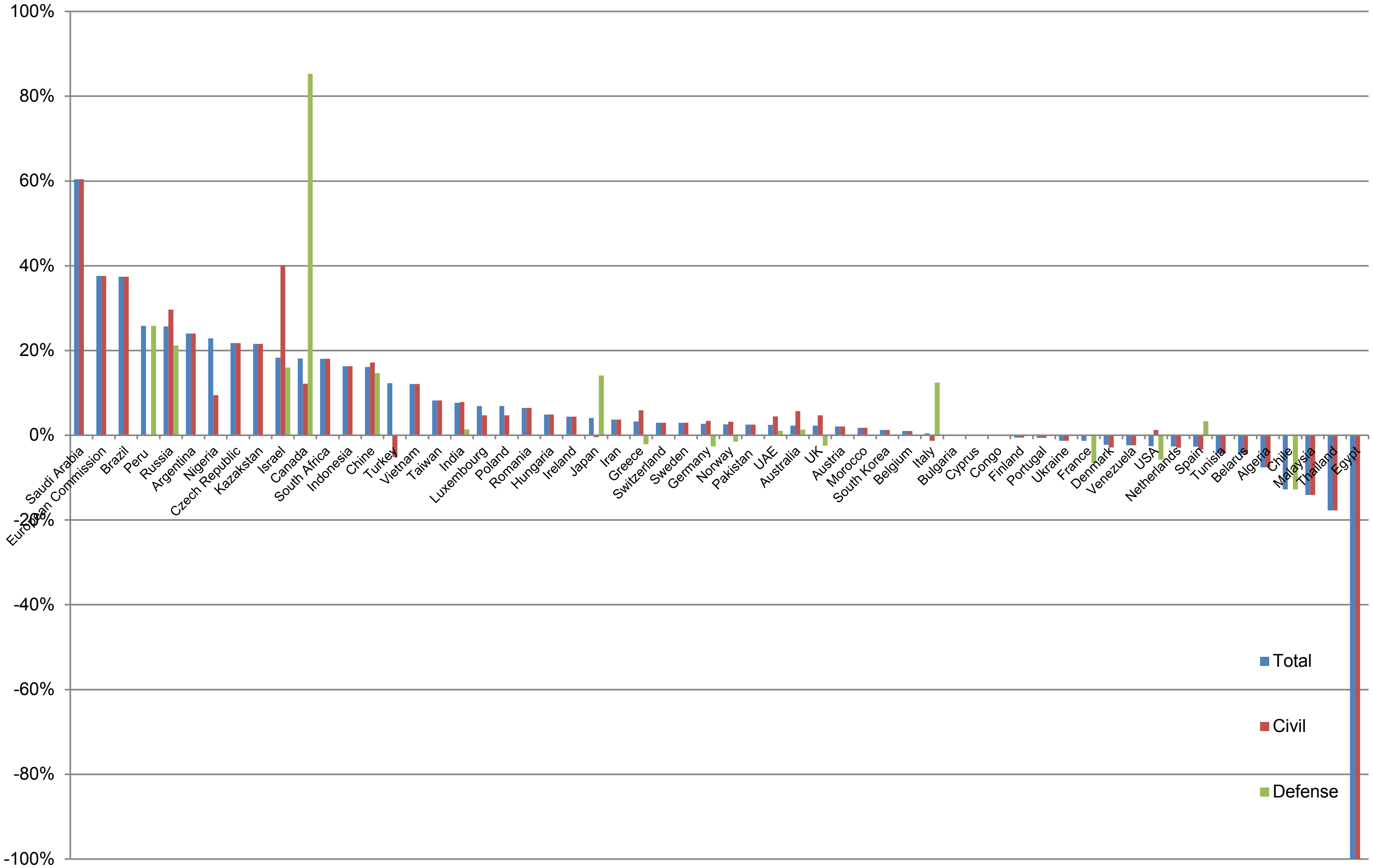
Figure 3-4. Expenditures for Defense Space Programs, 2013



Source: Euroconsult (2014a).

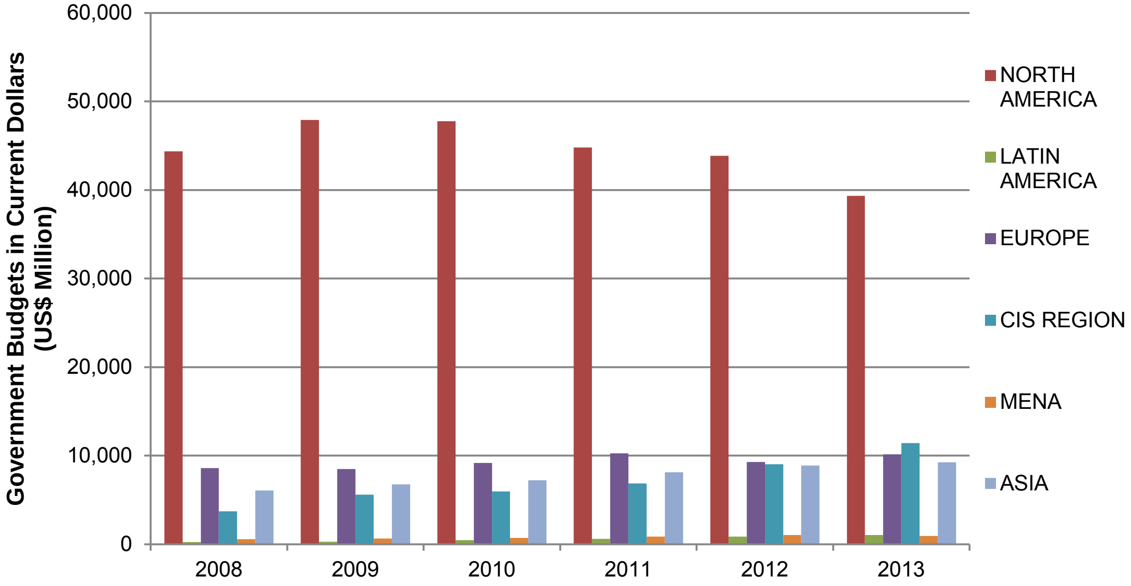
Note: Classified budget is not included in Military Space Budget.

Figure 3-5. World Government Budgets for Space, 1990–2013



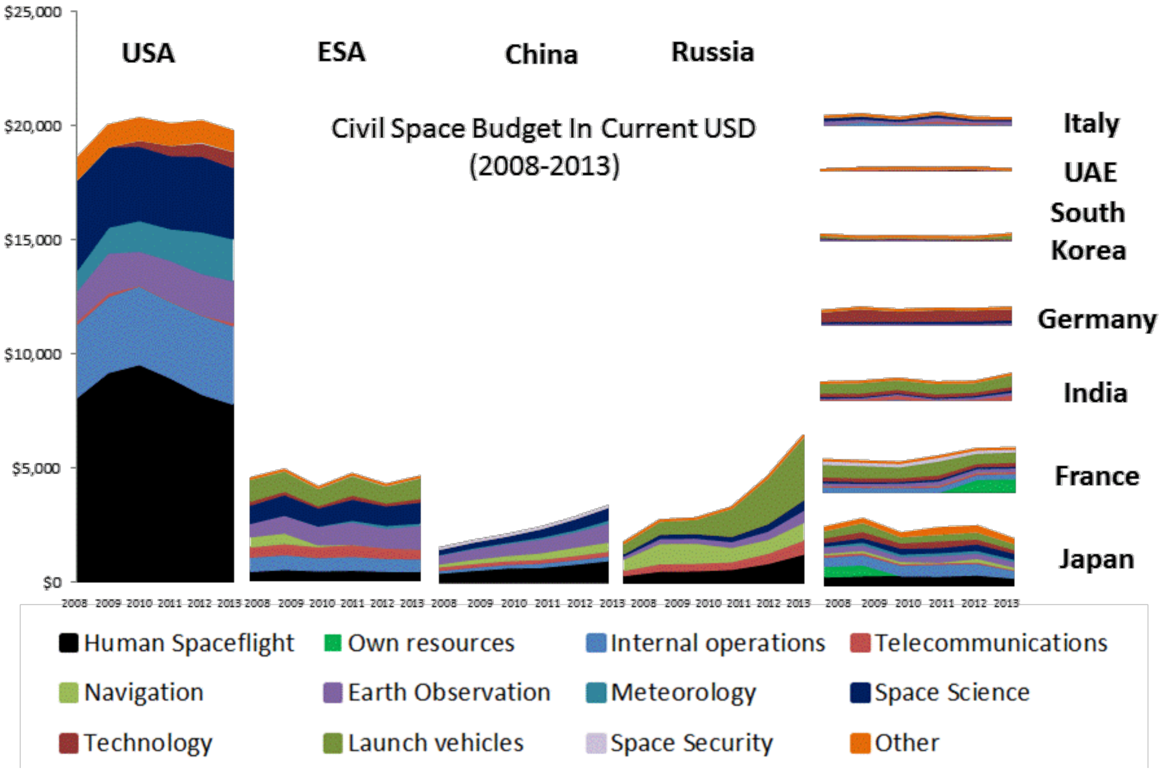
Source: Data from Euroconsult (2014a).

Figure 3-6. Combined Annual Growth Rate in Government Budgets, 2008–2013



Source: Data from Euroconsult (2014a).

Figure 3-7. Space Budgets by Region



Source: STPI analysis using data from Euroconsult 2014a.

Figure 3-8. Civil Budgets by Mission Areas in Millions of Current Dollars

When speaking of civil budgets, it is important to note that countries in North America and Europe distinguish between military and civilian programs, with expenditures for both clearly delineated (with some exceptions). Many space-faring nations, including China and India, and, increasingly, Japan and Turkey, do not make as strong a distinction, instead preferring to see their activities in space as dual-use. For example, in China, the military runs the infrastructure and builds equipment, but scientific satellites are paid for by civilian ministries As a result, civil expenditures are not strictly comparable across all countries.

C. Range of Activities

While a large number of countries invest in space, they have different priorities. Figure 3-8 illustrates differences across the top few spenders globally, showing that the United States focuses heavily on human space flight, spending more in the area than the total space expenditures of all of the European Space Agency (ESA).

Going beyond just expenditures, we see that participation across subsectors of space is varied as well. The STPI team used data from Euroconsult (2014a) and organized activities in seven major subsectors of space participation: Earth observation; communication satellite services; space science and technology (S&T) and exploration; launch and access to space; position, navigation and timing (PNT); human space flight; and space situational awareness (SSA). Based on this information, the team broadly evaluated the relative capabilities of the activity of each country in each subsector and in the fast-evolving small satellite platform.[24] Capabilities fell into four categories: no interest or activity, interest and minimal development, operating or near-operating capability with international partnerships, and fully fledged and independent capability. The results are shown in Table 3-2. As the table shows, almost all countries are involved in activities in Earth observation and communication satellite services. Space S&T and exploration has a surprisingly large number of participants. Far fewer countries are involved in areas of PNT, human space flight, and SSA.

We were not able to get time-series data in all nine sectors. However, data are available on trends in participation in satellite and launch sectors. Figure 3-9 illustrates growth in the satellite sector, showing that the number of countries with satellites has gone from just the United States and USSR in the 1950s to 78 countries in the 2010s. Similarly, Figure 3-10 illustrates proliferation of launch capabilities, from two countries in the 1950s to twelve over the years. As will be discussed in subsequent chapters, this increasing participation has important ramifications for the development of the space sector.

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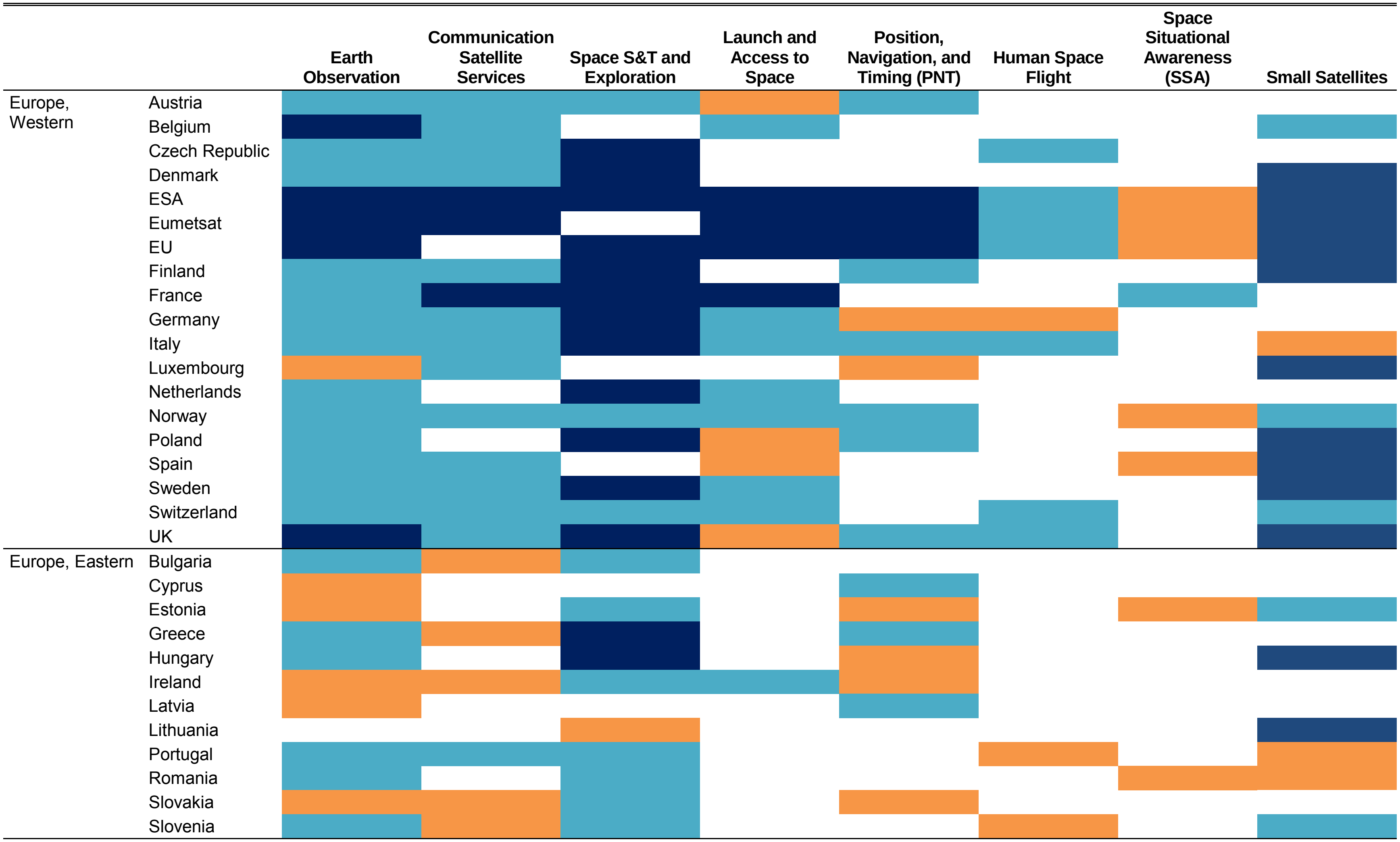
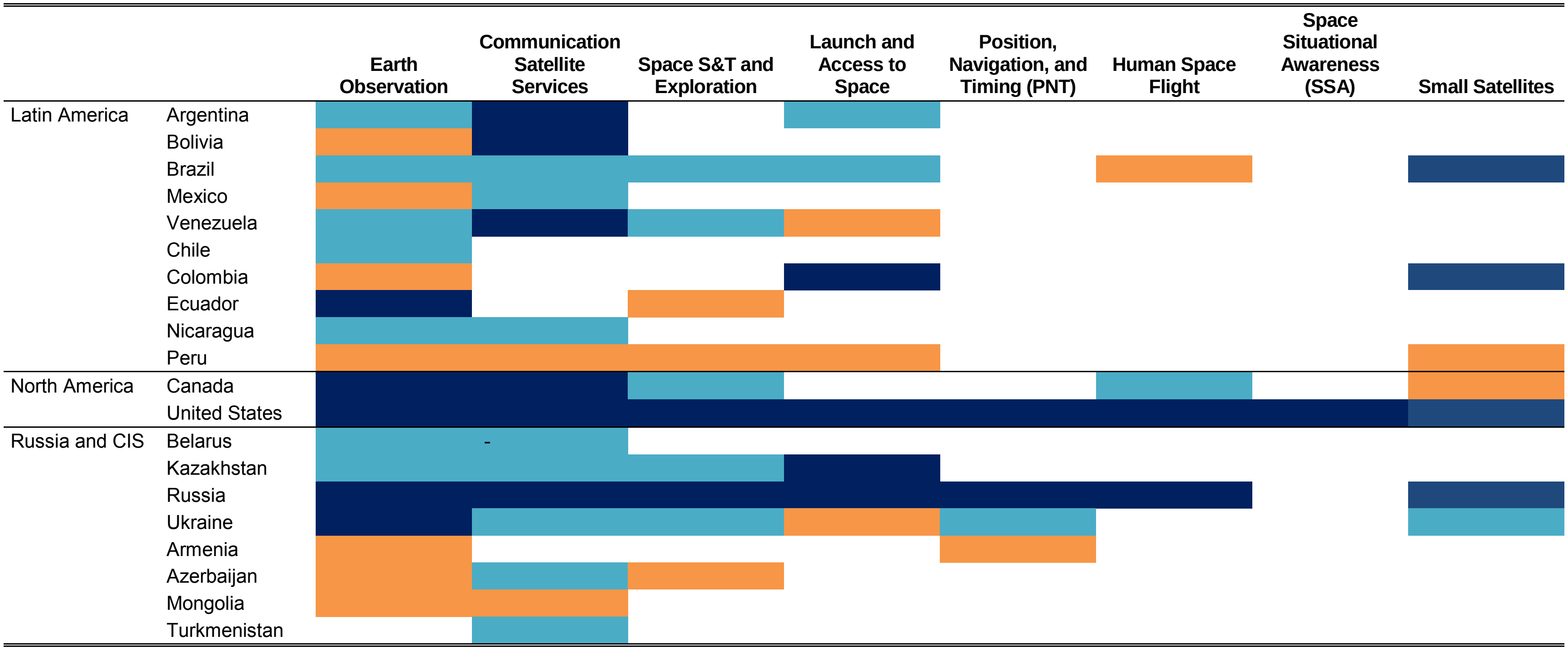
[24] For several countries, the Euroconsult (2014a) data were augmented by focused literature reviews, specifically Turkey, South Korea, Brazil, South Africa, Japan, the United Arab Emirates (UAE), and UK. The additional data led to several changes in country-sector evaluations, but a full review of each country was beyond the scope and task of this study.

Table 3-2. Type of Activity by Country

		Earth Observation	Communication Satellite Services	Space S&T and Exploration	Launch and Access to Space	Position, Navigation, and Timing (PNT)	Human Space Flight	Space Situational Awareness (SSA)	Small Satellites
Africa and Middle East	Algeria	🟧	🟧			🟦			🟧
	Iran	🟦	🟦	🟦	⬛	🟦			🟦
	Israel	🟦	🟦	🟧	⬛				🟦
	Nigeria	🟦	🟦	🟧	🟧				
	South Africa	⬛		⬛	🟧				⬛
	Turkey	⬛	⬛	🟦	🟦				⬛
	UAE	🟦	🟦	🟦			🟧		
	Angola	🟧	🟧						
	Congo		🟧						
	Egypt	🟦	🟧						🟧
	Gabon	🟧							
	Ghana								🟦
	Kenya	🟦		⬛					
	Morocco	🟦							
	Saudi Arabia	🟦	🟦	🟧					⬛
	Tunisia	🟧	🟧						🟧
Asia	Australia	🟦	🟦	⬛		🟦		🟦	
	China	⬛	⬛	⬛	⬛	⬛	⬛	🟦	⬛
	India	⬛	⬛	⬛	⬛	⬛	🟦		⬛
	Indonesia	🟧	🟦	🟧	⬛				⬛
	Japan	⬛	⬛	⬛	⬛	⬛	🟦	⬛	⬛
	Malaysia	⬛	🟧	⬛		🟧			🟦
	South Korea	⬛	🟦	⬛	🟦			🟧	🟦
	Taiwan	⬛		🟧	🟦				
	Thailand	⬛	⬛		🟦				
	Vietnam	🟦	🟦		🟦				
	Bangladesh		🟧						
	Laos		🟦						
	North Korea	⬛			⬛		🟧		
	Pakistan	🟧	🟦						
	Singapore	🟦	⬛						⬛



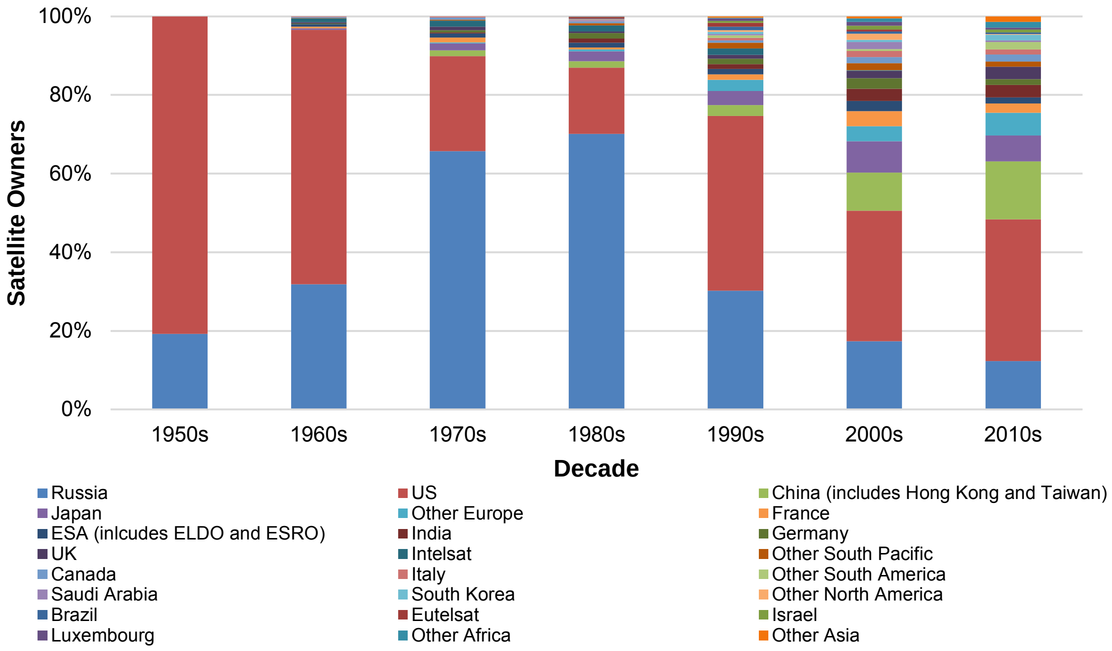
		Earth Observation	Communication Satellite Services	Space S&T and Exploration	Launch and Access to Space	Position, Navigation, and Timing (PNT)	Human Space Flight	Space Situational Awareness (SSA)	Small Satellites
Europe, Western	Austria	🟦	🟦	🟦	🟧	🟦			
	Belgium	⬛	🟦		🟦				🟦
	Czech Republic	🟦	🟦	⬛			🟦		
	Denmark	🟦	🟦	⬛					⬛
	ESA	⬛	⬛	⬛	⬛	⬛	🟦	🟧	⬛
	Eumetsat	⬛	⬛		⬛	⬛	🟦	🟧	⬛
	EU	⬛		⬛	⬛	⬛	🟦	🟧	⬛
	Finland	🟦	🟦	⬛		🟦			⬛
	France	🟦	⬛	⬛	⬛			🟦	
	Germany	🟦	🟦	⬛	🟦	🟧	🟧		
	Italy	🟦	🟦	⬛	🟦	🟦	🟦		🟧
	Luxembourg	🟧	🟦			🟧			⬛
	Netherlands	🟦		⬛	🟦				
	Norway	🟦	🟦	🟦	🟦	🟦		🟧	🟦
	Poland	🟦		⬛	🟧	🟦			⬛
	Spain	🟦	🟦		🟧			🟧	⬛
	Sweden	🟦	🟦	⬛	🟦				⬛
	Switzerland	🟦	🟦	🟦	🟦		🟦		🟦
	UK	⬛	🟦	⬛	🟧	🟦	🟦		⬛
Europe, Eastern	Bulgaria	🟦	🟧	🟦					
	Cyprus	🟧				🟦			
	Estonia	🟧		🟦		🟧		🟧	🟦
	Greece	🟦	🟧	⬛		🟦			
	Hungary	🟦		⬛		🟧			⬛
	Ireland	🟧	🟧	🟦	🟦	🟧			
	Latvia	🟧				🟦			
	Lithuania			🟧					⬛
	Portugal	🟦	🟦	🟦			🟧		🟧
	Romania	🟦		🟦				🟧	🟧
	Slovakia	🟧	🟧	🟦		🟧			
	Slovenia	🟦	🟧	🟦			🟧		🟦



		Earth Observation	Communication Satellite Services	Space S&T and Exploration	Launch and Access to Space	Position, Navigation, and Timing (PNT)	Human Space Flight	Space Situational Awareness (SSA)	Small Satellites
Latin America	Argentina	Turquoise	Blue		Turquoise				
	Bolivia	Orange	Blue						
	Brazil	Turquoise	Turquoise	Turquoise	Turquoise		Orange		Blue
	Mexico	Orange	Turquoise						
	Venezuela	Turquoise	Blue	Turquoise	Orange				
	Chile	Turquoise							
	Colombia	Orange			Blue				Blue
	Ecuador	Blue		Orange					
	Nicaragua	Turquoise	Turquoise						
	Peru	Orange	Orange	Orange	Orange				Orange
North America	Canada	Blue	Blue	Turquoise			Turquoise		Orange
	United States	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue
Russia and CIS	Belarus	Turquoise	Turquoise -						
	Kazakhstan	Turquoise	Turquoise	Turquoise	Blue				
	Russia	Blue	Blue	Blue	Blue	Blue	Blue		Blue
	Ukraine	Blue	Turquoise	Turquoise	Orange	Turquoise			Turquoise
	Armenia	Orange				Orange			
	Azerbaijan	Orange	Turquoise	Orange					
	Mongolia	Orange	Orange						
	Turkmenistan		Turquoise						

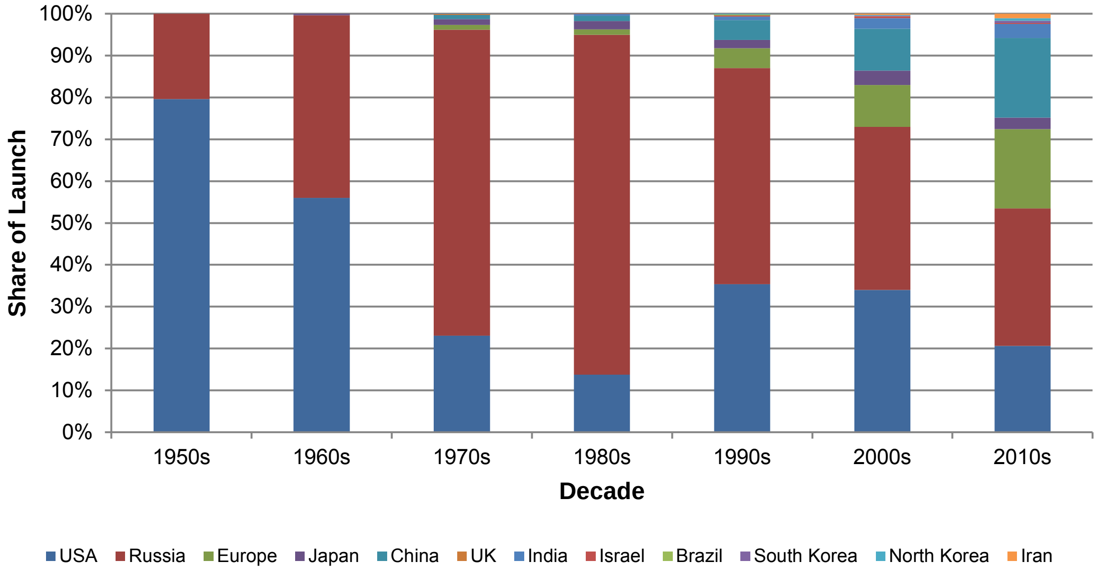
Source: STPI analysis using data from Euroconsult (2014a).

Legend:	**White**	**Orange**	**Turquoise**	**Blue**
	No interest or activity	Interest and minimal development	Operating or near-operating capability with international partnerships	Fully fledged and independent capability



Source: STPI synthesis of data from J. McDowell's Space Website, http://planet4589.org/space/log/stats.html.

Figure 3-9. Changes in Relative Percentage of Countries with Satellites over Time



Source: STPI synthesis of data from J. McDowell's Space Website, http://planet4589.org/space/log/stats.html.

Figure 3-10. Changes in Relative Percentage of Countries with Launch Capabilities over Time

4. Changes in Civil Space Developments

Space is not a uniformly monolithic sector, and it is difficult to identify trends that apply to the breadth of activities in the space sector. At one end, for example, is space-based telecommunications—a mature sector both upstream and down, that is largely commercial with large and global markets, and a globalized value chain. At the other end is the PNT sector, where upstream activities (satellite design, launch, and operations) are government- and military-owned, and require large and long-term investment, and the downstream market is accessible to more enterprises and consumers than ever before—a concept often referred to as "democratization" (Hasik 2014).

Due to these differences, instead of looking at space *in toto,* we explored trends in the seven principal subsectors of space—Earth observation; communication satellite services; space science and technology (S&T) and exploration; launch and access to space; position, navigation, and timing; human space flight; and space situational awareness. We also looked at small satellites. Trends in these areas are presented in Volume 2. Using observations from these subsectors, we then identified trends that cut across several areas. The rest of this volume discusses these cross-cutting trends. In this chapter we explore the emerging structural changes in civilian space developments.

A. Non-Traditional National Development Pathways

Before many space products and services were available for purchase, a country's capabilities in space were based on indigenous technology development. This dependence on indigenous capability meant that countries followed a reasonably predictable trajectory toward advancing their level of participation in the space sector. Space was also traditionally a closed sector, geared towards military and exploration uses (with civilian uses also being managed by government agencies). These traditional pathways are changing.

Today, while many more countries have space agencies than did before, many others have begun activities in space without a formal space agency in place. Examples include developing satellites with technical assistance from foreign firms (e.g., Chile), using satellite data (e.g., Kenya), starting a commercial communications company (e.g., Thailand), and carrying out space-related research and development (e.g., Turkey) (Wood and Weigel 2014).

Traditionally, the first satellite a country would own or operate would be a telecommunications satellite.[25] However, today new entrants are not necessarily starting with telecommunication satellite, but instead with a scientific research or Earth observations/remote sensing satellite.[26] This could partly be because launching an Earth observation low-Earth orbit (LEO) satellite is cheaper than it used to be, and certainly cheaper than launching to geostationary orbit (GEO), and partly because there are global enterprises like Intelsat, Eutelsat, and others, that are able to provide communications services.

Three main factors are enabling the non-traditional development of countries in space. First, modularization and increasing accessibility of space technology is now allowing countries to acquire space technology without needing to possess indigenous development capability. This is due, in part, to the increasing availability of COTS parts (discussed in Chapter 2 of this volume, and in more detail in Volume 2). Second, a country can purchase capability from turn-key solution providers like Surrey Satellite Technology Ltd. (SSTL) in the United Kingdom. Companies like SSTL offer entities around the world the ability to build and launch satellites. They sell design, manufacture, and launch services, and they offer a technology transfer program aimed at giving countries technical independence (SSTL n.d.). Third, countries involved in space are now extremely interconnected through partnerships, collaborations, and international forums such as the United Nations (UN) Committee on the Peaceful Uses of Outer Space (COPUOS). These countries partnerships (described in the next section) have grown steadily over the past decade and are giving countries multiple options to gain (or buy) capability that did not exist before. These factors all combine to make it challenging to predict pathways that countries may follow to gain capabilities quickly and potentially become space leaders. Countries are now limited only by aspiration and budget; indigenous technological sophistication is no longer a requirement.

One observation resulting from the increasing ability of a country to purchase or partner to gain capability is that countries are simultaneously pursuing different space-related activities requiring varying levels of technology advancement, such as procuring a LEO satellite, which does not require indigenous capability, and developing launch capabilities, which requires advanced technological capabilities (Wood and Weigel 2012). For example, India developed its first satellite launch vehicle (SLV-3), launched in 1980,

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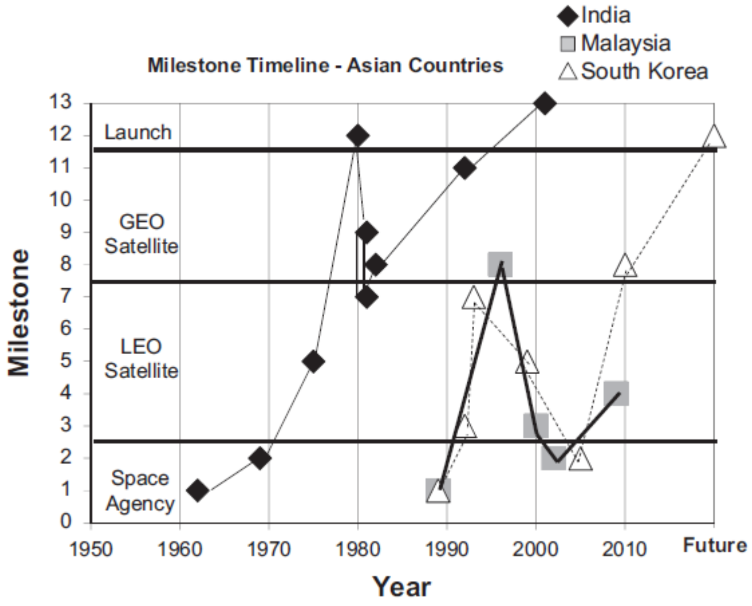
[25] According to the Union of Concerned Scientists (UCS 2015), Argentina, Australia, Azerbaijan, Bolivia, China, Egypt, Greece, Iran, Italy, Kazakhstan, Luxembourg, Malaysia, Mexico, Netherlands, Norway, Russia, Spain, Thailand, Turkey, United Kingdom, United States, Venezuela, and Vietnam. The first U.S. satellite in space had a scientific payload. Explorer 1 carried a cosmic ray detector (Jet Propulsion Laboratory 1998).

[26] EO/Remote Sensing: Algeria, Belarus, Brazil, Chile, Israel, Pakistan, Singapore, Taiwan, United Arab Emirates, and Ukraine. Science: Belgium, Canada, Denmark, ESA, France, Germany, Japan, Saudi Arabia, Sweden (UCS 2015).

nearly simultaneously with its first locally built LEO satellite, Bhaskara II, launched in 1981.[27] As Figure 4-1 shows, countries may no longer need to progress linearly from low to high complexity technical activities. Also, with capabilities like launch becoming more available and competitive, some countries, like Singapore, no longer see a need to develop some types of capabilities domestically, and can invest in areas that they deem more relevant to their national development. Such a strategy may allow countries to become world class experts in specialized categories with relatively little investment. Certain activities, like launch, are of particular interest to countries that are interested in developing ballistic missile capabilities (e.g., Iran). Other activities, like research and development (R&D), are of interest to a wider range of countries, partly because it helps develop and inspire the workforce, and potentially limiting brain drain.



Source: Wood and Weigel (2012).

Note: Milestones are as follows: 1—Space Agency: Establish First National Space Office; 2—Space Agency: Establish Current Agency; 3—LEO Satellite: Procure with Training Services; 4—LEO Satellite: Build with Support in Partner's Facility; 5—LEO Satellite: Build Locally with Outside Assistance; 6—LEO Satellite: Build Through Mutual International Collaboration; 7—LEO Satellite: Build Locally; 8—GEO Satellite: Procure; 9—GEO Satellite: Build Locally with Outside Assistance; 10—GEO Satellite: Build through Mutual International Collaboration; 11—GEO Satellite: Build Locally; 12—Launch Capability: Satellite to LEO; and 13—Launch Capability: Satellite to GEO.

Figure 4-1. Pathways of Development: Technical Complexity

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[27] See http://www.isro.gov.in/launchers/slv and http://www.isro.gov.in/Spacecraft/bhaskara-ii/.

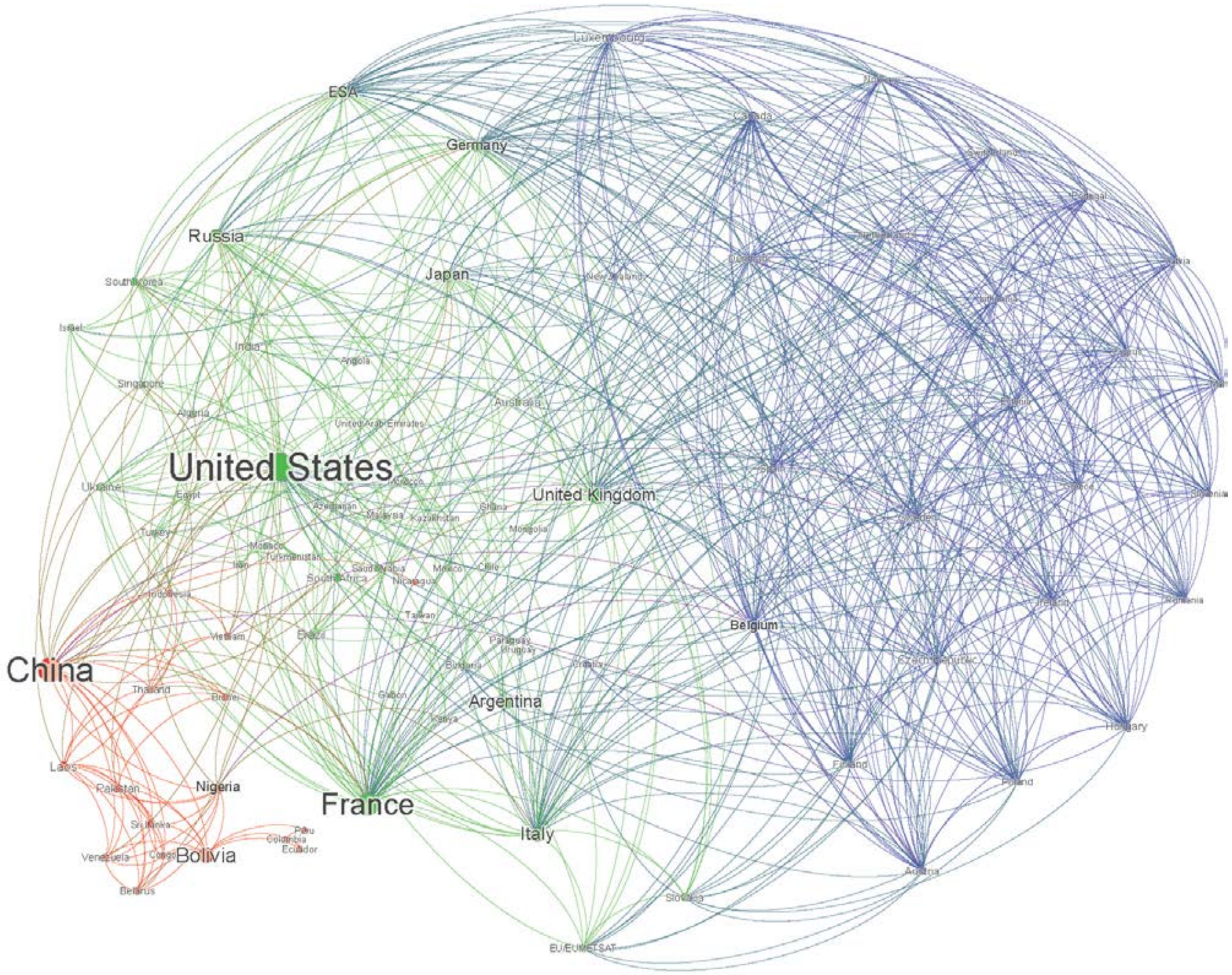
B. Leveraging Foreign Partners

With growing capabilities in the private sector, governments of many countries are leveraging them to accelerate the development of domestic capabilities. For example, when Saudi Arabia purchased two telecommunication satellites from U.S.-based Lockheed Martin, the contract included a commitment by Lockheed to create a joint-venture company to build, assemble and integrate satellites on Saudi territory (Selding 2015e). Other countries, including Azerbaijan, Kazakhstan, Turkey, Brazil, and Peru among others, have demanded that with a purchase, a sustainable local satellite industry be stood up, sometimes almost from nothing.

The network of country-to-country collaborations provides a useful view of how connected a space aspirant country is within the global community, and can provide insights to the ways that countries may follow diverse pathways in their technological advancement. To examine the ways that different countries are connected, we mined the Euroconsult report *Profiles of Government Space Programs* (2014a) and documented over 280 civilian collaborations between different nations. STPI researchers aggregated each collaboration mentioned, the countries involved and the purpose for the collaboration (Earth observation, workforce development, research and development, etc.). The resulting data sets offer snapshots of the network of nation-to-nation collaboration and cooperation.

Figure 4-2 shows the 80 countries discussed in the Euroconsult report clustered into three groups. The different groups are indicated by their colors. In this and other figures in this section, collaborations are shown as lines, with nodes representing individual countries. Each line represents at least one collaboration but can represent more. The lines do not contain information about the extent, success, or depth of the collaborations. Figure 4-2 shows that countries in the EU generally fall into a single group (blue), countries collaborating with the United States make up another group (green), and developing countries often collaborating with China are a third group (red). This figure and others in this group (Figures 4-3 through 4-6) are limited to what Euroconsult reports and do not list all partnerships, but a selection of primary partnerships.

A few large countries, such as the UK, France, Italy, Germany, Japan, and Russia straddle the green and blue groups, most likely because as large players in the space sector, they collaborate both with the EU and the United States. This shows that while there are U.S.-centric and EU-centric countries, there is cross-over and collaboration between these groups. Interestingly, there are few countries that straddle the red (China collaborators) and blue (EU collaborators) or red (China collaborators) and green (U.S. collaborators) groups. This indicates that China and many South American and Southeast Asian countries may be isolated from the rest of the world. The figure also shows that China, like other countries, does not only collaborate with resource-rich countries like Brazil, as is the common perception, but with those where it has geopolitical interests *writ large*.



Note: Red denotes collaborations with China; blue, with EU countries; and green, with the United States.

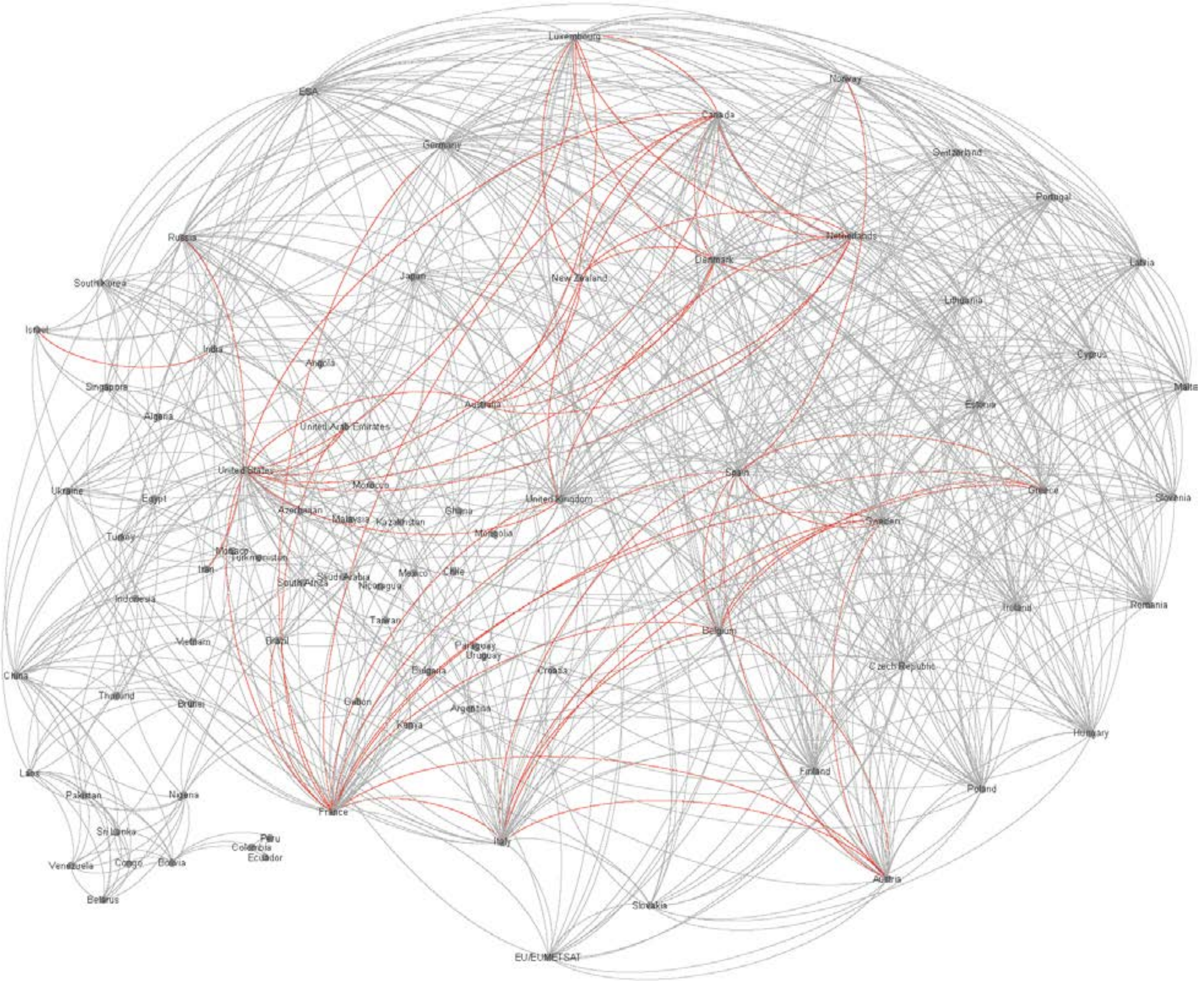
Figure 4-2. Country-to-Country Collaborations

Keeping the spatial location of the country nodes fixed, we plotted the collaborations that focus on defense, workforce training, Earth observations, and space S&T and exploration. These collaborations are displayed in Figures 4-3 through 4-6.

As anticipated, defense collaborations (Figure 4-3) mostly occur between the United States, Europe, and the members of the Commonwealth of Nations, which are traditional defense partners. Workforce development collaborations (Figure 4-4) fall into two categories, government-sponsored workforce training, which, again, occurs between traditional defense technology collaborators and a second set of partnerships between firms like UK's SSTL and small countries such as Nigeria, Malaysia, and Kazakhstan.

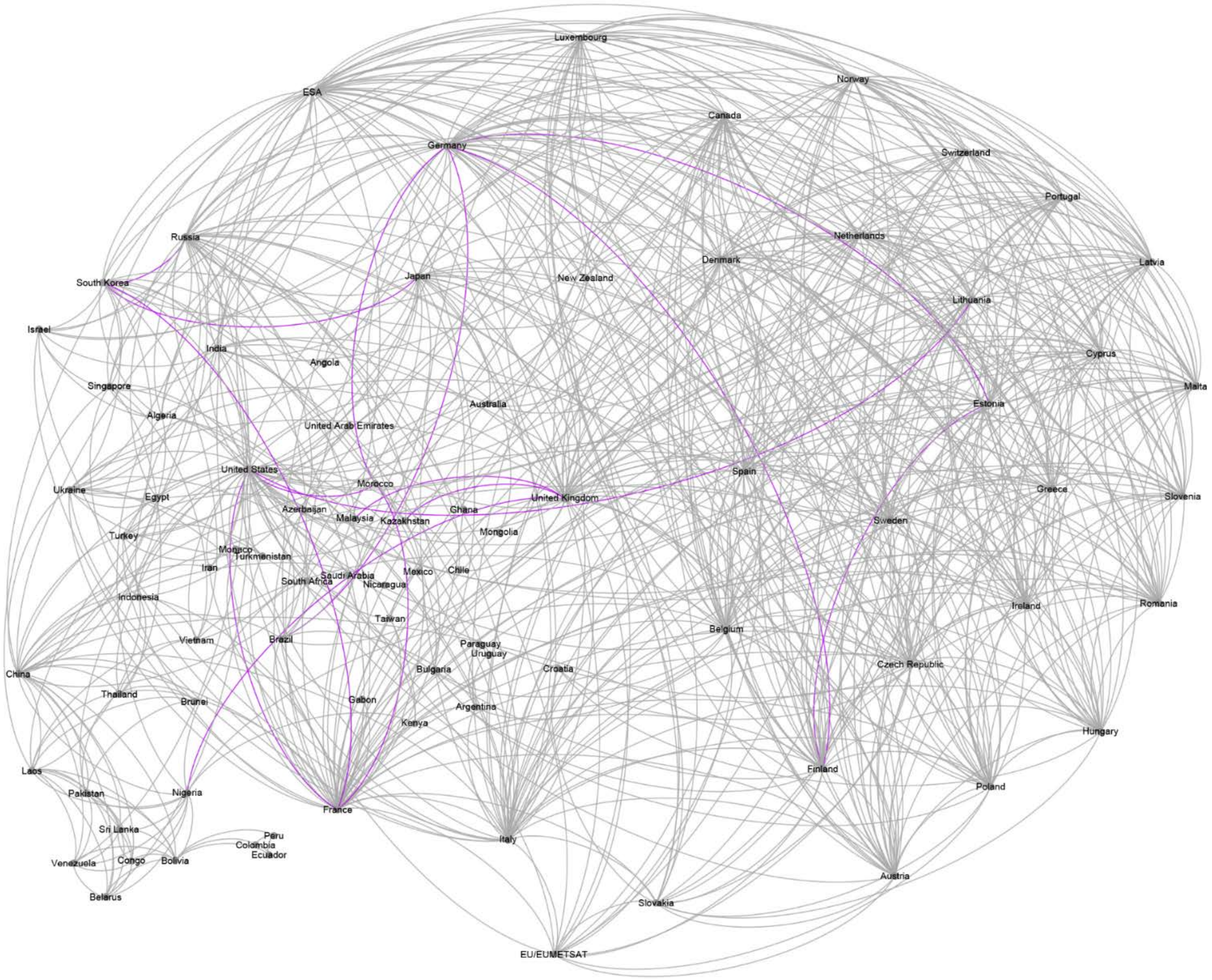
While the United States and European countries are primary hubs in Earth observation collaborations (Figure 4-5), the collaborations are more far-reaching and include more Asian, African, and South American countries.

Partnerships in space S&T and exploration show strong interconnections between U.S.-partnering and EU-partnering countries, with the United States, United Kingdom, France, Germany, Japan, Russia, and Canada being among the main collaboration hubs. Finland and Sweden are also strong research collaborators in this area. Despite having a significant growth in publications related to space S&T and exploration over the last decade (Figure 4-6), China has limited space S&T and exploration collaborations documented in the sources used for this study.



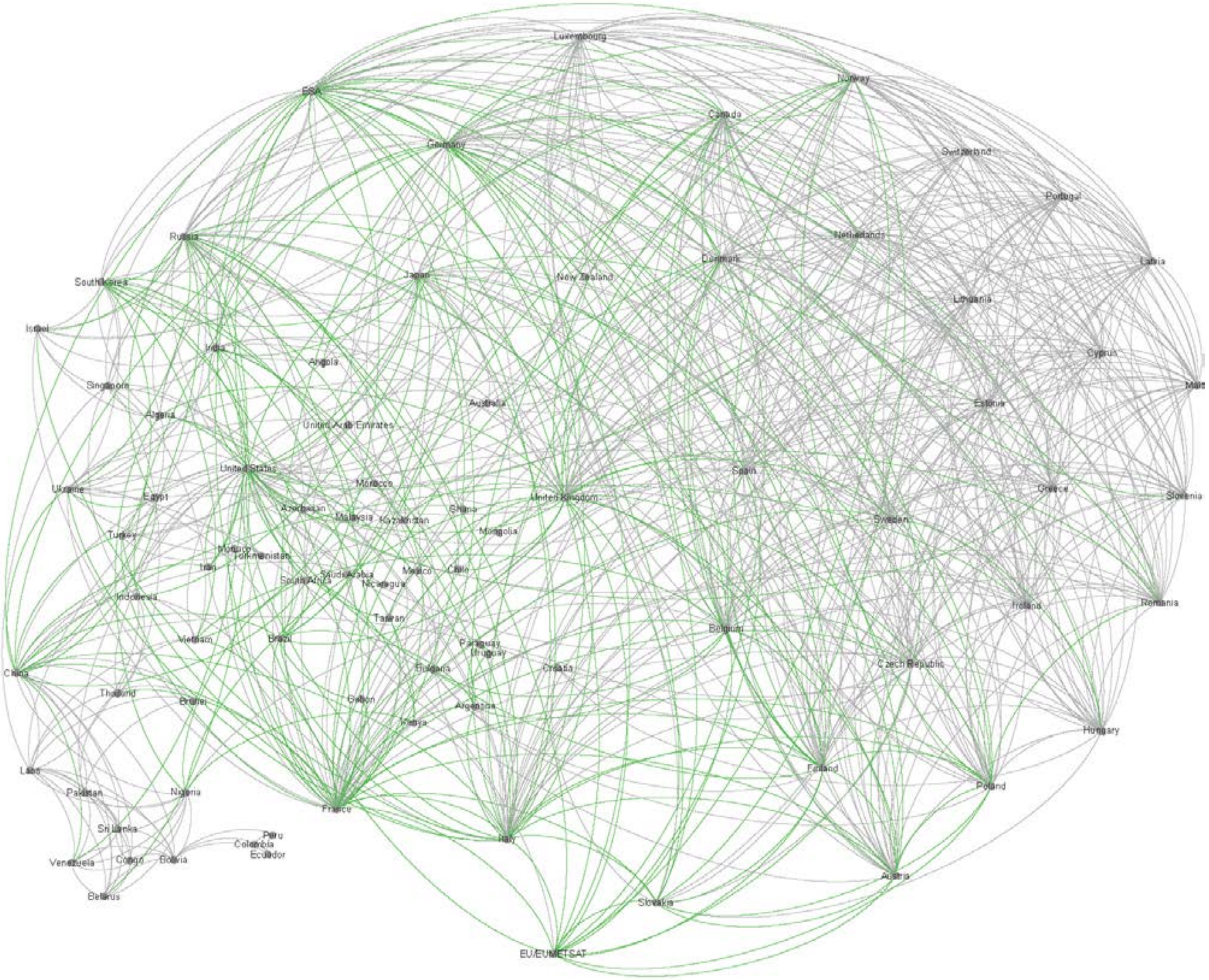
Source: STPI synthesis of data from Euroconsult (2014a).

Figure 4-3. Defense Collaborations



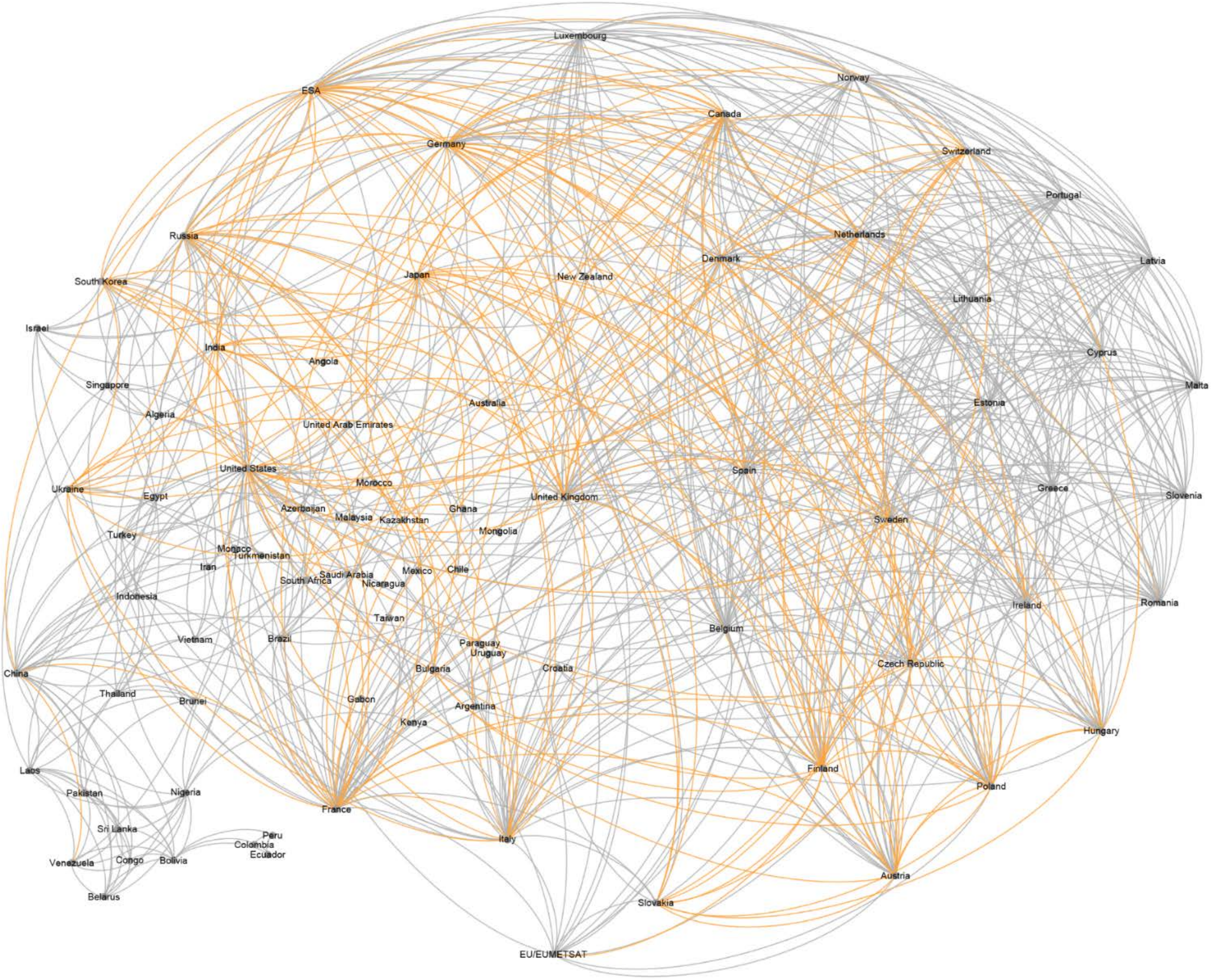
Source: STPI synthesis of data from Euroconsult (2014a).

Figure 4-4. Workforce Development Collaborations



Source: STPI synthesis of data from Euroconsult (2014a).

Figure 4-5. Earth Observation Collaborations



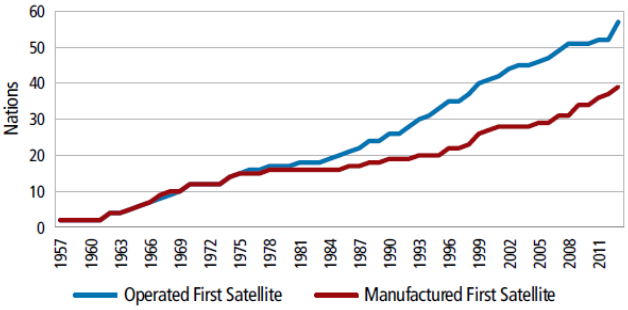
Source: STPI synthesis of data from Euroconsult (2014a).

Figure 4-6. Space S&T and Exploration Collaborations

C. Collaboration as a Means of Leapfrogging

Collaborations with various external entities have changed the pathways available to countries to participate in space. In fact, what it means to participate in space has changed in a fundamental way.

The emerging structural changes in the space sector imply that participation in space is not limited by the lack of domestic capability; a space-aspirant nation can partner with public or private entities to purchase both the technology and expertise to launch a space sector. Figure 4-7 shows that the number of countries that have operated a satellite is much higher than the number of countries that have manufactured a satellite, and that this difference is growing because of the relative ease with which countries can purchase a satellite. In this section, we explore how countries are leveraging purchases of satellites and associated technology.



Source: Space Foundation (2014).

Figure 4-7. Cumulative Number of Nations Operating or Manufacturing First Satellites

Organizations like the Surrey Satellite Technology Ltd. (SSTL) provide an interesting lens through which to view how countries aspire to build capabilities in the space sector, and invest in the same. SSTL offers a wide range of products and services that any country can procure.[28] SSTL sells satellite platforms starting at $10 million USD,[29] instruments starting at under $1 million USD,[30] and technology transfer packages at around $14 million USD (see Leloğlu

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[28] SSTL is not the only company to provide such services. Through their role in the Asia-Pacific Space Cooperation Organization, Chinese space organizations provide opportunities for training and access to data to member states that have relatively modest space capabilities. China's space industry has also signed agreements to export satellites or launch services to developing countries that until then had no significant space assets.

[29] From http://www.sst-us.com/shop/satellite-platforms.

[30] From http://www.sst-us.com/shop/satellite-payloads.

2008).[31] The following case study looks at countries' partnership agreements with this foreign contract solution provider as a way of assessing domestic capabilities.

Case Study: Partnering with External Contract Solution Providers and Implications for a Country's Participation in Space

Nigeria is in its second agreement with SSTL, 5 years after the start of its first satellite launch program in partnership with SSTL, and Algeria recently entered into a partnership with SSTL for a nanosatellite.[32] Because of the lack of domestic capability and infrastructure in these countries, their collaborations with SSTL include procurement of technology as well as expertise; in essence, they purchase their entire space capability from an external commercial source. While they have the potential for developing new and innovative services and applications based on these purchased capabilities, it seems likely that these countries will remain dependent on turnkey solutions. Their level of participation in space is therefore closely tied to what they can obtain by collaboration and procurement.

This presumption is substantiated by observed data on a country's decision to partner externally for its first satellite launch, which is a strong predictor of whether future satellites that have a government or civil operator will partner on future satellites. Countries with their first satellite that is at least partially civilian- or government-operated most often[33] have a foreign contractor for their subsequent satellites. In contrast, most of the launches for countries that do not have foreign contractors for their first civilian- or government-operated satellite rarely use foreign contractors on subsequent satellites. There is not enough data to show whether countries have "brand loyalty," or whether, once a civil or government entity partners with a foreign country, whether they partner with the same country in future satellites.[34]

A different trajectory is seen in countries that, in addition to partnering with external entities, have developed or are actively developing a domestic technology base, including research institutes, manufacturing capability, and a trained technical workforce. Here, the effect of the SSTL technology-transfer partnerships have allowed countries to gain skilled engineers that can use the country's R&D and manufacturing base to build up national capacity for space activities. This was the case for Turkey, in which the SSTL-trained Turkish engineers were able to distribute their knowledge to other engineers within the Turkish Space Technologies Research Center and establish relationships with manufacturers, distributors, and owners of test facilities in Turkey. After the training program ended, the Turkish engineers designed and built RASAT, an Earth observation satellite in Turkey. RASAT was launched in 2011, 8 years after the end of the SSTL training program (Jason, da Silva Curiel, Liddle, et al. 2010). In another example, South Korea, which had a SSTL training program in 1989–1993 for KITSAT, effectively transitioned from depending on outside help in a few steps. KITSAT-1 was built with SSTL and launched in 1992. The next year, the Korean engineers used a kit from SSTL for the platform of KITSAT-2, but built the platform and developed the payloads independently.

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[31] Other examples of countries purchasing capabilities from other countries or companies other than SSTL. For example, through their role in the Asia-Pacific Space Cooperation Organization, Chinese space organizations provide opportunities for training and access to data to member states that have relatively modest space capabilities. China's space industry has also concluded a string of agreements to export satellites and launch services to developing countries that theretofore had no significant space assets. UAE effectively purchased a commercial space industry by paying $280 million for a 32-percent stake in Virgin Galactic (Schreck n.d.).

[32] From http://www.sstl.co.uk/News-and-Events/2014-News-Archive/ASAL-and-SSTL-enter-a-new-collaboration-for-Alsat-.

[33] According to UCS data, of the eight countries with multiple satellites labeled with government operators, five have foreign contractors for all of their subsequent government launches. One has a foreign contractor 60 percent of the time, and the other two shared contractors both within and outside their countries. The list does not include satellites operated by multiple countries.

[34] According to UCS data, of the 27 countries that have multiple at least partially operated by a government entity, only 12 have more than 3 government-operated satellites, and only 7 have had a foreign partner. The list does not include satellites operated by multiple countries.

Six years later, in 1999, South Korea launched an independently developed satellite, KITSAT-3. For both South Korea and Turkey, expertise gained from partnering with SSTL allows them to leverage their long-term investments in R&D and manufacturing infrastructure for space applications.

Based on this observation of collaborations with a turnkey solutions provider and on analysis of data available on different trajectories taken by space-participating countries, it appears that countries fall into three groups:

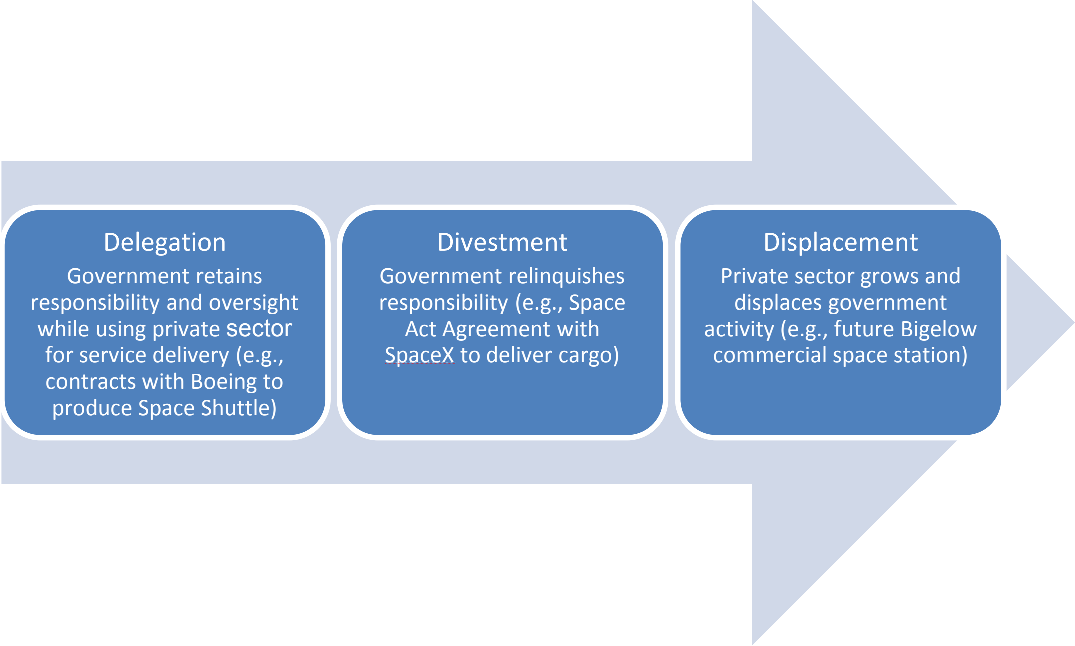
- Group 1 consists of countries like Nigeria, Algeria, and Malaysia that have high aspirations for a satellite, space agency, or space applications (most commonly, remote sensing), but have not made significant investments in R&D infrastructure or advanced manufacturing capabilities.
- Group 2 consists of countries that, like Group 1 countries, are interested in satellites, space agencies, or space applications, but are interested in developing a level of independence. Unlike Group 1 countries, Group 2 countries, such as Turkey, South Korea, and Singapore, are working to further develop a domestic technology base consisting of research institutes, a technologically savvy workforce, and advanced manufacturing facilities.
- Group 3 countries consist of countries with established space programs that are trying to build capability independently, though they may enter traditional country-to-country partnerships. Group 3 countries often have invested in building independent research and technology development capability.

The nature and outcomes of the partnership with a country may vary depending on the group that the country falls within. For example, due to their lack of infrastructure, Group 1 countries tend to go back to working with SSTL for future satellites. Group 3 countries, such as China, India, and Canada, which have with established space programs, rarely work with SSTL. Rather, capability is gained slowly and steadily through investments in education, research infrastructure, and manufacturing abilities. Group 2 countries, which have begun to invest in research infrastructure but are willing to partner with SSTL are able to transition from depending on SSTL for a capability to having independent, indigenous capabilities. As a result, these countries have a relatively high potential to advance their space capabilities.

D. Leveraging Domestic Private Actors

Not only are governments diverging from traditional models of development, they are also experimenting with new models of innovation and business practices, and leaning on the private sector in the process. Crowdsourcing, open innovation, and prizes have been used as ways to encourage space-oriented activities in Europe and the United States. The United States is also experimenting with bringing in the private sector as a cost-sharing partner rather than a contractor and paying by milestone delivery, buying services instead of products, and writing milestone based payment plans instead of cost-plus contracts. One example of this emerging business practice is NASA’s Commercial Crew program, which awarded $4.2 billion to Boeing and $2.6 billion to Space Exploration Technologies (SpaceX) to provide transport to the International Space Station (ISS) (NASA 2014b). Another is that of the U.S. firm Hamilton Sundstrand, which provides water services to the ISS on a performance-for-fee basis (Cruzan, Edeen, Grohs, and Samplatsky 2009; Comstock 2010). Through the funding of activities related to design and launch of a class of nano-satellites referred to as “CubeSats,” NASA’s Facilitated Access to the Space Environment for Technology Development and Training (FAST) program is encouraging “citizen space” activities. For example, PhoneSat, a small project developed in conjunction with NASA, is using smartphones to develop CubeSats for photography, meteor detection, atmospheric remote sensing, and topography for the general public at a fraction of the cost and time to access.[35] Similarly, NASA’s Ames Research Center manages an Emerging Space Office that is working with Google Lunar X Prize competitors to adapt smartphones and other off-the-shelf technologies for use in satellites.[36]

Figure 4-8 illustrates the evolution of the approach—from delegation to divestment to displacement.



Source: Adapted from Anderson (2013).

Figure 4-8. Evolution of the Role of the Private Sector

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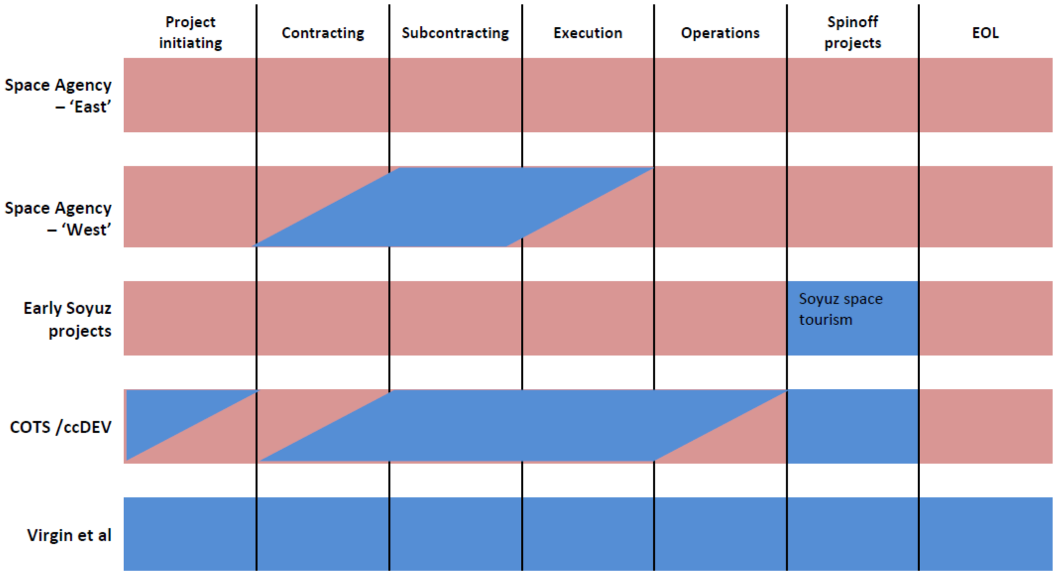
[35] From http://www.nasa.gov/offices/oct/stp/flight_opportunties/fast/index.html and http://www.nasa.gov/directorates/heo/home/CubeSats_initiative.html.

[36] From http://www.nasa.gov/centers/ames/about/impact-commercial-space.html.

The United States may be unique in its approach to engaging the private sector, and governments in other countries will likely remain more in control of their space enterprises than the United States. For example, while Arianespace is a commercial launch company, the ESA provides design authority and funding, and the French space agency *Centre National d'Études Spatiales* (CNES), is the prime contractor, and operates the Guiana Space Center.[37] The difference between approaches across countries was presented at a recent international conference, and is illustrated in Figure 4-9. As the figure shows, space agencies in the United States are sharing more of the life cycle of a space project with the private sector (areas shaded in blue). This contrasts with other countries where, even as they involve the private sector, the government retains control (areas shaded in coral).



Source: Payson (2014).

Note: Blue refers to activities led by the private sector and coral, to activities led by the government.

Figure 4-9. Differences across Countries in Leveraging the Private Sector

E. Acquiring Services Rather than Products

The United States and some other governments are making increased use of services. For example, the Federal Government has a "cloud first" policy in which agencies increasingly rely on cloud-based services instead of purchasing hardware and software for use within organization-specific computer centers (Kundra 2010).

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[37] From http://www.arianespace.com/spaceport-intro/who-does-what.asp.

NASA has been at the leading edge for implementation of a services model for space launch. In 1972, the only practical way for NASA to launch the Landsat I earth observation satellite was by government development and provision of a Delta 904 launcher and launch services (NASA 2010a). Initial support to the International Space Station (ISS) used the same model. More recently, through its Commercial Orbital Transportation Services (COTS) partnerships with firms, NASA has enabled an alternative access model through which it can obtain cargo delivery to the ISS as a service provided by firms. This practice is similar to NASA using FedEx to send packages or using commercial airlines to ferry its employees, rather than building its own fleet of airplanes.[38]

Many of the missions conducted by NASA have the primary objective of obtaining information, either for NASA (exploration missions) or for agency partners and customers.

F. Growing Globalization of Space

Space used to be a single country activity. For example, in the 1960s, the weather satellite TIROS was ordered by NASA, and built and assembled by U.S.-based RCA in East Windsor, NJ. The rocket used to launch it was built by another U.S.-based firm Douglas Aircraft,[39] and the satellite was operated by NASA, using a NASA mission control center in Greenbelt, MD. In contrast, in 2015, the Turkmenistan Ministry of Communications launched TurkmenÄlem52E/MonacoSat successfully to geostationary transfer orbit (GTO). The satellite was built by the Italian/French multinational company Thales Alenia Space, was launched by U.S.-based firm SpaceX, and is operated by Monaco-based satellite operator Space System International-Monaco. Most recently, Lockheed Martin submitted a CRS2 "Jupiter" Space Tug proposal to NASA. In the proposal, spacecraft bus is to be made by Lockheed Martin (U.S. firm), the pressurized module by Thales Alenia (European multinational), and the robotic arm by MDA (Canadian firm). Developments like this are expected to increase in number and intensity.

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[38] This paradigm is new to government but old to businesses. For example, Xerox's Managed Print Services allows companies to buy copies rather than equipment that is time-consuming and expensive to maintain, and Rolls Royce sells what it calls "Power by the Hour" instead of jet engines.

[39] J. McDowell's Space Website, http://planet4589.org/talks/global/global5.pdf.

5. Increasing Private Participation in Space

The private sector has been active in the space economy since its earliest days, and is one of the principal pillars of the space sector, together with the government, the scientific community, and the public. Firms like North American Aviation and McDonnell Aircraft Corporation were heavily involved in producing the Project Mercury hardware in the 1950s. The Space Shuttle era involved the efforts of Boeing/Rockwell, Lockheed Martin, and Alliant Techsystems. In the early 2000s, Microsoft's co-founder Paul Allen supported the firm Scaled Composites' development of the piloted SpaceShipOne vehicle, and SpaceX was founded by a former Internet entrepreneur in 2002.

Since the early days, private sector interest in space has only increased. Some of this interest emerges from technology improvements, reliance on COTS technology, and freely accessible data that have all contributed to increasingly specialized functions (and therefore actors) in multiple space sectors. In the EO sector, for example, the entity that launches, operates, and collects satellite imagery may be different from the entity that analyzes the data, which may be different from the entity that stores the information and processing power. This allows multiple firms to specialize and enter the sector. This is similar to changes that have occurred in sectors like computing and semiconductors. According to Euroconsult, over the next decade, sixty Earth observation satellites launched will be at least partially privately financed (Euroconsult 2014b, 164). In this chapter, we discuss who the private sector space actors are, with the next chapter focusing on approaches taken by them.

A. Emergence of a New Private Sector[40]

According to NewSpace Global, a market data and strategic analysis firm, from 2011 to 2014, the number of companies targeting commercial space opportunities has increased from 100 to 800, of which roughly 70 percent are not publicly traded. Investment in these private companies are expected to reach $10 billion by the end of 2015 (David and Strevy 2014; Hall and Johnsson 2015).

These firms are referred to as "NewSpace," and described as "an emerging global industry of private companies and entrepreneurs who primarily target commercial

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[40] The difference between private and commercial space is explained in Appendix D in Volume 2.

customers, are backed by risk capital seeking a return, and profit from innovative products or services developed in or for space."[41]

Details about the firms from these sources are not publicly available, and so to better understand the emergence of NewSpace companies globally, we developed and analyzed our own list using an adjusted criterion that firms included be technology-centric firms that target primarily commercial customers, aim for risk capital seeking a return, and organize to profit from innovative products or services developed in or for space. We identified a total of 169 firms in 33 countries, of which 124 have started since 2000 (full list since 2000 available in Appendix E in Volume 2 of this report).

Most of the 124 NewSpace firms that have started since 2000 are in the United States (86 in the United States, 38 abroad) (Figure 5-1 and Figure 5-2), although it is important to note that most of these firms see not just the private sector but the world as their customers. Indeed the private space sector is exceedingly global. Of the 33 teams working on the Google Lunar X Prize, 20 are non-U.S. entities. Of the nine winners of the Landing, Mobility, and Imaging prizes awarded in 2015, four are from countries other than the United States (India, Japan, and Germany).[42]

Looking at the firms from the point of view of their services and products offered, we see a range of offerings, with satellites (25 percent of all firms since 2000, 19 in the United States 16 abroad), and launch and transportation (26 percent of all firms, 19 in the United States) dominating (Figure 5-3). A non-surprising finding was the growth of data-analytics related services in the remote sensing and imaging area (16 percent of firms, 17 in the United States).

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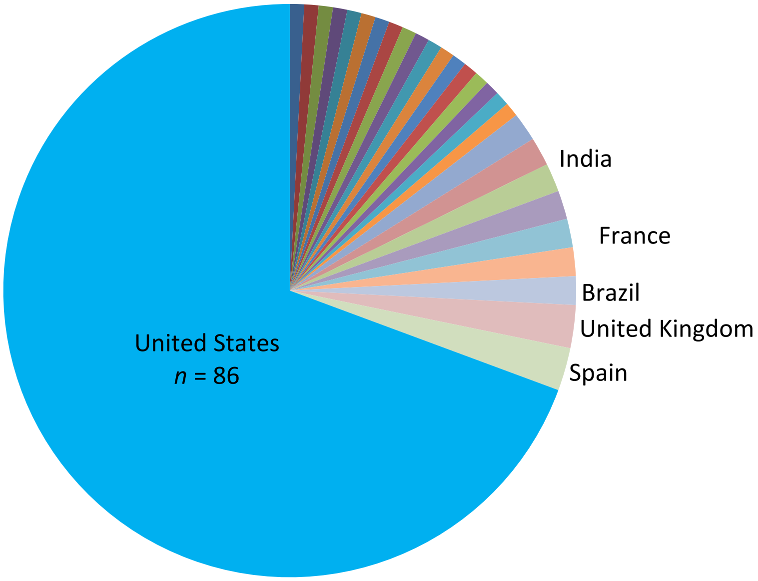
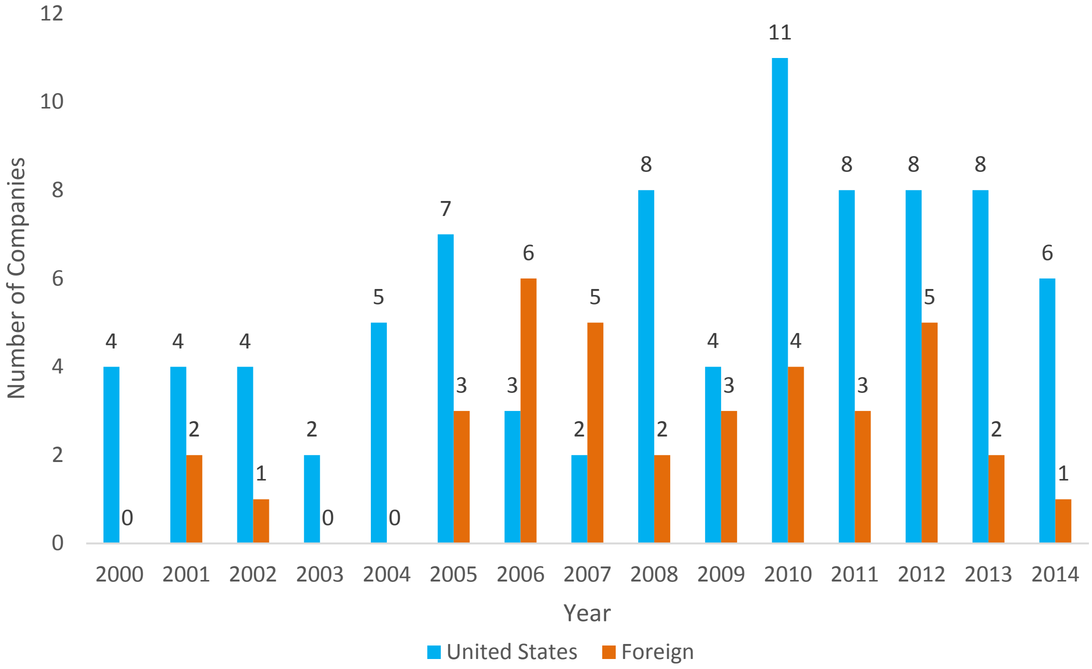
[41] From https://www.newspaceglobal.com/ and http://spacefrontier.org/what-is-newspace/. It is noteworthy that despite the moniker, some firms considered NewSpace have been in existence for a long time, implying that the term has more to do with a philosophy or a movement rather than novelty alone.

[42] From http://lunar.xprize.org/teams.



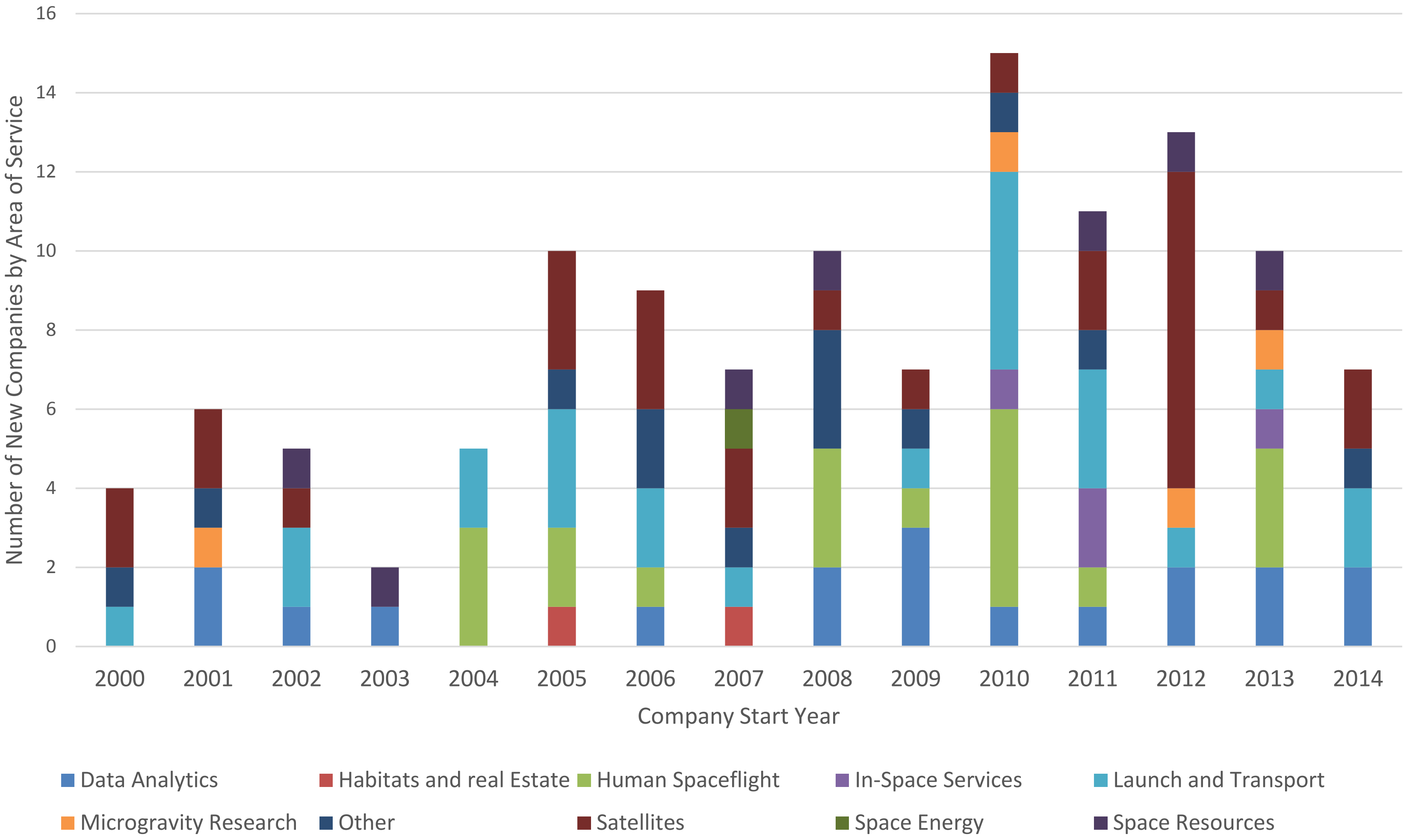
Source: STPI synthesis of data from public sources.

Figure 5-1. Geographical Distribution of NewSpace Companies (*n* = 124)



Source: STPI synthesis of data from public sources.

Figure 5-2. NewSpace Companies since 2000 (*n* = 124)



Source: STPI synthesis of data from public sources.

Figure 5-3. Areas of NewSpace Investment

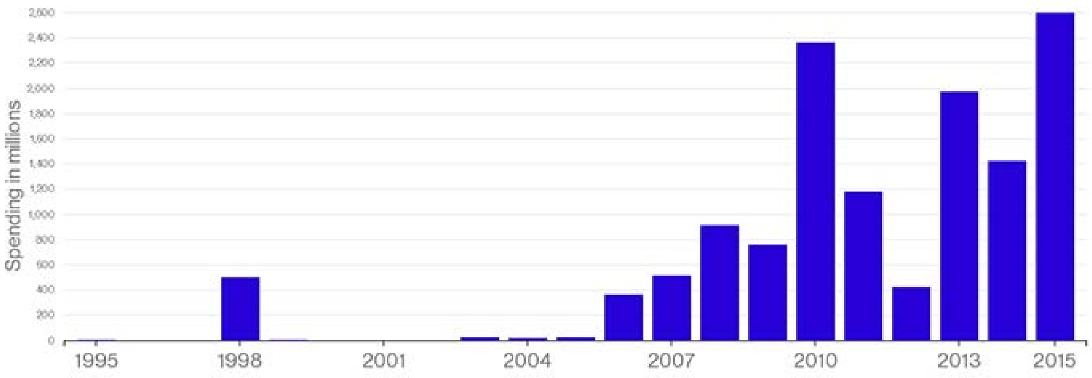
NewSpace firms are emerging in different parts of the world. In Australia, Saber Astronautics develops spacecraft systems that can automatically repair themselves if damaged, and Launchbox is an education-focused start-up enabling school students to launch their own prototype satellites into space. Astroscale is a Singapore-based company that is developing space debris removal technology.

They are providing low-cost services to non-traditional customers of space data. NewSpace entrepreneurs and firms especially in the Earth observation and remote sensing applications (e.g., Planet Labs, BlackSky Global, and OmniEarth in the United States and Urthecast in Canada) are departing from a tradition of customizing their products for government users to provide services to a wide range of customers. Most see themselves as IT or media, and not space companies.

These firms are also coming from sectors outside space. Leading internet companies, particularly those involved in the communication, storage and analysis of data have also begun investing in space. In addition to buying Skybox, Google has also announced its intention to invest in WorldVu (now called One Web), a constellation of LEO satellites similar to Iridium’s, but operating in Ku-band. Google is also collaborating with the French government in Project Loon.

Lastly, they inhabit space subsectors that traditionally have not seen private investment. While Earth observation may have the lowest barriers to entry and the largest number of private sector entrants, private sector participation is growing in in other subsectors as well. In launch, for example, there new firms engaged in rocket development for large (e.g., SpaceX in the United States) and small payloads (e.g., Rocket Lab in New Zealand).

With respect to their financing, little quantitative detail is readily available about NewSpace firms. They tend to be privately held and their finances—and their approaches to how they close their business case—tend to be closely guarded. Figure 5-4 shows NewSpace Global’s synthesis of the fundraising for the 100 largest closely held NewSpace companies, which indicates that most fundraising has occurred in the last five years.



SOURCE: NewSpace Global

1995-2002 annual totals were $2.5 million or less except 1998. 2015 includes projected funding.

Bloomberg

Figure 5-4. Fundraising in Millions for the 100 Largest Closely Held NewSpace Companies

B. Growing Nonprofit and Citizen Involvement

1. Philanthropic Involvement

Since 2003, commercial human space flight has received $2.5 billion in private investment (NASA 2014a). Some fraction of this investment is philanthropic and is driven by altruistic reasons. Most philanthropists are in the United States, and many are from the IT sector (Table 5-1). There is minimal space-related philanthropic activity in other countries. The only example found in the course of this study was that of Wang Jing, a Chinese national whose wealth is valued at $6 billion by Forbes. According to an Asian news source *The Straits Times*, Wang, through his company, Xinwei Telecom Enterprise Group, is planning to launch a network of satellites. The company has launched one satellite, which was jointly developed with Tsinghua University, and plans to build a telecommunication “constellation” over the next 10 years.[43]

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[43] See http://www.straitstimes.com/news/asia/east-asia/story/chinese-tycoon-wang-jing-develop-network-space-satellites-report-20141027.

Table 5-1. Individuals with High Net Financial Worth that Have Promoted or Invested in Space

Name	Citizen-ship	Net Worth (Billions)	Affiliation or Business	Space Project(s)
Elon Musk	U.S.	$11.9	PayPal, Tesla Motors, Solar City	SpaceX
Eric Schmidt	U.S.	$9.2	Google (chairman)	Google Lunar X Prize, Planetary Resources
Guy Laliberte	Canada	$1.9	Cirque du Soleil	Space tourist
Jeff Bezos	U.S.	$34.7	Amazon.com (CEO, founder)	Blue Origin
Larry Page	U.S.	$29.8	Google (CEO, co-founder)	Google Lunar X Prize, Planetary Resources
Paul Allen	U.S.	$17.5	Microsoft (co-founder)	Stratolaunch, SpaceShipOne SETI array
Richard Branson	UK	$4.8	Virgin Group (CEO, founder)	Virgin Galactic
Robert Bigelow	U.S.	~ $1.0	Real estate	Bigelow Aerospace
Ross Perot	U.S.	$3.7	Computer services and real estate	Planetary Resources
Sergey Brin	U.S.	$29.7	Google (co-founder)	Google Lunar X Prize

Source: Parabolic Arc, http://www.parabolicarc.com/2013/03/05/not-many-billionaires-focused-on-commercial-space/ and public sources (*Forbes* magazine)

Note: Other investors include Ram Shriram, Dennis Tito, Anosheh Ansari, Charles Simonyi, James Cameron, Lee Valentine, Stephen Fleming, Esther Dyson, Ed Tuck, and David S. Rose.

2. University Programs

We found no database of university participation in space-based activities that compares prior participation to present day. One of the most recent instances of university participation in space, especially internationally, is through university CubeSat programs. While the first university CubeSats were from Santa Clara University in 2000, the Aalborg University in Denmark, the University of Toronto, the University of Tokyo, Tokyo Institute of Technology, and Technical University of Denmark followed in 2003. The list of universities with CubeSat programs now also includes those in Norway, Germany, South Korea, Colombia, the Netherlands, Istanbul, France, India, Switzerland, Romania, Hungary, Poland, Italy, Spain, United Kingdom, Estonia, Pakistan, Peru, Singapore, Lithuania, Uruguay, Israel, Taiwan, and the Ukraine.[44] In some countries, universities are especially important players in the space realm and help the country with respect to building space capabilities. In Singapore, for example, Nanyang Technical University has been instrumental in a government-supported effort to develop a small satellite manufacturing, applications, and services ecosystem. With government support, Nanyang

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[44] See https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database.

Technical University established a satellite research center that has developed and launched several satellites, included a high-resolution imaging technology demonstration (X-Sat) co-developed with the national defense research laboratory of Singapore.[45]

Lacking a formal inventory of university participation in space activities, STPI researchers plotted membership in the International Astronautical Federation (IAF), classifying members into four categories—government, industry, university, and other. Figure 5-5 shows the results, which are also discussed in Chapter 3. The sections of the bar in grey (university members) began to appear in larger numbers only in recent years, indicating growing university presence. It is important to note though, as the inset pie charts in the figure show, that this increase is not uniform across the world.

3. Citizen Science and Crowdsourced Activities

Internet-enabled growth of citizen science and crowd-sourced activities in space has surged in past years. Crowd-funding allows projects to pursue opportunities that are not high priorities for space agencies or profitable targets for private companies.[46] Furthermore, they offer a potentially less expensive solution to otherwise resource-intensive tasks.

Private organizations and companies, as well as the United States Government, are interested in crowd-sourced and crowed-funded projects. One well-funded example from private industry is the Google Lunar XPrize, which has issued a challenge to develop a robot that lands on the moon, travels 500 meters, and transmits images back to Earth. The grand prize for completing these tasks is $20 million dollars.[47] The finalists for the milestone prizes include teams from the United States, Japan, Germany, and India.[48]

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[45] See http://www.sarc.eee.ntu.edu.sg/aboutUs/Pages/DirectorsMessage.aspx.

[46] One popular platform for crowd-funding projects, Kickstarter, has had 74 projects categorized as "Space Exploration," 43 of which were fully funded. The character of these projects ranges from developing CubeSats that would release hundreds to thousands of postage-stamp sized spacecraft to building plasma jet electric thrusters for spacecraft. Space companies are harnessing citizen participation for tasks that are small but difficult to automate. According to an article in *SingularityHUB*, Kickstarter has raised over $1.6 billion and funded 80,000 projects. The article says a 2013 World Bank-commissioned study reports that "by 2025, the global crowdfunding market will reach about $100 billion—roughly 1.8 times the size of the global venture capital industry today" (Diamandis 2015).

[47] From http://lunar.xprize.org/about/overview.

[48] From http://lunar.xprize.org/press-release/private-moon-race-heats-five-google-lunar-xprize-teams-take-home-525-million-key.

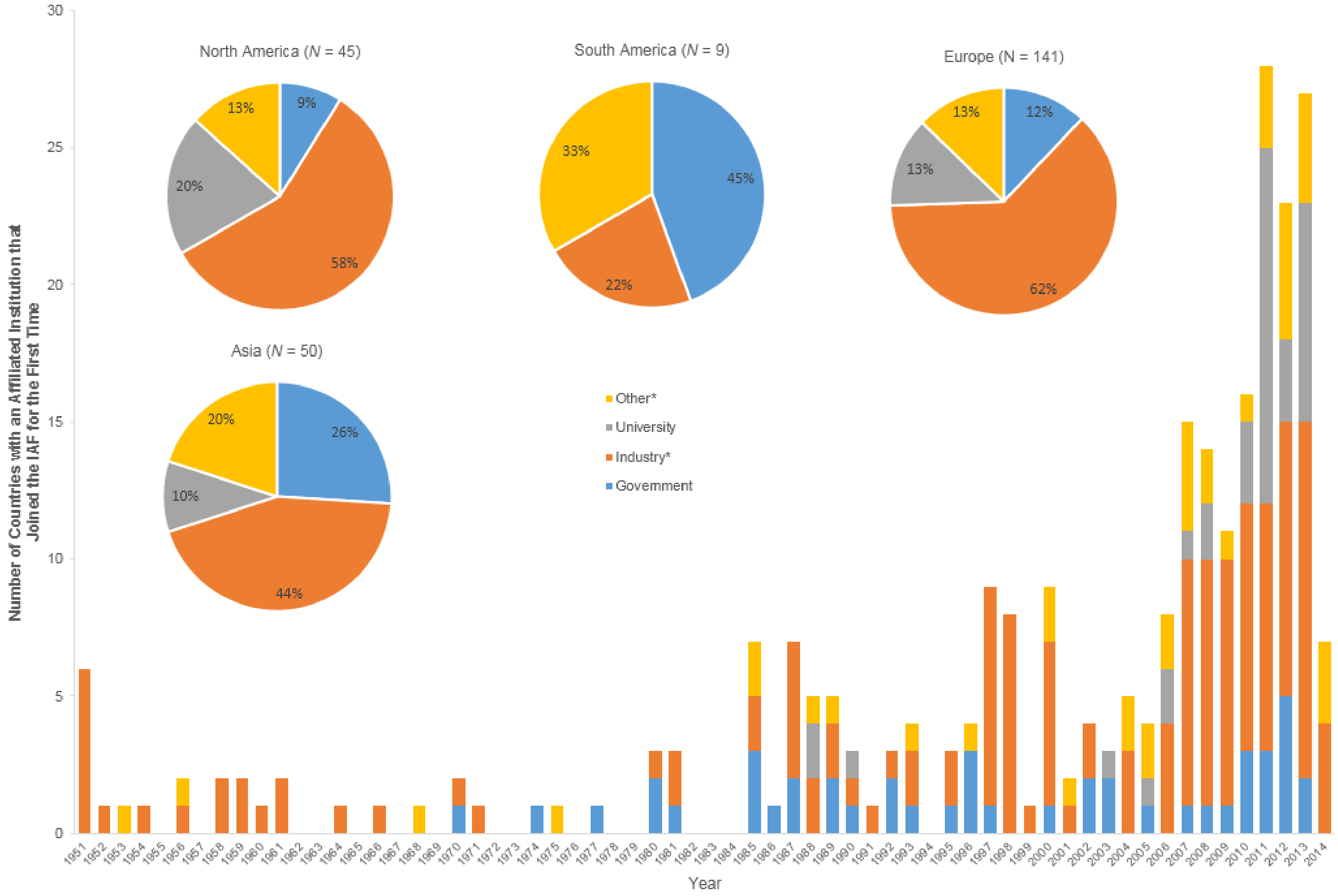

Figure 5-5. Percentage Increases in University Membership (Grey Sections), and Differences across Regions with IAF Institutional Membership (*N* = 270)

Zooniverse, another example, is a website and organization that houses citizen science projects focused on space. It has over 1.2 million participants worldwide. Individuals are asked to help classify galaxies from Hubble Space Telescope images or identify planets around stars. Citizen science and crowd-funding were both employed in the repurposing of an old NASA probe, the International Sun-Earth Explorer (ISEE-3), which was launched in 1978. And in May 2014, NASA granted the group of citizen scientists working with Skycorp Inc. permission to contact and possibly command and control ISEE-3.[49]

The Defense Advanced Research Projects Agency (DARPA) has also taken interest in the potential for crowdsourcing tasks. SpaceView, part of the DARPA Orbital Outlook program, is a plan to build a network of amateur astronomers and provide them with hardware and software to supplement the current space surveillance network. According to a program manager, “There is an untold amount of potential in the amateur astronomy community that we hope to use to broaden our situational awareness in space” (David 2012).

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[49] From http://www.skycorpinc.com/isee-3-reboot.html.

6. Alternative Approaches in the Private Sector

As discussed in the preceding chapter, there has been renewed private sector interest in space. New developments that lower the cost of entry into space, have allowed both new start-ups (e.g., Skybox in the United States and Gumush in Turkey) and firms that would not normally be considered space firms (e.g., agricultural sciences giant Monsanto[50]) to take up space activities. As these new firms enter the space sector, they are challenging the concept that "space is still not a 'business like others'" (OECD 2014, 32). Developments are beginning to mirror those in other sectors (like telecom or IT)—businesses can start and gain scale with speed while using little capital, entrepreneurs and start-ups often have new advantages over large established businesses, the life cycle of companies is shortening, and not only the markets but also the supply chains are global.

This chapter highlights approaches NewSpace companies are taking to reduce cost rather than push the limits of performance. Focusing on "good enough," these firms are making space hardware that is simple, small, and, in some cases (like small satellites) practically disposable, as opposed to big with built-in redundancies.

A. Selling Services Rather than Products

One of the most important changes has been the increased emphasis on acquisition of services rather than products. For example, if a firm needs to intermittently accomplish computationally intensive calculations, it no longer has to purchase the necessary hardware and software. Instead, it can purchase the needed computer memory and analytical tools as a service using a web-based provider, and thereby avoid the costs entailed in obtaining and operating in-house hardware and software and the staffs that might not be needed every day (Carraro and Chong 2006). This is a buy-it-by-the-drink model as opposed to owning and operating your own brewery. This logic also extends to manufacturing. Apple designs the A series chips used in its iPhone but outsources fabrication (Zeman 2015).

In the space sector, as discussed in Volume 2, many companies, especially those in the Earth observation sector that are launching fleets of small satellites and developing cutting-edge analytics, are focusing on providing actionable insights and services rather

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[50] In late 2013 Monsanto purchased the Climate Corporation, which provides crop insurance to farmers who use satellite imagery and data analytics.

than a product. The global market for satellite-sourced intelligence is predicted to grow by over $5 billion by 2019.[51]

It is important to note that not all firms (or governments) engaged in space sectors have moved towards a services model. For example, SpaceX has deliberately implemented a vertically integrated model in which it does as much manufacturing as possible in-house (Rich 2014). However, generalizing across firms and over time, the broad trend in many subsectors is towards increased use of services, both their acquisition and provision.

B. Adopting Agile Manufacturing

For years, satellites and launchers have been treated like one-off prototypes, like custom-made Italian suits, even when standard platforms have been developed to gain processing efficiencies and reduce production costs. Today, adaptation of new industrial qualification procedures are being pursued to use existing experience and data from high-volume industries (such as automobile or aeronautics) to mass produce spacecraft and launchers. SpaceX, a California-based U.S. launch company, is a case in point. The company's factory is configured to achieve a production rate of up to 40 Merlin rocket engines annually. These new industrial processes (among other reasons, including governmental support) allow the company to sell space launch services of its Falcon rocket for around $60 million, at a price less expensive than its established competitors (OECD 2014). Smaller firms take the concept further. Planet Labs, for example, has redesigned the firm's CubeSats twelve times since the firm was established in 2010 (Planet Labs 2015).

This agile development model—making continual incremental improvements to hardware and software to ensure that operations can be rapidly configured to satisfy changing markets demands—is prevalent in Silicon Valley, and rapidly being integrated by many of the newer space firms.

C. Adapting Technology from Other Sectors

When nations began investing in space, many of the necessary technologies had to be invented from scratch because no COTS solutions were available then. Solar cells were first invented and used in the Vanguard program, integrated circuit development was funded by NASA and the Department of Defense, and first real-time embedded computers and operating systems were built for Apollo, as were advances in precision matching, robotic welding, and assembly. The preponderance of "space-only" technologies in the early years of the space program is illustrated notionally in Figure 6-1 in blue as technology led by space as a niche, unique application (Summerer, 2012).

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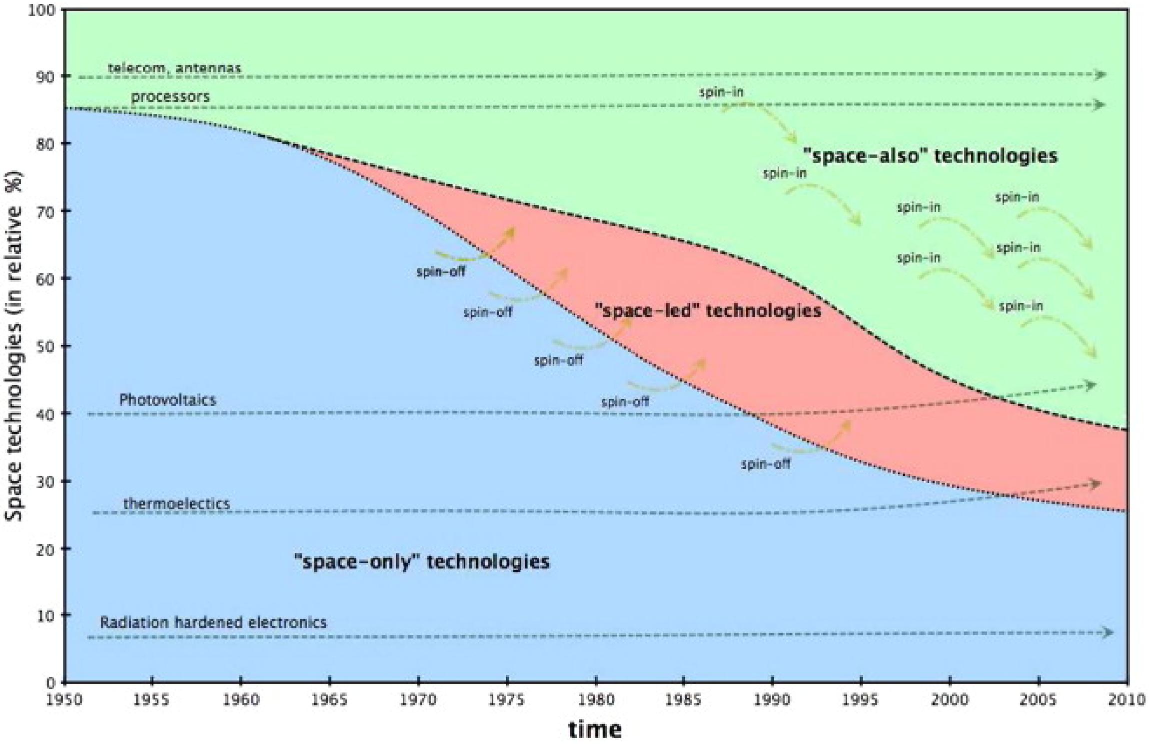
[51] See https://www.vlab.org/events/satellite-imaging.



Source: Summerer (2012).

Figure 6-1. Evolution of Development from Space-Only Technologies to Space-Led and Space-Also Technologies

As time passed, technology development occurred within or outside space but still using space as a lead market. Figure 6-1 shows the growth of these “space-led” technologies in coral.

In recent years, a third category of technologies, developed in terrestrial markets for terrestrial use, and subsequently adapted for space, has become dominant (shown as “space-also” technologies in green in Figure 6-1). As examples, satellite manufacturing firms are using “inertial measurement units from video games, radio components from cell phones, processors meant for automobiles and medical devices, reaction wheels meant for dental tools, cameras intended for professional photography and the movies, and open-source software available on the Internet” (Kumagai 2014). As Figure 6-1 shows, the proportion of this category of technologies is increasing in the space domain, and beginning to overpower the other two.

A NASA report (2014c) reinforces the trend, discussing how robotic mining and wireless power are two areas of technology that are beginning to cross over to space applications, despite being unrelated to the space industry. Robotic mining helps in-situ resource utilization, which could help replenish supplies for long missions in space. Automated mining equipment, autonomous heavy hauling, automated trucks, and advanced technology for mineral sorting and recovery are already in development for terrestrial mines in many countries, especially in Australia, Sweden, and the United Kingdom. Wireless charging technology is being developed mostly for electric vehicle charging, and many major car manufacturers are pursuing this technology. This technology has the potential to improve long-distance wireless power transmission, which could help power satellite systems or rovers that do not have enough sunlight exposure to charge solar cells (NASA 2014c).

D. Adapting Approaches from Other Sectors

Many NewSpace companies, unlike traditional space companies, are leveraging space as just another means of gathering and distributing information. For them, the business is in developing and profiting from applications, not hardware. Skybox is an example of this thinking:

> The company's founders, graduate students in a course on entrepreneurship at Stanford University, took a bootstraps approach, writing their own image-processing and change-detection algorithms and raising financing from Silicon Valley venture capital firms. Skybox eventually brought in a space industry veteran, Tom Ingersoll, to lead the operation, but even he views the company first and foremost as an information provider (*SpaceNews* Editor 2014).

Given how many of the firms in the sector see themselves as IT or media firms, it is no surprise that they borrow practices from the IT sector. For example, NewSpace firms showcase using the *worse-is-better* approach of programming that holds that cheaper, simpler software can be faster and easier to use than expensive, complicated software. Planet Labs claims, for example, that 20 percent of its small satellites can fail in orbit—can never work at all—without the company losing a meaningful amount of imaging capacity (Meyer 2014). The Russian private firm Sputnix (which in June 2014 launched its microsatellite TabletSat-Aurora[52]) is following a "LEGO ideology" where onboard systems connect to the central bus in the same way as modern plug-and-play computers. All of the platform's service systems include a common service interface, which allows the satellites to be constructed from standardized blocks (Zhukov and Kokorich 2014).

Absorbing the culture of Silicon Valley, many of these companies pitch themselves to venture capitalists as IT companies offering big data plus analytics (*SpaceNews* Staff 2014). In the same vein, they are, at least for the moment, the takeover targets of technology giants like Google, Facebook, Samsung, Apple, and Amazon, not of traditional aerospace firms like Boeing.

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[52] From http://www.sputnix.ru/en/mediainfo/item/356-sputnix-has-launched-the-first-russian-private-earth-remote-sensing-satellite.

7. Increasingly Complex Governance Landscape

Outer space it not subject to the sovereignty of any particular state. Similar in its legal nature to the high seas, international air space, and Antarctica, states exercise jurisdiction over their nationals in outer space and space objects launched on their national registries. No State has authority over the activities of another state, and there is no international body that exercises control of or regulates the behavior of activities in outer space.

Governance of the behavior and relations of states in carrying out activities of scientific exploration and various other uses of outer space is established through a mosaic of international treaties, international organizations, and non-binding international arrangements. Space governance among nations began in the late 1950s and early 1960s, when the UN General Assembly passed a number of resolutions on cooperation and the peaceful use of outer space. In 1959 the UN established COPUOS, which is responsible for developing policies related to outer space on behalf of UN Member states. In 1963, the International Telecommunication Union (ITU), a specialized agency of the UN that is responsible for issues that concern information and communication technologies, held its first Extraordinary Administrative Conference for space communications and began allocating frequencies to space services. In 1967, the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space* ("*Outer Space Treaty*") entered into force. Together, UN COPUOS, the ITU, and the *Outer Space Treaty* form the institutional and legal foundation for international space governance.

Traditionally, the space governance landscape was relatively simple, guided primarily by the *Outer Space Treaty*[53] and complemented by the ITU Telecommunication Development Sector (ITU-D) and driven by a small number of space-faring states and their national activities. In this paradigm, the *Outer Space Treaty*, the ITU, and complementary arrangements were able to provide sufficient guidance to a relatively small set of space-active stakeholders, meeting the needs of the global community.

But as the previous chapters have amply illustrated, there is a growing global space stakeholder community consisting of new government and private sector entrants, which

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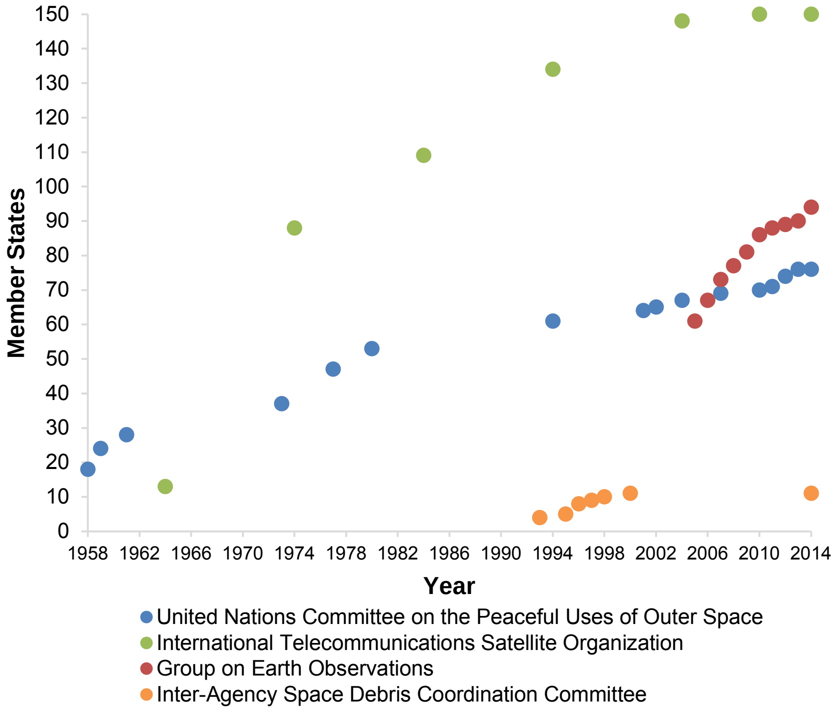
[53] Including the *Outer Space Treaty,* five international treaties govern activities in outer space. The *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies* (1967) is the foundational document and all space-faring nations, including the United States, are parties to this treaty.

is increasing the complexity of the space governance landscape; and there is increasing participation and membership in the global space governance community evidenced by participation rates in COPUOS, ITU-D, Group on Earth Observations, and the Inter-Agency Space Debris Coordination Committee (IADC). See Figure 7-1. These new entrants have governance interests as both operators of space assets and recipients of space data and services that are not all adequately addressed under the current global space governance regime.[54] As the numbers of stakeholders increase and stakeholder interests diversify, it will be more challenging to reach consensus on critical global space governance issues, increasing the likelihood that states will adopt divergent positions. More time and resources will need to be spent on the development and establishment of space governance norms and mechanisms.



Source: STPI synthesis of data from public sources.

Figure 7-1. Membership in Space Governance Related Organizations

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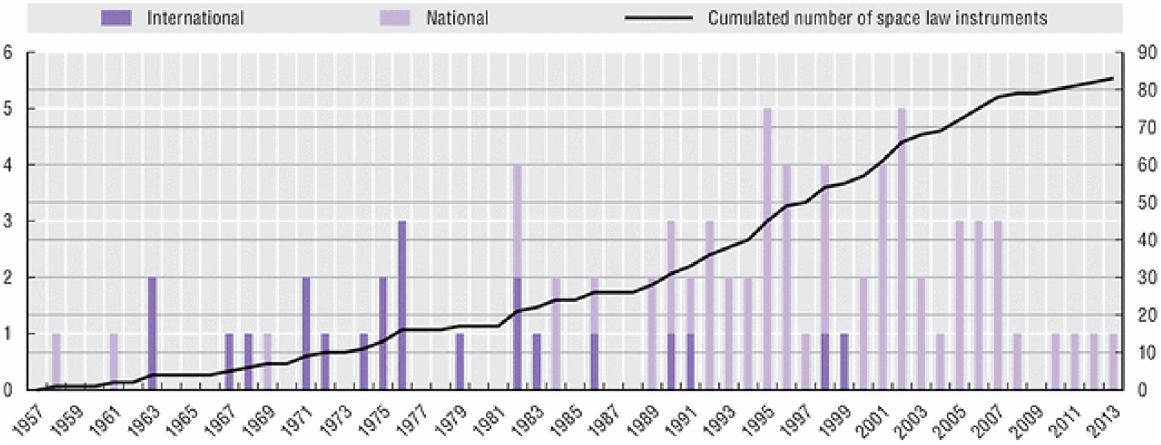
[54] For example, several companies around the world are proposing to provide on-orbit services, physically interacting with active and defunct satellites. This activity was not foreseen in the outer space treaties, and it raises concern among stakeholders with regard to transparency, jurisdiction, ownership, control, and responsibility—issues that the current global space governance regime does not effectively address.

A. Evolution of Governance

Global governance regimes traditionally evolve through a bottom-up approach in which state activities evolve to become custom, usually evidenced through national laws and non-binding international legal arrangements, and eventually posited as legally binding international treaties. What is unique about space governance is that it did not follow this traditional model. The United States and USSR agreed to the *Outer Space Treaty* in 1967, (only 9 years after *Sputnik*), partly because the United States and Soviet Union were the only space-faring states in the 1960s and partly because of fears of a U.S.-Soviet nuclear arms race in outer space.

Today the evolution of global space governance is reverting to the more traditional model, with states leading the evolution of governance through practice, national laws, and non-legally binding international arrangements. This is seen in an increase in national space law and regulations (Figure 7-2) and the number of international efforts underway to establish non-legally binding international arrangement that will contribute to global space governance. Examples include COPUOS Long-Term Sustainability Guidelines (Secure World Foundation 2014) and International Space Code of Conduct (Zenko and Dillon 2011).



Source: OECD calculations based on United Nations data (OECD 2014, 45).

Figure 7-2. Number of Treaties, National Space Laws, and Regulations per Year, 1957–2013

B. Emerging Governance Challenges

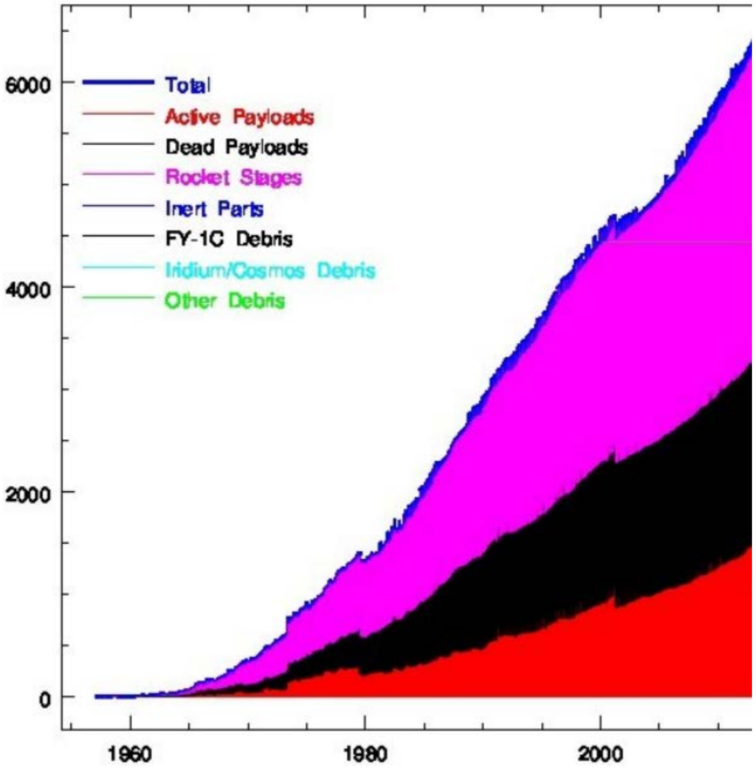
Within an increasingly complex governance landscape, several emerging challenges warrant attention as they are likely to have effects on global trends in space. These challenges are summarized in Table 7-1 and described in the following subsections.

Table 7-1. Emerging Space Governance Issues

Issue	Current Governance Regime	Status	Forecast
Management of Space Debris	Voluntary Space Debris Mitigation Guidelines	States improving implementation of debris mitigation guidelines, but no clearly recognized international norms	Continued development and adoption of mitigation best practices and standards; development of international guidelines on space sustainability; customary international practices
Management of Radio Frequencies	ITU International coordination of radio frequency assignments in light of increasing demands for limited frequencies	WRC-15 will debate reallocation of satellite C-band frequencies for terrestrial uses and increasing the ITU's enforcement powers to address harmful interference	ITU will continue to be the primary global governance mechanism. In order to strengthen the ITU, additional enforcement powers will be granted.
Exploitation of In-Situ Celestial Resources	None	Private U.S. companies are proposing to exploit in-situ celestial resources for commercial purposes, soliciting regulatory approval, and seeking legislative support. Other countries are observing U.S. signals.	United States will be the first actor and will move forward with a national governance solution. Other countries will follow the normative standards set by the United States, creating a de facto global governance regime.
Space Traffic Management	None	There is no international system to manage on-orbit space traffic	To help fill the gap, states will move towards a more coordinated approach for managing civil and commercial operators. Private sector space-situational awareness (SSA) providers will market safety-of-flight information and services directly to owner-operators.
Planetary Near-Earth Object (NEO) Defense	None	Government stakeholders are in the process of implementing recommendations of UN COPUOS working group on NEOs (AT-14)	Development of the International Asteroid Warning Network (IAWN) and International Space Mission Planning Advisory Group (SMPAG)

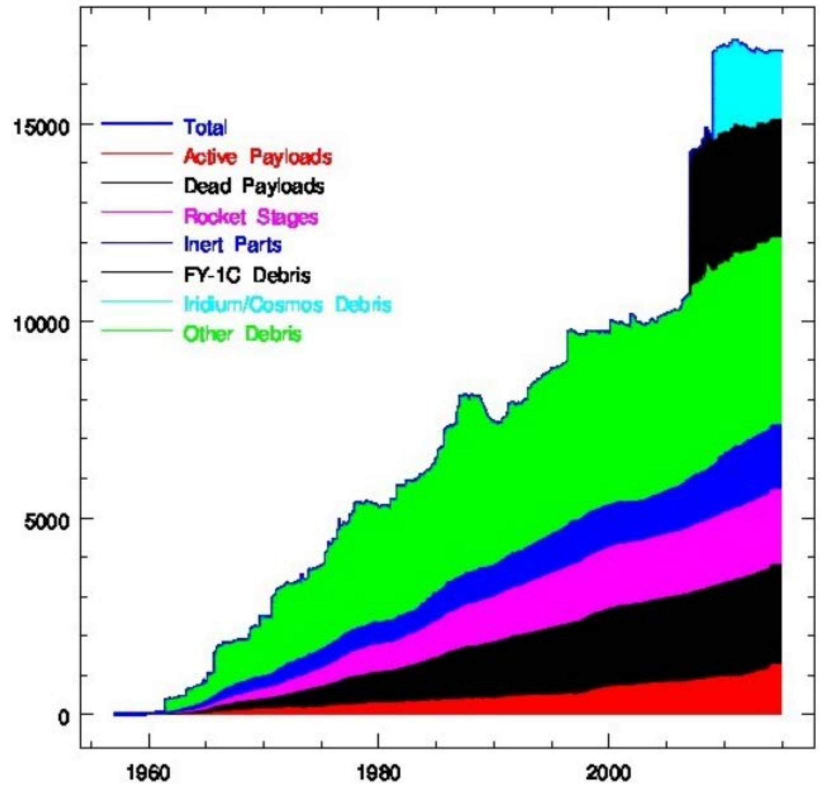
1. Management of Space Debris

Space debris, which comprises human-generated, non-functional objects and micrometeoroids, represents a threat to all functional objects in orbit, regardless of their nationality, ownership, or purpose. Human-generated space debris has steadily increased over the past 50 years. In the last ten years, over 7,000 new pieces of orbital debris larger than four inches have been added to the most heavily used earth orbits (Simpson and Lopez 2015). By weight of objects, 85 percent of the debris comes from the United States and the Russian Federation (Figure 7-3). By number, however, China's contribution is substantial (bottom chart, Figure 7-4). Moreover, models and simulations by major space agencies have shown that the orbital debris will continue to multiply, even without further launches (Figure 7-5). This distribution of debris is primarily concentrated in LEO between 600 and 1500 kilometers and in GEO, the orbits where activity is the greatest (Jakhu 2011, 17) when compared to medium Earth orbit (MEO).



Source: J. McDowell's Space Website, http://planet4589.org/talks/global/global5.pdf.
Note: The *y* axis represents weight in metric tons.

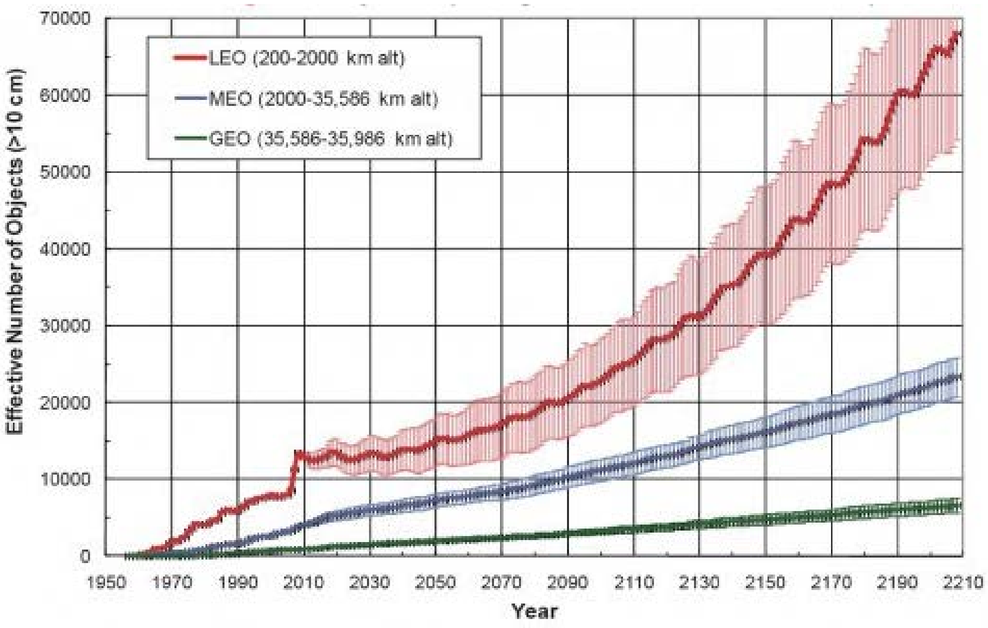
Figure 7-3. Sources of Debris in Terms of Weight of Objects



Source: J. McDowell"s Space Website, http://planet4589.org/talks/global/global5.pdf.

Note: The y axis represents number.

Figure 7-4. Sources of Debris in Terms of Number of Objects



Source: NASA (2010b).

Figure 7-5. Projection of the Growth of >10 cm Space Objects if Post-Mission Disposal Measures Are Not Implemented

NASA projects nearly one collision per year in the next 200 years if there is no debris mitigation, and insurance companies predict a total exposure of $18 billion in GEO and $1.3 billion in LEO (Euroconsult 2014b, 24). With concern for space debris and the long-term sustainability of the space environment, the international community established space debris mitigation guidelines in 2007, which have been endorsed by space-faring nations.[55] These non-binding international guidelines, combined with nationally binding policies and regulations, serve as a policy driver and affect the design and operation of on-orbit spacecraft with a focus on their end-of-life disposal.

Debris mitigation guidelines have created incentives for investments in technologies that address the issues of debris generation, debris mitigation, debris remediation, and tracking debris on-orbit. In the commercial sector, both technological and business innovations are being driven by the challenge of space debris. For example, several private companies are developing and planning to offer on-orbit end-of-life mitigation services, premising their business model on the value extracted from extending satellite operations.

The issue of space debris has gained significant international attention and encouraged space-faring nations to adopt international and national guidelines to mitigate debris generation.[56] These non-binding international guidelines, combined with nationally binding policies and regulations, serve as a policy driver and affect the design and operation of on-orbit spacecraft with a focus on their end-of-life disposal. While not legally binding, international guidelines are increasingly perceived as legitimate best practice standards by the international community and increasingly likely to influence the behavior of states and private actors.

From a governance perspective, several challenges are likely to arise in promoting universal adoption of debris mitigation guidelines. First, the non-binding nature of space debris guidelines means that violations of norms may be difficult to enforce. Second, the costs associated with debris mitigation may become a challenge for less wealthy or technically advanced space-faring nations. Third, the ability to assist other states in the development or deployment of debris mitigation technologies may be encumbered by concerns of dual-use technology proliferation, particularly for launch vehicles.

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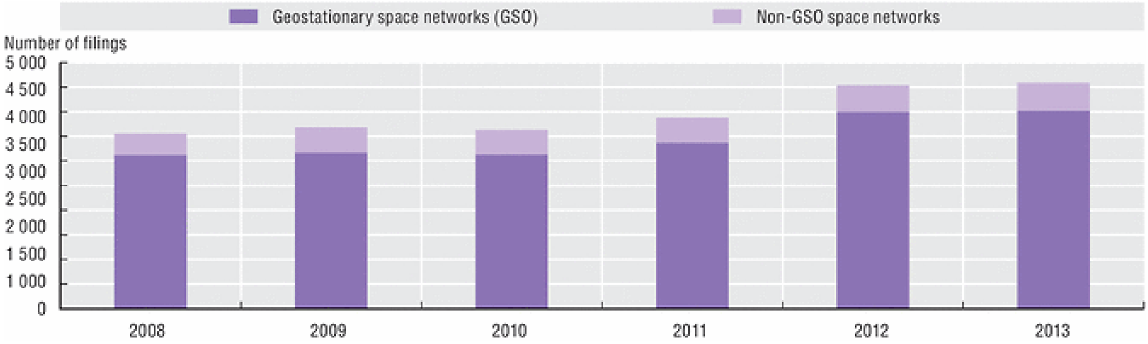
[55] See IADC Space Debris Mitigation Guidelines (Inter-Agency Space Debris Coordination Committee 2007) and the UN COPUOS Space Debris Mitigation Guidelines (United Nations Office for Outer Space Affairs 2010).

[56] In addition to the previously mentioned IADC Space Debris Mitigation Guidelines and the UN COPUOS Space Debris Mitigation Guidelines, other such treaties include the European Code of Conduct on Space Debris, U.S. National Space Policy, and NASA Debris Mitigation Guidelines.

2. Management of Radio Frequencies

Satellites and other space-based systems require radio frequencies, a limited and finite resource, to communicate. Absent an unforeseen breakthrough in laser communication, management and allocation of radio frequencies for space-based stations will become more challenging with increasing demand for spectrum/orbit usage for practically all space communication services. This increase is attributable to technological progress, the liberalization of telecommunication services, the introduction of non-GEO satellite systems for commercial communications, and the general globalization and commercialization of communication systems, among other factors (ITU Regulatory Framework for Space Services n.d.).

The three most commonly used satellite frequency bands are the C-band (4–8 Ghz), Ku-band (11–17 Ghz), and Ka-band (20–30 Ghz). The management and use of these radio frequencies in space is challenged by increasing demand from both space-based and terrestrial telecommunication services, as well as issues related to intentional and non-intentional interference. An example of increasing demand for GEO communication satellite allocations include recent efforts to have the ITU assign C-band satellite frequencies to terrestrial wireless broadband operators (Patton 2014). See Figure 7-6.



Source: OECD calculations based on ITU data (OECD 2014).

Figure 7-6. ITU Filings for Satellite Networks

The ITU will continue to be the primary governance mechanism for radio frequency management. However, the ITU faces governance challenges related to managing satellite signal interference, proliferation of non-ITU registered spacecraft operators (e.g., CubeSat operators), terrestrial wireless-broadcasts, and the allocation of increasingly scarce space-station frequency assignments. As a sign of how the governance mechanisms of the ITU may evolve to face these challenges, there is currently a proposal to be considered at the 2015 World Radio Communication Conference (WRC-15) for the ITU to have access to a global network of satellite Earth stations capable of verifying that telecommunications satellites are doing what they are registered to do (Selding 2014a).

3. Exploitation of In-Situ Natural Resources

Asteroids and other celestial bodies (e.g., Moon) contain in-situ natural resources that may warrant commercial exploitation. Near-Earth objects and asteroids located in the asteroid belt are reported to contain metals like gold and platinum as well as deposits of water, hydrogen, and oxygen (Brophy, Culick, Friedman, et al. 2012). Private U.S. companies are proposing to exploit in-situ celestial resources for commercial purposes, soliciting U.S. regulatory approval, and seeking legislative support.[57] Other countries are observing how the U.S. Government responds to this and the precedent that will be established in the legality and governance of in-situ resource exploitation.

While the *Outer Space Treaty* and international space law clearly defines the legal status of celestial bodies, the legal status of celestial bodies' resources remains controversial. There is no clear answer as to whether the removal and commercial utilization of in-situ celestial resources is an internationally legally admissible undertaking. From a governance perspective, there is no mechanism in place to resolve this issue and manage the exploitation of celestial resources. Article 11(6) of the *Moon Treaty* does call for the establishment of an international regime to govern exploitation, but no major space-faring state is a party to the *Moon Treaty* (United Nations Office for Outer Space Affairs 1979).

As the community of space-active states approaches a future where the exploitation of in-situ resources is feasible, both domestic and international stakeholders will raise questions regarding the legality of such activities and call for some type of governance beyond national legislation. How states choose to interpret international space law and govern in-situ resource exploitation will have long-term implications on the rules governing human activity in outer space (Delgado-López 2014).

4. Space Traffic Management

The Goddard Space Flight Center lists 2,271 satellites currently in orbit, and by the end of this decade, based on announced plans by various companies and space programs, between 2,000 and 2,750 CubeSats and other nano-satellites (SpaceWorks Enterprises, Inc. 2014) and ~5,000 other satellites will be launched (Selding 2015d). Figure 7-7 shows numbers of active satellites from 1957 to 2014, and Figure 7-8 shows the dramatic increase in the launch of CubeSats in recent years.

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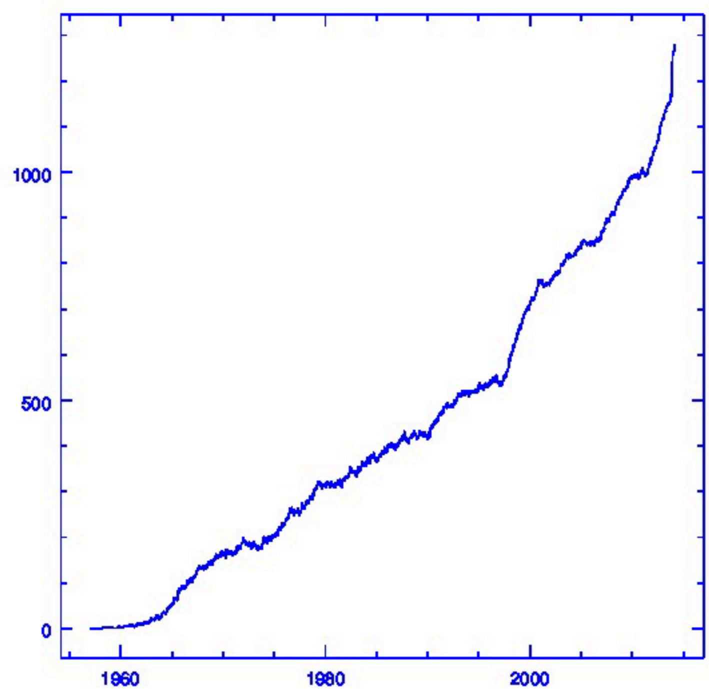
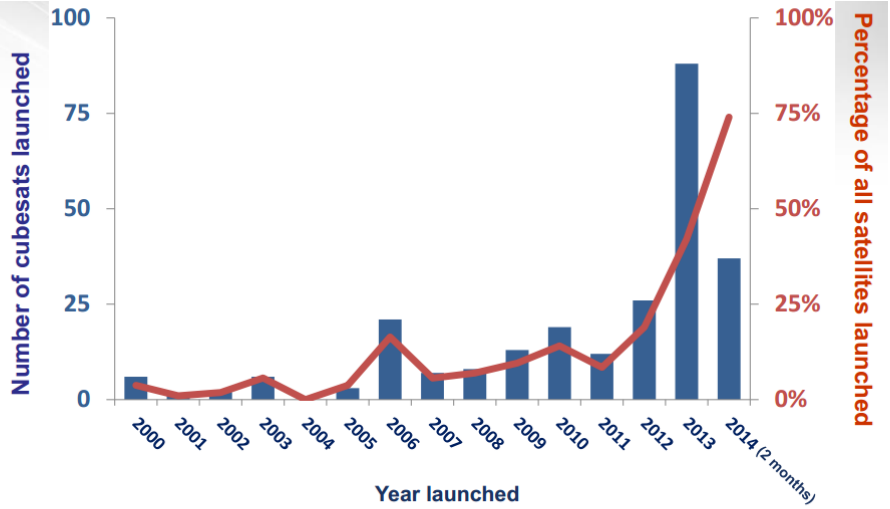
[57] Some U.S. companies (e.g., Planetary Resources, Deep Space Resources, Moon Express, and Kepler Energy) have announced plans involving in-situ resource exploitation.



Source: J. McDowell's Space Website, http://planet4589.org/space/log/stats.html.

Figure 7-7. Active Satellites, 1957–2014



Source: Space Data Association, 2014.

Figure 7-8. Cube Satellite Launches

Today, there is no international space traffic management[58] (STM) system to manage this increasing number of satellites, their flight safety, or there end-of-life disposal (Selding

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[58] Space traffic management is the set of technical and regulatory provisions for promoting safe access to, operations in, and return to Earth from outer space that are free from physical or radio-frequency interference (Contant-Jorgenson, Lála, and Schrogl 2006).

2015d). The ITU is responsible for assigning radio frequencies and assisting states in resolving claims of interference with the ITU registry. Individual spacecraft owner-operators are responsible for managing their own operations and, in some instances, voluntarily coordinate the exchange of data and maneuver planning.[59] But these alone are not sufficient to resolve the forecasted needs of coordinating internationally SSA information, data, services, and maneuvers for the purposes of space traffic management. As stated by Contant-Jorgenson, Lála, and Schrogl (2006):

> At first glance, the management of space traffic does not appear to be a pressing problem. On closer examination, this judgment has to be challenged. A high level and ever growing number of launches from more and more launch sites and spaceports, the participation of non-governmental entities, the positioning of satellite constellations, an increase in space debris and the advent of reusable launch vehicles support this judgement. Considering this scenario, conceptualizing space traffic management will turn out to become a relevant task during the next two decades.

Some states are beginning to address the need for a more global approach to space traffic management. In the United States, the U.S. military operates a space situational awareness (SSA) sharing program to encourage data-sharing in the realm of SSA and help ensure safe operations in space. Private sector ventures, such as Analytical Graphics, Inc.'s Commercial Space Operations Center (COMSpOC), are offering a commercial solution to enhance SSA.[60] Global investments in SSA capabilities are also being driven, in part, by the challenge of space debris. For example, the International Scientific Observational Network (ISON) includes verification of existing space debris distribution, evolution models of space debris, estimation of the real level of danger caused by space debris fragments for operational spacecraft, testing and improvement of the technology of space debris studies, and the improvement of the motion models for measurements processing space debris objects as research objectives (Agapov and Molotov 2008).

5. Planetary NEO Defense

In addition to new actors and activities, the global civil space community is developing an interest in the existential threat of NEOs that will require new governance mechanisms to inform and coordinate NEO planetary defense efforts.

NEOs are asteroids and comets that orbit the sun and whose orbits come within 0.3 astronomical units of Earth's orbit. Geological evidence supports findings that in the past NEOs struck the Earth and caused catastrophic destruction. Increasing awareness of the

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[59] According to its website, the Space Data Association brings together satellite operators who value controlled, reliable, and efficient data-sharing critical to the safety and integrity of the space environment and the radio-frequency spectrum (http://www.space-data.org/sda/).

[60] See AGI's COMSpOC at http://comspoc.com/.

potential threat posed by NEOs has been prompted by a recent NEO collision in Chelyabinsk, Russia, exploding with the energy of approximately 500 kilotonnes of TNT, injuring ~1,200 people, and causing $33 millions of dollar in property damage (Sample 2013, Perna, Barucci, and Fulchignoni 2013). NASA's Near Earth Object Program currently catalogs and assesses potential NEO Earth impact threats.

In 1999, the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space was held in Vienna, Italy. One of the recommendations of the Conference was to improve international coordination of activities related to near-Earth objects. In order to implement that recommendation, in 2001 UN COPUOS established the Action Team on Near-Earth Objects (Action Team 14). The General Assembly approved a multi-year work plan on NEOs, beginning in 2007, that would review progress on international cooperation and collaboration on NEO observations, facilitate, for the purpose of NEO threat detection; provide a more robust international capability for the exchange, processing, archiving, and dissemination of data; draft international procedures for handling the NEO threat; and seek agreement on those procedures. In 2013 Action Team 14 recommended the establishment of both the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG). The first meetings of IAWN and SMPAG took place in 2014.

8. Overarching Trends

This chapter synthesizes insights from both volumes of this report to present a set of overarching trends and extrapolates them forward to explore their future implications.

A. Trends

Trends described in the preceding chapters can be clustered into six distinct though inter-related categories of space-wide trends. They must be read with the caveat that "wildcards" discussed in Volume 2 have the potential to disrupt them.

1. Advances in Technology

The confluence and acceleration of technological developments, many related to information and communications technology and availability of COTS products, are improving the performance of, reducing the size of, lowering the costs of, and enabling a diversity of approaches to space projects.

2. Growing Participation and Expenditures

As a result of the falling cost of entering space and other drivers, more actors—both governments and private sector entities—are investing in, pursuing, and expecting to benefit from space activities. There are eighty countries with activities in space, up from just twenty in 1975. Hundreds of private actors have entered the fray in the same time frame. As the number of actors proliferates, the United States is becoming a declining fraction of international activities and partnerships.

3. Structural Changes in Civil Space

Countries that are developing their space capabilities are not necessarily following the development pathways of the traditional space-faring nations. Furthermore, the development paths taken by new entrants are not homogenous. Some countries are focusing on developing indigenous capabilities, and others prefer to be users of space-based data and leverage collaborations with international government and private sector actors.

Many countries also do not distinguish as sharply between military, commercial, and civilian firewalls as the United States does, making civil and commercial activities more difficult to track. These countries consider civilian-military integration as mutually supportive, and aim for industrial reforms and development in the space sector to maximize the synergies and complementarities between the civilian-commercial and defense segments of the sector. Civilian-military integration is seen to have benefits in at least three dimensions: organizational efficiencies resulting from pursuing the parallel development of civilian-commercial and defense space activities; manufacturing and operational processes applicable to both types of activities, and dual-use articles of hardware (Krolikowski 2015).

4. Diversity of Approaches in the Private Sector

New technologies attract new entrants, and new entrants are bringing new approaches to the sector. Many of the NewSpace companies are bringing attention to cost control rather than performance improvement. The small satellite platform, for example, is being pursued by a range of private companies, and is enabling the conceptualization of disruptive new approaches to satellite development and use. Absorbing the culture of Silicon Valley, many emerging NewSpace companies see themselves as IT companies that offer big data and analytics, with space as one place where they collect data.

5. Growing Space-Based Services Industry

Increasing commercial demand for space-based data as well as applications built on this data, resulting in a growing space-based service industry in new and non-traditional arenas (business intelligence data and mapping applications). Governments are also beginning to consider buying services rather than products. An example of the latter is NASA buying cargo services to the International Space Station, or the NOAA buying observational data, in both cases from private sector firms.

6. Complex Global Governance

The presence of both more actors and more space-based activities is resulting in more congestion in space, making the domestic and global space governance landscape more complex to manage. As with other strategic sectors, such as advanced manufacturing and high performance computing, there is growing tension between globalization and protectionism within the space sector.

Overall, there is an emerging narrative driven by the private sector, which is playing a larger role now than it has in past decades. First, there are increased fiscal pressures that motivate governments to experiment with new procurement tools. (This is being tried largely in the United States, but followed closely elsewhere, especially Europe.) Second, there are now more sophisticated managerial skills within government agencies, especially in top-tier space countries like the United States, Russia, and China, to be able to manage external firms using new contractual vehicles. Third, governments (especially the United States Government) are moving in the direction of obtaining services rather than products. When doing so, the government is using a different procurement philosophy, which specifies what products/services are needed rather than how they are to be provided. A larger fraction of these contracts are fixed-price rather than cost-plus contracts, letting participating firms take a greater share of the technological and market risk and having an incentive to be cost effective.

A critical factor in the narrative is that technology is at a point that some of it (e.g., launch and some activities in LEO) has overcome some of the biggest uncertainty challenges. Private sector firms have matured and are ready to leverage government-developed capabilities. Lastly, the presence of a new breed of entrepreneurial business leaders who are not depending on capital markets for funding and are driven not by traditional short-term business returns on investment, but rather by “intrinsic motivations” to accelerate human presence in outer space (MacDonald 2012).

B. Extrapolating the Trends

This study of the space sector provides a useful lens through which to understand how “strategic” sectors are changing, particularly when the development of advanced technologies is increasingly moving to the private sector, and space technology is accessible and available to any country or company that has the money and motivation. This transformation is reflected in the implications discussed below. Similar to the overarching trends above, they must be read with the understanding that the potential disruptions discussed in Volume 2 could upend any of them.

1. Distribution and Acceleration of Innovation

Technological advances and other external drivers are reducing barriers to entry as an increasing number of actors are bringing a diversity of approaches to space development. As a result of the many non-traditional pathways new entrants are taking, innovation in the space sector is likely to become more widely distributed across the world, especially in the private sector. Because of the larger number of participants, the pace of innovation is also likely to accelerate greatly.

The following example illustrates the trend. Novel space-related patent applications[61]—a proxy for innovation in the space sector—have become nearly four times as common over the past two decades (OECD 2014, 68). As Figure 8-1 shows, while the largest concentration of space-related patents is in regions in the United States (OECD 2014, 68), the relative fraction of U.S. patents is decreasing and that of other regions in China, France, and other countries is increasing. This increase should be expected to continue.

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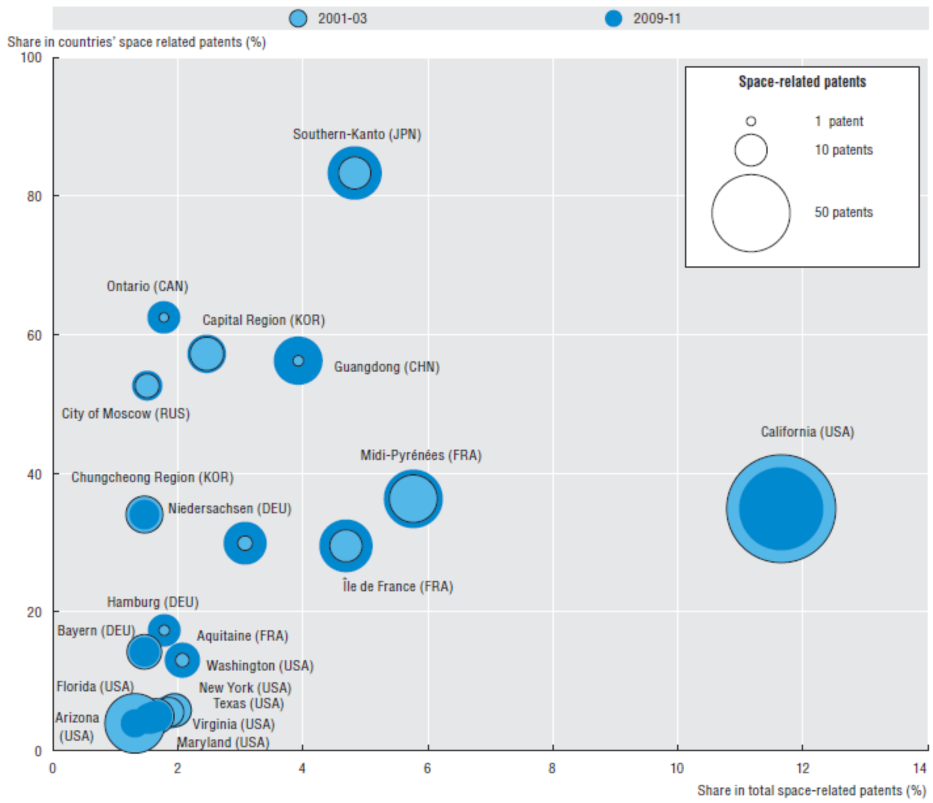
[61] According to OECD, space-related patents are identified using a combination of codes from the International Patent Classification (IPC) and key word searches in the patent title. (i.e., satellite navigation, Earth observation, and telecommunications).



Source: OECD (2014, 71).

Figure 8-1. Comparative Chart of Top 20 Regions in Space-Related Patents, by Year and Location

2. Continued Ascendancy of Consumer/Commercial Interests

The proportion of the private sector in space is expected to continue to grow and the government contribution, to shrink. Figure 8-2 shows that at current rates, the U.S. Government space budget (currently 13 percent of the total $314 billion USD in global space activity), is likely to shrink to only 5 percent of space activity projected for 2024 (forecasted to be $600 billion USD, almost twice as large).[62]

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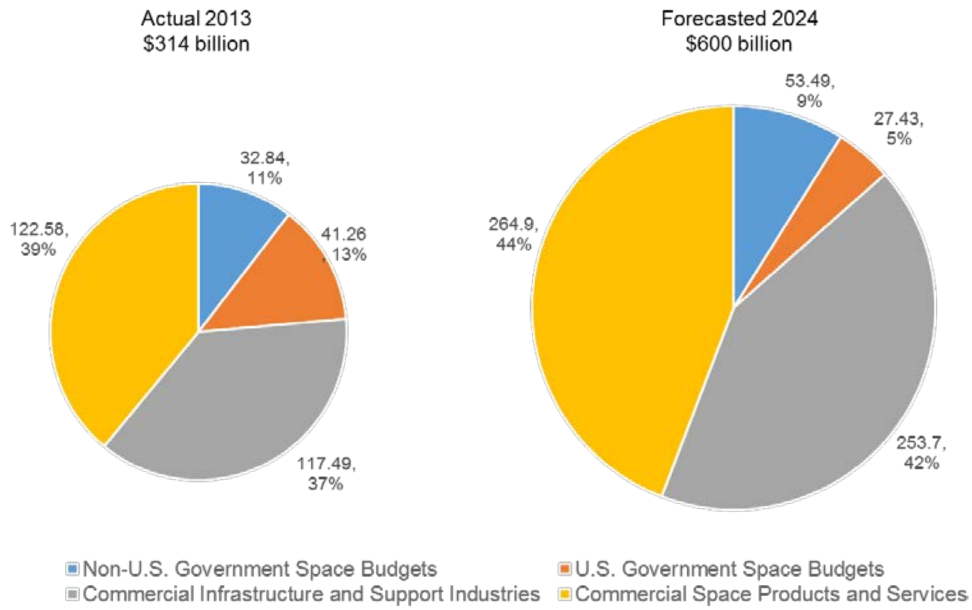
[62] The analysis assumes an annual 4-percent decline for the U.S. Government, an annual 5-percent increase for other governments, and continued annual growth of 8 percent for commercial sectors.

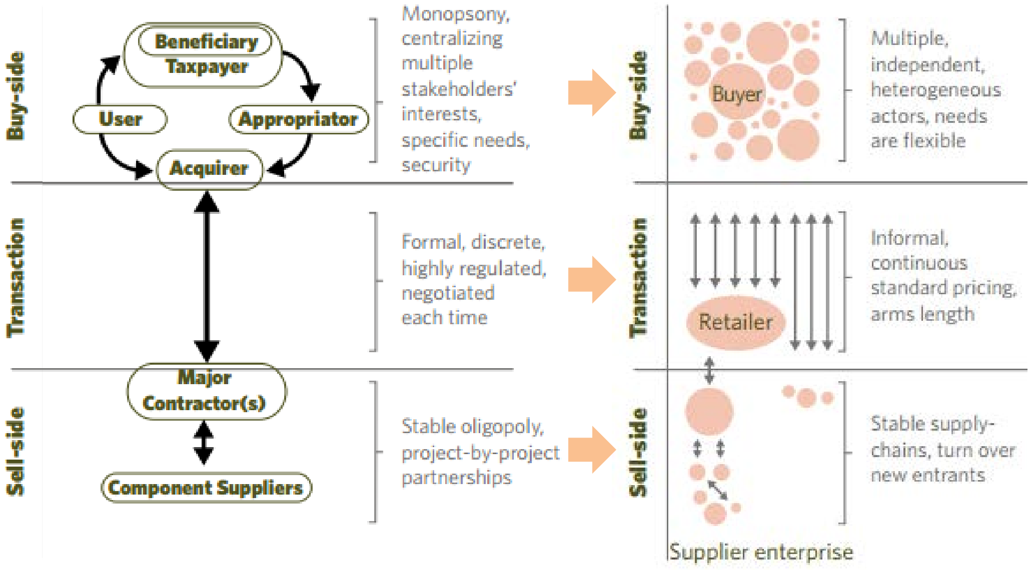


Source: Data adapted from published and unpublished data from the Space Foundation (2014).

Figure 8-2. Contributions to the U.S. Government Space Budget (Current and Forecasted from the Space Foundation)

Several likely structural changes in many of the subsectors of space will lead to mainstreaming (i.e., civilianization, commoditization, or internationalization) of previously protected subsectors. Sectors like Earth observation, for example, currently managed within civilian governments, will likely begin to bifurcate. After a period of rapid changes in the private sector, some higher-end functions relating to the provision of public goods (e.g., weather modeling) will likely remain within the government, but more consumer-driven functions may migrate to the private sector. These markets would then behave as traditional free markets, as has happened in other sectors that have had origins in the government (e.g., computing). See Figure 8-3.

As many of the space-based subsectors start to become more mainstream, there will likely be growing numbers of global enterprises, supply chains, partnerships, and competitions, especially in satellite manufacturing, Earth observation, and space S&T and exploration.



Source: Adapted from Szajnfarber, Richards, and Weigel (2011).

Note: The left side of the diagram depicts the space sector structure as it is currently. The right side depicts a traditional free market, where some subsectors of space may be moving.

Figure 8-3. Migration of Space into Mainstream

3. Difficult to Manage the Space Sector Top-Down

The expanding role of the private sector will have other implications as well. COTS hardware, software, and the satellite manufacturing industries are developing globally. This will make it more difficult for most governments, not just in the United States, to manage the space sector top-down especially in downstream activities (but also some upstream ones such as satellite manufacturing in the Earth observation sector).

4. Difficult to Predict Developments

Given the acceleration of the diversity and pace of innovation, and the resultant structural changes, as well as the diverse approaches taken by the nations themselves to develop their space sectors, it will likely be increasingly difficult to predict where countries' space capabilities are. Common metrics used for assessing the technological capabilities of a country involved in space (such as the size of national space budgets or investment in infrastructure) may lose some meaning.

5. Waning Asymmetric Control for Traditional Leaders

With more countries operating in space, and actively participating in international space organizations such as UNCOPUOS, and with the private sector seeking to take on additional roles, both the domestic and global governance landscapes are becoming more complex. Not only will the United States and other traditional space-faring countries have waning asymmetric control of global decisions related to space activities, there will likely be pressure on them to accommodate the needs of the private sector and emerging space countries.

9. Summary and Conclusion

A. Summary

Space activities, previously the exclusive realm of the United States and the Soviet Union, now include many more actors, both governmental and commercial. This growth is not new—the number of countries involved in space activities has been growing continually since the early 1960s. While there has been commercial activity in space for decades, recent years have seen growth both in the number and variety of space-related technologies and services available for purchase.

This increasing number of purchasable products and services has significantly changed the space sector's landscape. For example, countries are now able to rapidly expand their technological capabilities without achieving the corresponding level of indigenous technological advancement, as space-based data analytics services, workforce training packages, satellite design and operation, and standard CubeSat components are a few of many types of new products and services for sale in the civilian space global marketplace. The amount of time, money, and expertise needed for a company to produce satellites has also decreased, as a result.

The first goal of our study was to understand the factors that are driving recent changes in the space sector changes. We found that the primary driver of these changes is that falling cost of technology has allowed more entities—public and private—to participate in space activities. COTS microelectronics and consumer electronics components are increasingly being integrated into space technology, primarily in small satellites, which have increasingly become more capable. Because many of these technologies are rapidly increasing in performance while decreasing in size, they allow for space technology to advance at a rapid pace. The decreasing cost and increasing availability of COTS technology worldwide is lowering the barriers to entry, allowing not only countries and companies but also nonprofit organizations and citizens to engage in space activities.

The second goal of our study was to identify trends in the space sector. The space sector is highly multifaceted, and trends are specific to a particular subsector or type of participant. Because of this, the report explores trends in government space programs and commercial space, trends in small satellites, and trends in seven different subsectors: Earth observation, communication satellites, space S&T and exploration, launch capability and access to space, PNT, human spaceflight, and space situational awareness.

Across many of these subsectors we found an increasing diversity of approaches in government space programs. Countries that are just beginning their space activities are not following the development pathways of traditional space-faring nations. Some countries are focusing on developing indigenous capabilities, while others prefer to use assets or data developed by others. Because many governments are leveraging partnerships with governments and private sector companies in other countries, they are able to advance their technical capabilities rapidly and without prior investment in advanced manufacturing or R&D or operational infrastructure.

In the private and non-profit sectors, recent years have seen growth in the number of private sector space companies that expect a growing portion of their revenues to come from customers other than governments. They see themselves more as service providers than technology companies. Many of them, especially in the Earth Observation subsector, are benefiting from recent advances in data collection, processing, storage, and analysis that allow for new data products to be produced at lower cost than was previously possible. Not only do the companies themselves but also their investors view them as media or IT companies rather than space companies.

Looking across, we found three major implications of these changes. First, the increased ability for countries and companies to purchase capabilities will likely make it more difficult to assess country capabilities, both from national security and partnership purposes. Second, the increased ability of purchasable technology and services is likely to lead to an increased mainstreaming of activities that were previously undertaken by only few actors. Lastly, traditional spacefaring nations will have less control, both in space and in global governance, and face increasing pressure to accommodate the needs of private companies and new government entrants.

B. Conclusion

In the civil and commercial space sector, there are two concurrent trend narratives underway. The first is the “numbers” narrative, which is based on the absolute amount of spending and activity by different space actors. This narrative shows that the United States will likely be a principal player for a long time to come, though in a less dominant role than in the past. The other is a “vector” narrative, which describes how the space landscape is changing. This narrative speaks to the potential disruptive changes that are driven by the growing presence and influence of a larger number of countries. The vector narrative is also driven by the private sector, which though currently U.S.-led, sees the world as its market. A major implication of this vector is that 10 to 20 years from now, the landscape of space is going to look different.

It is important to note that the steepness of the vector of space sector growth may be due, in part, to hype.[63] The history of space exploration is littered with failed projects (reusability, space-based telephony, among others), and some of the projects proposed today may similarly fail.[64] The current "gold rush" in the satellite broadband/telephony sector draws parallels with the Internet bubble of the 1990s, which saw more companies fail than succeed.

Optimistic projections notwithstanding, this report provides some evidence that the space sector is undergoing a transformation, as it expands beyond the confines of the militaries and governments of the few countries fielding space technology. This transformation is caused by worldwide governments acting on their space aspirations (by participating in space activities in different ways) and by the private sector producing more space-based products and services.

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[63] Some of this "irrational exuberance" comes from assuming that all development will follow Moore's Law. While digital COTS technologies reliably follow exponential laws governing miniaturization, non-digital technologies (power and energy systems and optical payload) are improving at far lower linear rates.

[64] For example, Google's satellites could cost up to $20 billion USD rather than $1 billion (Dorrier 2014).