

Chapter 1

The space sector in 2014 and beyond

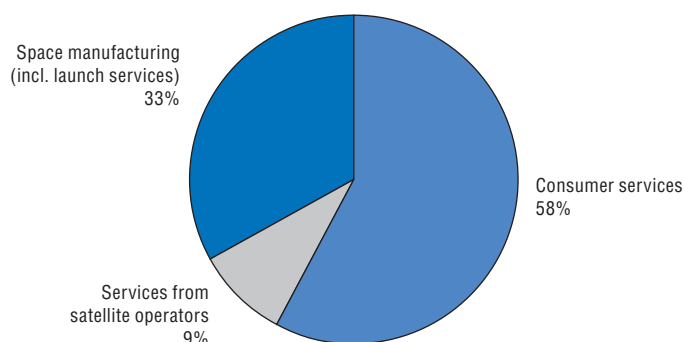
Chapter 1 reviews major trends in the space sector. It first provides a review of the “space economy” in 2014. It then focuses on an original analysis of global value chains in the space sector, including a spotlight on fifty years of European space co-operation. The chapter also looks at new dynamics in the sector, which may impact incumbents and new entrants, with a focus on innovation in industrial processes and the development of small satellites.


Defining the “space economy” in 2014

Straddling the defence and aerospace industries, the space sector has for decades been a relatively discrete sector, developed to serve strategic objectives in many OECD and non-OECD economies, with security applications, science and space exploration. The space sector, like many other high-tech sensitive domains, is now attracting much more attention around the world, as governments and private investors seek new sources of economic growth and innovation. The “space economy” has become an intriguing domain to examine, bringing interesting innovation capacities as well as new commercial opportunities.

Over the past decade, the number of public and private actors involved in space activities worldwide has increased, spurring even further the development of the nascent space economy. Despite strong headwinds in many related sectors (e.g. defence), the space sector overall has not been significantly affected by the world economic crisis. It remains a strategic sector for many countries, relatively sheltered because of national imperatives (e.g. rising security concerns in many parts of the world feeding the needs for more satellite surveillance), its long lead time to procure, build and launch satellites (i.e. current activities are a reflection of projects planned a number of years ago), but also because of an ever stronger demand in its main commercial branches, particularly satellite telecommunications. When examining other sectors, the highest proportion of internal value creation for firms is often found in certain upstream activities (new concept development, R&D or the manufacturing of key parts and components), as well as in certain downstream activities, such as marketing, branding or customer service. Such activities involve “tacit, non-codified knowledge in areas such as original design, the creation and management of cutting-edge technology and complex systems, as well as management or organisational know-how” (OECD, 2014). This is also true for space products and services chains overall.

Figure 1.1. Main segments of the space economy
Revenues from commercial actors, USD 256.2 billion globally in 2013



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The global space economy, as defined by the OECD Space Forum, comprises the space industry's core activities in space manufacturing and in satellite operations, plus other consumer activities that have been derived over the years from governmental research and development. In 2013 commercial revenues generated by the space economy amounted to some USD 256.2 billion globally (i.e. including actors in Europe, North America, South America, Asia, the Middle East). The breakdown was as follows:

- The space manufacturing supply chain (described in details below, from primes to Tiers four, from assembly of complete spacecraft systems to components) represents conservatively some USD 85 billion globally. This number is probably relatively underestimated since there are institutional programmes in many countries that are the sources of unreported contracts to national space industries (e.g. defence activities). This important segment is often characterised by largely captive markets, since much of the demand for institutional satellites, launchers and ground segment is often directed at national industries. However, as we will see in the next section, more actors than ever before are involved in supplying space products.
- As a second segment, services from satellite operators -which own and operate satellites- are included for some USD 21.6 billion (i.e. revenues from the satellite telecommunications operators: fixed and mobile satellite services, satellite radio services, and commercial remote sensing operators). These are important actors, as they have to service governmental and commercial customers outside the space sector (e.g. providing bandwidth, imagery), so they tend to push space manufacturing suppliers for more innovation to respond to market needs at lower cost (e.g. development of broadband via satellite).
- Finally, the consumer services include actors, usually outside the space community, which rely on some satellite capacity for part of their revenues. These downstream activities are an integral part of the space economy, although their share is the most difficult to assess, as valuable satellite signals or data need to be tracked in equipment and services. They include direct-to-home satellite television services providers, satnav consumer equipment and value-added services, and very-small apertures terminals providers (e.g. data handling, banking), with revenues estimated at some USD 149.6 billion.

All measurements are of course beset with definitional and methodological issues, and so estimates may vary. For example, using a slightly different scope and more limited national data, the space economy was valued in 2011 at USD 150-165 billion (OECD, 2011). By way of comparison, the institutional budgets for space activities amounted to some USD 64.3 billion (current) for 40 economies in 2013. In all countries, the role of governments remains essential as a source of initial funding for public R&D, as well as a major anchor customer for many space products and services. When national space budgets are converted using purchase power parities to allow better international comparisons, the United States, China, India and the Russian Federation are among the top-four investors on space in 2013. The United States has the highest space budget per capita, representing some USD 123 PPP per habitant, followed by the Russian Federation, France, Luxembourg, Japan, Belgium, Germany and Norway (see 3. *Institutional space budgets* for more data).

Table 1.1. **Space budgets in PPP and per capita for selected countries**

	Space budget in USD millions (PPP), 2013	Budget per capita
USA	39 332.2	123.2
CHN	10 774.6	7.9
RUS	8 691.6	61.0
IND	4 267.7	3.3
JPN	3 421.8	26.9
FRA	2 430.8	38.0
DEU	1 626.6	20.1
ITA	1 223.3	20.7
KOR	411.5	8.2
CAN	395.9	11.5
GBR	338.9	5.3
ESP	302.9	6.7
BRA	259.2	1.3
BEL	244.8	21.9
IDN	142.0	0.6
CHE	133.0	16.6
SWE	122.0	12.7
NDL	110.5	6.6
TUR	104.3	1.4
NOR	89.6	18.5
ISR	89.3	11.1
POL	80.7	2.1
ZAF	76.4	1.5
AUT	73.0	8.6
FIN	53.9	9.9
DNK	38.2	6.9
PRT	32.2	3.0
GRC	30.3	2.7
CZE	25.4	2.5
IRL	25.3	5.6
AUS	24.9	1.1
LUX	17.0	34.5
HUN	8.9	0.9
MEX	8.5	0.1
EST	5.4	4.0
SVK	4.8	0.9
SVN	2.9	1.4

Source: OECD calculations based on national data and OECD MEI data.

When examining the many actors involved in space products and services, the respective roles of public sector agencies, universities and industry can be more or less pronounced in the research and development phases, and in the actual production of space systems. The companies that form the core of the supply chains for the space industry in OECD economies range from major multinationals, to small and medium size enterprises (SMEs) in Europe, North and South America and Asia. Elsewhere, the model can be slightly different. In India for instance, the Indian Space Research Organisation (ISRO) centres dominate the supply chain. According to their respective speciality, these are manufacturers and assemblers of space systems, with the Indian industry providing only selected equipment and components. Zooming in a typical space manufacturing supply chain, it is divided in “Tiers” like the automobile or the aeronautic sectors, where many players are often involved in several segments at the same time. The US Department of Commerce found for example, via a large industrial survey conducted on the space sector’s industrial base, that some 71% of respondents were serving more than one market segment (i.e. aircraft, electronics, energy, missiles, ground vehicles, ships...) (DoC, 2014).

The main segments of what can be called the space manufacturing supply chain (selected companies are cited for illustration purposes, many have subsidiaries around the world) look like this:

- “Primes” are responsible for the design and assembly of complete spacecraft systems, which are delivered to the governmental or commercial users (e.g. telecommunications, earth observation satellites, launchers, human-rated capsules). Selected companies include Airbus Space and Defence (FRA, DEU), Thales Alenia Space (FRA, ITA), Orbitale Hochttechnologie Bremen (OHB System) (DEU), MacDonald, Dettwiler and Associates (MDA) (CAN), Lockheed Martin (USA), Boeing (USA), Space Systems/Loral (USA), Orbital Sciences Corporation (USA); Northrop Grumman Space Technology (USA), Mitsubishi Heavy Industries (JPN), Alenia Spazio (ITA), Surrey Satellite Technology Ltd (GBR), China Aerospace Science and Technology Corporation (CASC) (CHN), Krunichev State Research and Production Space Center (RUS), Israel Aircraft Industry (ISR)...
- “Tier 1” actors intervene in the design, assembly and manufacture of major sub-systems (e.g. satellite structures, propulsion subsystems, payloads). The division between primes and Tier 1 actors is sometimes blurred, as some subsystem manufacturers have been taken over as subsidiaries by multinationals in North America and Europe over the past five years. Yet more vertical consolidation is expected over the next two years. Selected Tier 1 actors include therefore most of the primes indicated above, which may even provide sub-systems to their competitors in some cases, and other firms with specific expertise (in terms of propulsion, structures...): Snecma (FRA), OKB Fakel (RUS), L-3 ETI (USA), Aerojet Rocketdyne (USA), Com Dev (CAN), UTC Aerospace Systems (USA), Teledyne Brown Engineering (USA), Ruag (CHE)...
- “Tier 2” actors are manufacturers of equipment to be assembled in major sub-systems. Again, some companies may be involved in both equipment and subsystems design and manufacturing. As the equipment costs, overall reliability and timely-availability are to a significant extent driven by their components, these companies can play a middle-man role for others, as “Central Parts Procurement Agent” with components’ suppliers in the lower tiers. Many space agencies and companies do not deal with the lower tiers’ component suppliers directly, and have lists of approved agents (e.g. ESA approved agents include the Alter Technology Group (Hirex Engineering, FRA; Tecnologica and TopRel, ESP), and Airbus’ Tesat-Spacecom, DEU). Selected equipment manufacturers include: Sodern (FRA), APCO Technologies (CHE), Bradford Engineering B.V (NDL), Selex ES (ITA), Airbus’ Space Engineering (ITA), Aeroflex (USA), Raytheon (USA), Kongsberg Gruppen (NOR)...
- “Tier 3 and 4” actors include producers of components and sub-assemblies, which tend to specialise in the production of particular electronic, electrical and electromechanical (EEE) components and materials (e.g. cables, electrical switches). They tend to be either small specialised firms or large electronics groups with only a minor activity linked to space programmes. This “tiers” also includes providers of scientific and engineering services, acting as contractors to space agencies and the space industry. They include specialised or generalist engineering firms, as well as universities and research institutes. Examples are Composite Optics (USA), M/A-COM (USA), Thales Electron Devices (FRA)...

In terms of customers, the space manufacturing supply chain addresses government and commercial satellite operators' demand for spacecraft, launchers and satellites. Depending on the country, the institutional demand may be much more important in terms of revenue generation, as compared to the commercial demand. Typically, space manufacturing activities are more developed where strong institutional customers are established (e.g. United States, China, Russian Federation). The satellite and launchers manufacturers' other customers (i.e. the commercial operators, providing commercial satellite telecommunications services or earth observation and geospatial data to third parties) play a key role in enhancing competition and innovation in the space industry. There are more than 50 satellite telecommunications operators established around the world, e.g. Eutelsat (FRA), Intelsat (USA/NDL), Inmarsat (UK), Telenor (NOR)... For earth observation, smaller satellite operators are generally involved, although some of them have been taken over recently by larger groups. Selected operators with satellite constellations include: BlackBridge's Rapid Eye (DEU), Airbus's Spot Image (FRA), DMC International Imaging Ltd (UK), DigitalGlobe (USA), ImageSat (ISR)...

At the final end of the space industry supply chain, "downstream" actors are the companies providing commercial space-related services and products to the final consumers. They are generally companies that are not connected to the traditional space industry, and are only using space signals and/or data in their own products. Typically, their services concern communications, satellite television (e.g. BskyB, Dish and DirectTV), geospatial products and location based services (e.g. Trimble, Garmin). Often only a small part of their revenues and employment are derived directly from their space-related activity. They are included in the "space economy" as far as a share of their activity directly depends on the provision of satellite signals or data.

The manufacturing supply chain is discussed in more detail in the next sections, particularly its internationalisation, as new actors are positioning themselves in specific sub-segments. The table below provides an overview of selected products and services in the broader space economy.

Major challenges lie ahead both for the incumbents and for the new entrants into the space economy. In a globalised world, few sectors are sheltered from competition as the rapidly evolving global value chains in the space sector demonstrate. In addition a new industrial revolution is looming on the horizon which holds out the prospect of deep-seated change in the traditional space industry. Some of these major disruptive innovations will also be presented.

Table 1.2. **Overview of the supply chain in the broader space economy**

Positioning	Actors	Selected products and services
Tiers Three and Four	Scientific and engineering consulting	<ul style="list-style-type: none"> ● Research and development services. ● Engineering services (design, testing...)
	Material and components suppliers	<ul style="list-style-type: none"> ● Materials and components for both space and ground systems: passive parts (around 70% of components in space sub-systems: cables, connectors, relays, capacitors, transformers, RF devices...) and active parts (e.g. diodes, transistors, power converters, semiconductors).
Tiers One and Two	Designer and manufacturer of space equipment and subsystems	<ul style="list-style-type: none"> ● Electronic equipment and software for space and ground systems. ● Spacecraft/satellite platform structure and data handling subsystem (e.g. on-board computer, interface unit, satellite and launcher electronics). ● Guidance, navigation and control subsystems, and actuators (e.g. gyroscopes, sun and star sensors rendezvous- and docking sensor). ● Power subsystems (e.g. electrical propulsion, power processing unit, solar array systems, photo voltaic assembly). ● Communications subsystems (e.g. receivers and converters, fibre optic gyro, solid state power amplifier, microwave power module, downlink subsystem, transponders, quartz reference oscillators, antenna pointing mechanism). ● Propulsion subsystems (e.g. mono- and bi-propellant systems, apogee engines, thrusters, tanks, valves, electric propulsion systems). ● Other satellite payload's specific subsystems: positioning, navigation timing systems, reconnaissance, surveillance, and target acquisition; weather and environmental monitoring instruments; scientific/R&D demonstrator and human-rated systems (e.g. payload data handling electronics, navigation clock electronics, cryo cooler, scanning mechanism).
Primes	Space systems Integrators/ full systems supplier	<ul style="list-style-type: none"> ● Complete satellites/orbital systems. ● Launch vehicles (and launch services provision in some cases). ● Control centres and ground stations.
Operators	Space systems operators	<ul style="list-style-type: none"> ● Launch services provision. ● Satellite operations, including lease or sale of satellite capacity (telecom: commercial FSS and MSS operators; earth observation operators).
	Ground system operators	<ul style="list-style-type: none"> ● Provision of control centres services to third parties.
Downstream	Devices and equipment supporting the consumer markets	<ul style="list-style-type: none"> ● Chipset manufacturers. ● Satnav and telecom equipment and connectivity devices vendors.
	Space-related services and products for consumers	<ul style="list-style-type: none"> ● Direct-to-home providers. ● Very Small Aperture Terminal (VSAT) network providers. ● Location-based signals services providers.

Global value chains in the space sector

In the 1980s, building and launching a satellite was the remit of relatively few developed countries with massive industrial complex, co-operating and competing with each other. Since then, globalisation has been impacting all sectors of the economy, including largely protected high-technology sectors, like the space sector. This section builds on OECD work on global value chains to examine key trends in the space sector, making particular use of case studies. As the supply chains for space systems evolve, new opportunities open up for all actors involved, public and private, as well as new inherent risks for incumbents and new entrants. This section provides several angles to review these globalisation aspects, notably the advances in international joint institutional space programmes and the evolutions of the international production networks for space programmes.

More international joint institutional space programmes

Joint space exploration and scientific missions have been an important source of international co-operation over the past decades, contributing to increased linkages between national space agencies and industries around the world.

Box 1.1. The concept of global value chains and the space sector

World trade, investment and production are increasingly organised around global value chains (GVCs), also called international production networks. A value chain is the full range of activities that organisations engage in to bring a product to the market, from conception to final use. Such activities range from design, production, marketing, logistics and distribution to support to the final customer. At each step – design, production, marketing and distribution – value is added in some form or other. Driven by offshoring and mounting interconnectedness, those activities have become increasingly fragmented across the globe and between organisations. Many sectors now include complex supply chains with many organisations involved in different countries.

The fragmentation of production and services across countries is not new. What is new is its increasing scale and scope for many sectors of the economy. As demonstrated by work conducted at OECD, global value chains are deepening the process of globalisation along three different lines: geographically (by including a larger number of countries, including emerging economies), sectorally (by affecting manufacturing but also increasingly services industries), and functionally (by including not only production and distribution but also R&D and innovation). Integrating a regional value chain is often a first step for many organisations.

As a result of these trends, a country's position in international production networks is becoming increasingly important for its competitiveness and overall economic performance. Each stage in the international production networks carries, to varying degrees, opportunities for new local activities, jobs and profits, as well as the associated new skills, technologies and public revenues in the form of taxes. Successful integration into a value chain potentially allows a country to seize a bigger share of those benefits, whilst putting more pressure on the incumbents.

To provide an accurate picture of a country's position in value chains, its trade with the rest of the world needs to be measured in value added whenever possible, rather than in gross terms (i.e. OECD work on Trade in Value Added or TiVA). But detailed trade statistics are not available for all economic sectors. As a first step, case study-based evidence can be sought, as for the space industry in this publication.

Source: To learn more about GVCs: OECD (2013), *Interconnected Economies: Benefiting from Global Value Chains*, OECD Publishing, <http://dx.doi.org/10.1787/9789264189560-en>

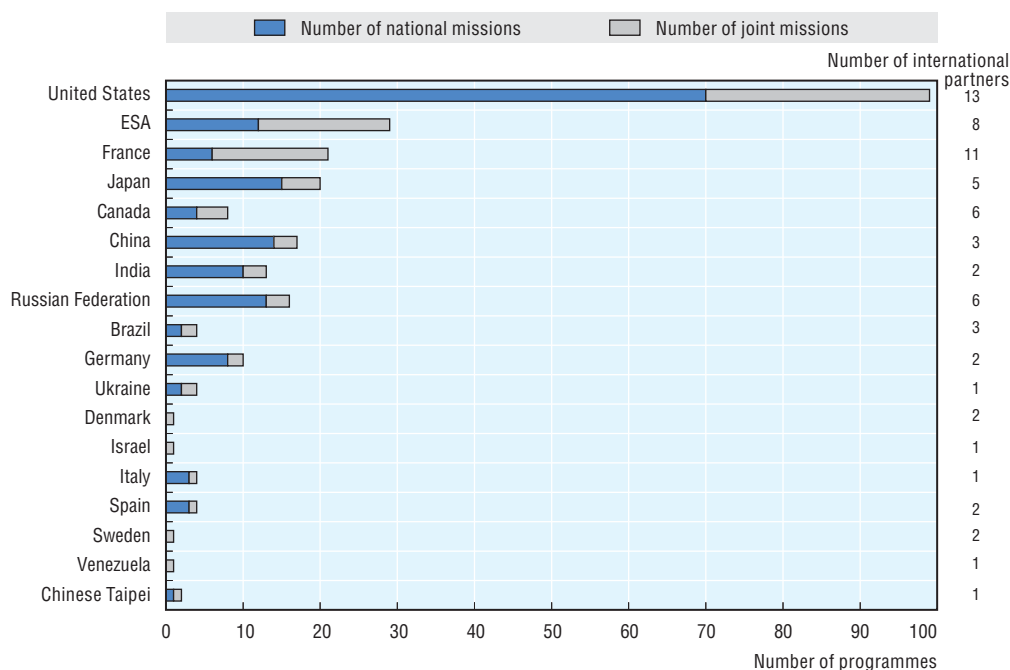
During the cold war, major scientific and engineering breakthroughs took place in different parts of the world, often in isolation, as military research and development and industrial secrecy forced economies to preserve their own technological advances. As international conferences of scientists have prospered since 1991, allowing researchers to collaborate on and disseminate scientific advances, knowledge flows and dual-use technological transfers have also increased from OECD countries and the Russian Federation to other parts of the world (see 16. *Scientific production in the space sector*). This has sometimes caused tensions concerning the illegal transfer of sensitive technologies (i.e. space launchers are based on missile technologies), and a tightening of technology export controls. One of the first emblematic joint space missions took place in 1975, when an American Apollo spacecraft, carrying a crew of three, docked in orbit for the first time with a Russian Soyuz spacecraft with its crew of two. In addition to the political significance of the event, it was a major engineering accomplishment as at the time both the US and the Russian industrial chains relied entirely on domestic hardware and national standards. Bilateral working groups were set up for the first time to develop compatible rendezvous and docking systems in orbit, which are still in use today.

Joint institutional space programmes still provide an excellent way to develop and use national expertise and scientific capabilities, while sharing financial burdens in common large-scale projects that would have been impossible to launch individually. The International Space Station (ISS) is a case in point, as it relies on barter agreements between all the different partners, with no direct exchange of funds. For example, as part of the NASA-ESA ISS agreement, the current Orion deep-space capsule manufactured by Lockheed Martin Space Systems for NASA should include a European propulsion service module, based on the European Space Agency's Automated Transfer Vehicle, an unmanned capsule which was used to carry cargo to the ISS. This module, built by Airbus and paid by ESA, could fly for Orion tests in 2017.

Another example of joint institutional space programmes concerns environmental satellite missions in low-earth orbit. Around 160 environmental satellite missions in low-earth orbit are currently measuring selected climate parameters, and around 30% of these are bilateral or multilateral missions, with different countries providing key instruments on-board satellites (Figure 1.2). The United States, the European Space Agency and France have established the most joint operations for environmental satellite missions (e.g. NASA is co-operating with Japan's Aerospace Exploration Agency on the Tropical Rainfall Measuring Mission (TRMM); ESA and NASA cooperate on the Solar and Heliospheric Observatory (SOHO), while the French CNES is co-operating with India on the Megha-Tropiques mission to study the water cycle) (see 10. *Satellite weather and climate monitoring*).

Figure 1.2. **Environmental satellite missions in low-earth orbit**

Number of national and joint missions, 2013

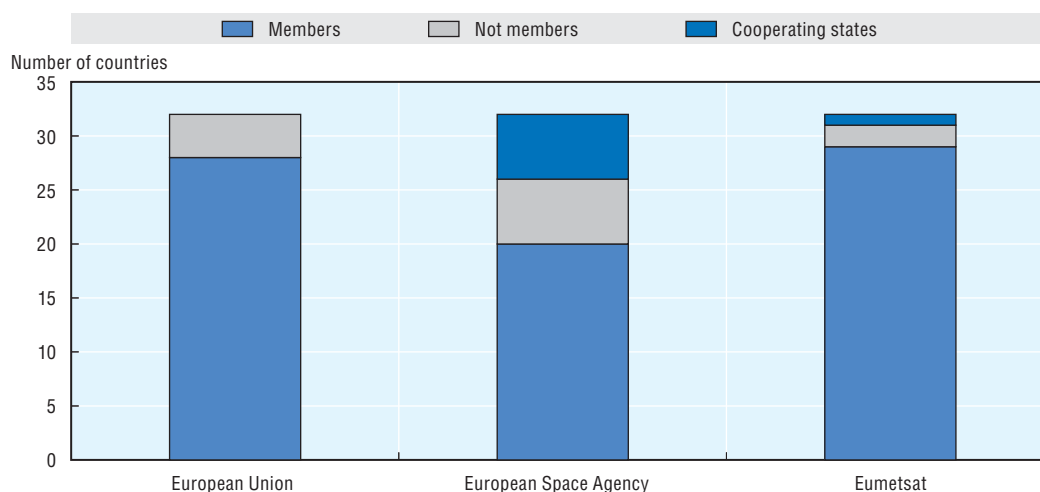


Note: Only economies (ESA is an intergovernmental organisation) with joint missions are included. Eumetsat also contributes to selected joint missions with ESA, France and the United States (e.g. Jason missions).

Source: Adapted from WMO, Oscar database, 2014.


Globalisation in the space sector can be particularly illustrated by zooming in on the European regional level. A number of European countries have been involved in space activities since the beginning of the space age with their national programmes, and have decided to join capabilities and funding for specific programmes. When looking at Europe as a whole, there are different European intergovernmental organisations that have responsibilities in European space programmes. There are currently some overlaps in terms of memberships, but also some noticeable differences (Figure 1.2). In recent years, an increasing number of European countries have shown an interest in investing in space programmes. For relative newcomers, this often means adhering to or co-operating with the European Space Agency, joining the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and/or supporting the Copernicus and Galileo programmes of the European Union. For these countries, the yearly contingent or programme payments account for the bulk of their space R&D budgets and industry support.

Figure 1.3. **Membership in European intergovernmental organisations**



Note: Eumetsat is an intergovernmental organisation supplying weather and climate-related satellite data, images and products to the National Meteorological Services of its Member and Cooperating States in Europe, and other users worldwide. Countries included in this graph: Austria, Belgium, Bulgaria, Croatia, Cyprus^{1, 2}, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom, Netherlands, Poland, Portugal, Romania, Spain, Sweden, United Kingdom, Norway, and Switzerland. Canada has a co-operation agreement with ESA.

1. Note by Turkey: The information in this document with reference to “Cyprus” relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the “Cyprus issue”.
2. Note by all the European Union Member States of the OECD and the European Union: The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

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There are several major ongoing European space programmes, most of them coordinated by the European Space Agency and two under supervision of the European Union, with technical support from ESA.

- The European Space Agency has some 17 scientific satellites in operation as of spring 2014. It has also designed, tested and operated in flight over 70 satellites, and has developed six types of launchers with its member states and their industry.

- The European Union is managing two programmes, with support from ESA: the Copernicus earth observation programme, which aims to provide “access to full, open and free-of-charge information in the areas of land, marine, atmosphere, climate change, emergency management and security”, with five Sentinel satellite missions (Sentinel-1 successfully launched in April 2014); and the Galileo satellite navigation programme (European Union Parliament, 2013).

In terms of budget, the ESA's annual budget is around EUR 4 billion per year, funded by its Member States. The European Union, also funded by its Member States, has dedicated around EUR 6.3 billion to the Galileo satellite navigation programme and EUR 4.3 billion to the Copernicus earth observation programme (2014-20). In addition, the 7-year European research and development programmes (Framework Programmes) have had in recent years a dedicated budget line for space. The Framework programmes FP6 received EUR 0.24 billion for space R&D (2000-06), for FP7 it increased to EUR 1.43 billion (2007-13) and in the Horizon 2020 programme (2014-20) it will reach EUR 1.73 billion. The key objective of the Horizon 2020 programme on space research and innovation is “to foster a competitive and innovative space industry and research community to develop and exploit space infrastructures to meet future Union policy and societal needs”. It comes in complement to the space research activities of its European Member States and the European Space Agency. Although overall funding for space seems to be on the increase, some industrial actors worry that European R&D funding may be too disparate, making it increasingly difficult to establish clear returns on investments.

In that context, aside from exports outside the continent, the European space industry has in essence three types of government customers: national European governments, the European Space Agency, and the European Commission. Procurement rules differ though, with the European Commission promoting competitive bidding procurements, and ESA using geographic return rules as a compulsory system to ensure that member governments' investment automatically returns to their national territories in the form of contracts. These policies have had the effect of creating more suppliers throughout Europe, thus increasing the benefits of investing in space programmes by developing national -if limited- space industries (in terms of qualified jobs, industrial and scientific capacities). For example, ESA's funded SmallGEO programme aims to create in collaboration with industry a new general-purpose small geostationary satellite platform. SmallGEO is being developed by an industrial team managed by the German OHB System AG, which includes its subsidiaries LuxSpace (Luxembourg) and OHB Sweden (formerly Swedish Space Corporation), as well as RUAG Space (Switzerland). In total, twelve countries are involved, eight with one industrial contractor in the supply chain, three with two contractors, and Germany with six contractors, as it provides the most funding to this ESA programme. Contracting out foreign suppliers is a mechanism that contributes to information and know-how transfers throughout Europe, as well as providing activities to a large number of suppliers.

Evolutions in international production networks for space programmes

As countries cooperate and compete more in space activities, space industries and operators located on their territory are also being impacted by globalisation trends. The international supply chains for the automotive and electronics sectors have become more complex, and the defence and aerospace sectors – home to many space manufacturers – have only followed the same patterns, although a bit differently when comparing countries. The ownership structures of some groups and mergers are contributing to ambitious international expansion strategies on regional and global scales, and the

multiplication of suppliers is making the production lines more complex, as illustrated by case studies on commercial satellites and launchers.

The impacts of ownership structure of space-related companies: Even if governments retain an omnipresent role in space affairs, as funders of major institutional R&D programmes and as customers, the private industry supply chains are getting more complex, influenced by the multinational nature of major space companies. The late 1990s saw a wave of major aerospace and defence company mergers in North America, Europe, Japan, mainly intended to deal with the industry's post-Cold War overcapacity. Large groups active in the space sector are now mostly held by international private shareholders, although governmental bodies still hold a few shares for strategic reasons in selected firms. As in any other economic sector, this influences corporate expansion strategies, since these groups aim for improved shareholder returns, examining new funding and commercial opportunities that are becoming available in different parts of the world. As an example, Airbus Defence and Space (formerly Astrium), which is part of the larger Airbus Group N.V. based in the Netherlands, has a complex structure of national “space primes”, systems- and sub-systems manufacturers, in-house equipment departments and subsidiaries in seven European countries and the United States (one subsidiary in Houston). Following initial mergers, the establishment of new companies and the acquisition of smaller firms, the group has a presence throughout Europe, allowing it to bid in countries that invest heavily in the space sector: France (six companies including one in Kourou, French Guyana), Germany (five), Spain (two), the United Kingdom (three), the Netherlands (one), and since 2010 Poland (one) and the Czech Republic (one). Another European group, Thales Alenia Space, is following the same strategy: it announced in April 2014 an expansion of its presence in Europe with the creation of a new British subsidiary. This has been spurred by the United Kingdom government’s commitment to fund space activities and create new initiatives to foster growth in the space industry. The third main European satellite manufacturer OHB has six main business units dealing with space activities, two in Germany (Bremen and Munich) and others located in Belgium, Italy, Luxembourg, and Sweden.

Linked to ownership issues, mergers are also continuing in the space sector, with established actors creating larger groups aiming to increase the vertical integration of their production lines. In the past two years, many mergers occurred and more are announced for 2014-15. Canada’s MDA Corporation acquired the US commercial satellite builder Space Systems/Loral in 2013. In propulsion, GenCorp’s Aerojet and Pratt & Whitney’s Rocketdyne were merged also in 2013 forming a new group called Aerojet Rocketdyne. The US satellite and rocket builder, Orbital Sciences Corporation, may merge with the rocket engine manufacturer ATK. In the Russian Federation, the 49 organisations and companies involved in space activities were merged in February 2014 within a centralised public holding, the United Rocket and Space Corporation (ORSC). The objective is to streamline the Russian supply chains, to enhance economies of scale and quality control, following several launch failures. But even at lower tiers, equipment manufacturers need to address their customers’ requirement that they provide full systems, such as complete antenna systems (including antenna, gimbals, waveguide, cables, etc.). This necessitates developing strategic alliances with other vendors, which are often located in different countries. This complex and lengthening supply chain for space products is often not well traced by primes and governmental customers alike.

For industry, internationalisation can be both an opportunity (e.g. cheaper labour in production processes, access to technologies and/or better components from foreign countries), as well as a source of inherent risks (e.g. longer supply chains, susceptible to

Box 1.2. Mexico entering global value chains in the space sector

Recent Mexican developments are good illustrations of how an economy can enter global value chains. The national Mexican space agency (Agencia Espacial Mexicana, AEM), was established in 2010, after its creation was adopted unanimously in November 2008 by the Mexican Senate. One of the agency's main objectives is to co-ordinate and build on different existing Mexican efforts, particularly in terms of international scientific and satellite remote sensing co-operation. The development of small satellites to help train engineers and for future institutional missions is also underway. Concerning evolutions in the commercial space sector, Mexico has concentrated since the 1990s, on developing commercial communications services, via a domestic satellite telecommunications system with some 120 earth stations. Mexican satellites are operated by Satélites Mexicanos (Satmex), a private company created in 1997, which provides broadcast, telephone and telecommunication services to some 40 countries in the Americas, with an 11% market share in Latin America. In July 2013, the European operator Eutelsat acquired the Mexican company, valued at a little more than USD 1 billion. Today, the Mexican space sector may follow the approach of key stakeholders in aeronautics. The Mexican aerospace industry increased intensely its development in the early 2000s, attracting major multinational companies. From about 65 manufacturing plants in 2004, the industry reached 150 in 2007 and 240 in 2010. Major Original Equipment Manufacturers (OEMs), such as Boeing, Airbus and Rolls-Royce, have developed joint ventures to develop their supply base in Mexico. Other actors such as Cessna, Bell, Hawker Beechcraft, MD Helicopters, Eurocopter and Triumph have also recently located subsidiaries in Mexico, to move closer production to the North American market. The annual foreign direct investments have grown from about USD 250 million in 2004 to over USD 1 billion in 2011. Aside from the United States, Mexico had the highest level of foreign investment of the aerospace sector that year.

regulatory complications). Two case studies are provided below with satellite and rocket manufacturing illustrations. The information is based on two workshops conducted in 2013 and 2014 by the OECD Space Forum with industry participants and governmental stakeholders (space agencies, ministries, governmental departments) involved in space programmes, as well as on consultation with actors in the space community.

Where is my satellite coming from? More than a hundred satellites were launched in 2013, mostly for institutional missions. Some 29% of these satellites were launched for commercial telecommunications, representing around USD 2 billion in revenues for manufacturers (FAA, 2014). The open market for satellites remains therefore quite small, and the dominant position of just a few companies in space manufacturing markets has been weakening.

In a 2012-13 survey of the US space industrial base, 78% of the US organisations surveyed considered they were not the sole manufacturer or distributor of a given space product, based on the total number of product areas identified. Respondents identified critical suppliers from 56 countries (DoC, 2014). The most prominent non-U.S. suppliers were located in Japan, Germany, Canada, France, and the United Kingdom, providing materials, structures, mechanical systems, electronic equipment, and communications systems. Russian hardware is also often procured by US manufacturers, particularly propulsion systems integrated on US rockets and satellites.

So when private operators buy large telecommunications satellites today, they have a much larger choice in terms of manufacturers internationally, with their main criteria

being costs, time-to-market and reliability; rarely do they need to care about the provenance of the satellite and its parts, except if it affects relations with their customers. As of end-2013, American satellite builders have built around 60 commercial telecommunications satellites in the past five years, while European manufacturers have sold around 50. And in that context, although the bulk of commercial satellites are still produced in North America and Europe, more actors from emerging economies are entering the already competitive market as commercial satellite manufacturers, i.e. the Russian Federation, China and India. They accounted in the 2000-10 timeframe for only 13% of the insured telecommunications satellites launched into geostationary orbit. In 2013, the Russian and Asian builders' share of the market rose to 27%, demonstrating in only three years an inclination of private satellite operators to now go to manufacturers they would not have gone to previously.

When examining a standard commercial telecommunications satellite built in the United States or Europe for geostationary orbits (16-20 commercial satellites launched per year), the main subsystems and equipment are all manufactured in different locations before being assembled by the space manufacturing prime. And these subsystems and equipment include themselves components produced in the United States, Europe and increasingly Japan. Although this provides only rough orders of magnitude, according to different industry sources: around 95% of a standard Loral telecom satellite is built in the United States; around 75% of a Thales Alenia Space's telecom satellite is built in France (with some sub-systems coming from its subsidiary in Italy); and around 25% of an Airbus standard telecom satellite is built in France, with most of the other equipment manufactured in European subsidiaries (Germany, Spain).

Deconstructing these commercial satellites further, their subsystems often consist of a large share of US components, still not manufactured elsewhere (e.g. selected oscillators, radio-frequency passive devices, some fuses). Originally many of these components were based on heavy-duty military standards (MIL) developed by US manufacturers, which are still used extensively in the space sector. The global market for space qualified components is difficult to estimate, although there is an important competition in some segments between American and European components manufacturers, particularly on capacitors and resistors. Other actors are getting involved and exporting components, like Japan, South Korea, Turkey and Israel. The European components market is largely divided equally between American and European manufacturers in 2013 (ESCIES, 2013). In the case of Japan, the market for space-qualified components represented roughly YEN 3 billion in 2012 (around EUR 23 million), with 52% of parts coming from the US, 36% from Japan and 12% from Europe (ESCCON, 2013).

In general the electronic, electrical and electromechanical (EEE) components' suppliers with some activity in the space sector are either small specialised firms with unique know-how, or divisions in large multinational groups dealing with many other sectors (e.g. automotive, aeronautics, defence). Very few EEE parts, ranging from cables to electrical switches, up to semiconductors, are designed specifically for space applications, due to the relatively low volume and sporadic manufacturing requirements. Some unique characteristics are required of space quality parts (i.e. high resistance to low temperature and high heat; extremely long reliability; high vibration capability, extremely low defect levels, etc.). The issue of "space qualification" is therefore an inherent cost driver, as it takes time to qualify selected components before they are deemed to be integrated in equipment which eventually will fly to orbit (two to four years, or much longer in some cases). As many companies seek to limit as much as possible the non-recurring

engineering (NRE) costs, which represent the one-time cost to research and develop components and equipment, relatively few invest in non-profitable R&D. For example, out of around 25 commercial manufacturers of Static Random Access Memory (SRAM) components, used in almost every industrial sector, internationally there are only six manufacturers of SRAM specifically designed for use in space. Still, EEE parts represent 40% to 70% of the value (and also quantity in average) of a space equipment (ESCCON, 2013). The space manufacturer Loral estimates, for example, that around 50 000 EEE parts are to be found in recent communications satellites. As another example, the centralised procurement for the ESA Automated Transfer Vehicle (an unmanned and expendable module bringing cargo to the International Space Station) covered for seven flight sets, 45 major equipment composed of over a million EEE parts.

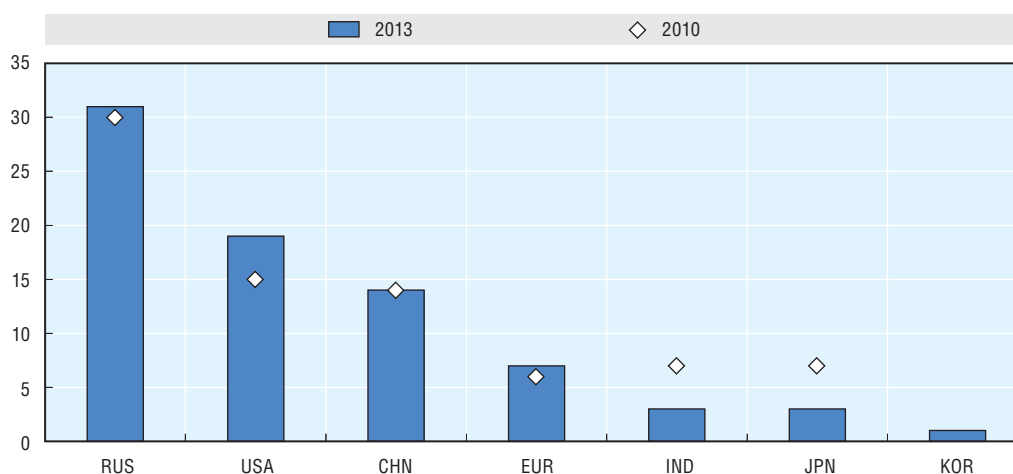
The long-standing reliance on American satellite components and equipment, subject to strict technology transfers and re-export restrictions from the United States (i.e. the US International Traffic in Arms Regulations regime, ITAR), has been a key reason for European, Israeli and Japanese industries' moves to develop home-base alternatives. ESA's European Components Initiative (ECI) also had the objective within a few years to turn Europe from a net importer of components into a net exporter, as well as to secure access to strategic components. The ECI entered recently its fourth Phase (2013-16), focussing on strengthening the European supply chain, with already around 40 qualified manufacturers registered. In Japan, some 27 qualified manufacturers are registered and supported by the Japanese space agency. Manufacturing commercial "ITAR-free" satellites (i.e. satellites with components not subject to US government authorisation for export and re-exports) have been a selling-point of several manufacturers for a decade now with some effects on the US industry. The impacts of the ITAR regime affected the US industry with lost sales opportunities of between approximately USD 988 million and USD 2 billion from 2009 to 2012 according to a recent US Department of Commerce survey (DoC, 2014).

Where is my rocket made? At first glance, the rocket business may not seem very impacted by globalisation. Satellite launchers are related to missile technology, and are therefore kept under tight government control worldwide. The open market to launch commercial satellites remains relatively narrow, about USD 2 billion in revenues in 2013 with six companies able to compete internationally (see 7. *Space launch activities*). However, access to space remains an important source of income and jobs for domestic ecosystems of companies and public organisations, as the requirement to launch many institutional satellites for civilian and military missions offer *de facto* captive national markets in many countries (e.g. earth observation, military satellites...). Governmental satellites are typically launched domestically in the United States, China, India, and the Russian Federation. In Europe, there is no policy imposing the utilisation of the European Ariane launcher for ESA Member States' institutional satellites.

Despite these captive domestic markets and tight regulations on missile technology transfers, globalisation has permeated the industry. Korea joined recently the small club of countries with space launch capabilities, thanks to initial active international co-operation in the 1990s. In the case of Europe, the different Ariane launchers were conceived from the start as complex international systems, bringing together parts and equipment manufactured all over Europe, so as to involve as many countries as possible in the funding and development of a sustainable independent European access to space. With current European negotiations about the future of the Ariane family of launchers and its long-term economic viability, the current supply chains spanning many countries are being challenged.

This co-dependence on launcher development can be found in other countries also for political and economic reasons. As soon as the cold war ended, contractual arrangements for commercial technology transfers were set up between the Russian industry and many national space industries, contributing to not only sustain the Russian sector, but also offering its Western and Asian customers the possibility to benefit from long-proven technologies. China and the Russian Federation have had for instance a very fruitful co-operation on space technologies transfers, which assisted the Chinese space administration in developing the first elements of its human spaceflight programme. The US space sector has also developed industrial co-operation, by acquiring Russian engines for several US rockets. The joint-venture United Launch Alliance (ULA), which merged in 2006 Lockheed Martin's and Boeing's US government space launch services, has been using a Russian engine, the RD-180 for more than a decade on its Atlas heavy-lift rocket, which is dedicated to US governmental launches. Similarly, the satellite and rocket builder Orbital Sciences Corporation is using a Russian-sourced first stage engine for its Antares medium lift launcher. This AJ-26 engine is built in the Russian Federation and refurbished by Aerojet Rocketdyne, another US company.

Figure 1.4. **International distribution of successful space launches in 2010 and 2013**



Source: Adapted from the US Federal Aviation Authority, 2014.

In parallel, the US-Japanese industrial co-operation in terms of rocket engines is also indicative of close bilateral technological co-operation. The collaboration started back in the late 1970s, with the Delta N rocket which was a licensed version of the US Delta rocket, built in Japan but using both US and Japanese components. More recent industrial co-operation concerns the Japanese H-IIA and American Delta IV launchers, which share the same second-stage propellant tanks' configuration. In exchange for Mitsubishi Heavy Industry's LH2 (liquid hydrogen) fuel tanks, ULA gets LOX (liquid oxygen) fuel tanks to fly on its rocket. In addition, Mitsubishi exports to the US several components (e.g. valves, heat exchangers) and propellant tanks for Delta IV's RS-68 engine. More joint engine development is currently underway, as both companies work on new upper stage engines for future launchers. For instance, the MB-XX engine under development since 1999 targets both the Japanese and US markets. Each company will be the prime contractor for the use in each country. On a more commercial launch services' level, Mitsubishi Heavy Industry has recently signed a memorandum of understanding with the European launch provider Arianespace to investigate possibilities for joint business opportunities.

Based on these illustrations, starting with limited exchanges, the situation has evolved so much that almost no launchers in activity today are composed solely of indigenous parts and equipment. Aside from developing bilateral co-operation axis, one of the main drivers for this international fragmentation of produced parts comes from evident cost-savings (i.e. no need to develop a multi-billion dollar engine for a rocket, when you can buy one off-the-shelf) and the possibility of accessing technologies already developed elsewhere to improve your own launcher. According to industry sources, propulsion systems can, for example, account for up to 40% of a launcher cost. These exchanges between companies and joint R&D projects are some of the opportunities available to the sector to reduce the cost of production.

So although restrictions in space technology transfers are still important in most parts of the world, including Europe, Japan, the United States and the Russian Federation, competition in major niche markets may soon intensify further at all levels of the space manufacturing supply chain. The US Department of Commerce published in May 2014 new regulations that will facilitate the US exports and re-exports of commercial, scientific, and civil satellites and their parts and components, by moving many items from the strictly controlled State Department's US Munitions List (USML) back to the Commerce Control List. The items moving to Commerce jurisdiction include communications satellites that do not contain US classified components, selected remote sensing satellites, as well as spacecraft parts, components, equipment, systems, and all radiation-hardened microelectronic microcircuits, that are essential for space systems. This will probably impact trade in components, equipment and subsystems around the world.

What are the impacts of these trends for policy-makers?

The more countries invest in space programmes, the more the overall market will be stimulated and the global value chains strengthened, but many nations will keep some control over sovereign interests and sub-sectors (e.g. defence space programmes). The key drivers for more globalisation will include sustained institutional support from new sources worldwide, double sourcing guaranteed on the market offering new commercial opportunities, and a wider global addressable market size for all actors. Globalisation can benefit a large number of countries in terms of economic development and innovation capabilities, but this will increasingly come with more challenges for incumbents and newcomers alike. To better face these trends, two avenues could be pursued by policy makers: better tracking of who is doing what, and sustaining value-creating industries.

Tracking who is doing what – A major challenge faced by national administrations, which are often customers of many space products and services, and their industrial primes concerns the need to have an overview of the complete supply chain, to allow a better visibility of procurement and handling of subsystems and equipment throughout the chain. There is a difference in the globalisation aspects of upstream and downstream segments in the space sector. The upstream segment is still influenced by R&D policy decisions of national governments, a situation that is likely to remain. Meanwhile, the downstream segment is increasingly addressing global markets. However, the segments are interdependent. The more lucrative applications of the downstream segment cannot exist without the infrastructure provided by the upstream segment, although the funding mechanisms and revenue generation between upstream and downstream are increasingly disconnected.

Europe is in a particular situation. As more countries join ESA, more national centres of space expertise can be expected to develop. ESA's geo-return policies, whereby a country's institutional funding provided to ESA programmes leads to contracts to the space

industry on its territory, have historically contributed to the creation and support of several national hubs of expertise in space research and development throughout Europe. Many European countries would not have invested in space if it were not for the principle of geo-return. This industrial policy is at the core of many of the successful scientific, institutional and commercial space programmes developed in Europe. With an enlarged ESA, the system could successfully endure without detrimental effects on incumbents, only if the European budget grows with sustained national budgets from both old and new members, to recoup enough industrial contracts on a national basis and keep a level of expertise in selected space fields. Otherwise, like in any other sector, know-how and capabilities could inevitably move where new national funding becomes available. This will need to be taken into account by policy-makers, if they wish to support a dynamic space industry and workforce on their territory, especially as the European Commission, an increasingly important player in the European space sector, defends a different set of contractual rules based on open competition.

To better track who is doing what in the space industry, a number of initiatives can be taken by national administrations. In addition to working with industry associations, promoting and conducting regular industry surveys, other information sources in governmental agencies could be better exploited to provide a better picture of the actors involved in space-related activities (e.g. analyzing administrative data on firms, information on contracts). This would be conducive to improving the quality of national industrial policy evaluations, with detailed information on the structure, positioning along the value chain and competitiveness of the space industry and other actors involved in the larger space economy.

Sustaining value-creating industries - Many producers of space products and services are still regulated by national regimes that limit foreign ownership of their activities. However there are a number of recent instances where entire firms and activities have been bought out by competitors, with international technology transfers taking place. Multinational groups have also been moving low-key activities from one subsidiary to another, with impacts on local employment. These practices can be expected to continue, in a more competitive world for the space industry, on regional and global scales. However, a major difference for the space sector as a whole, as compared to other high-tech sectors, still lies in the important role of national agencies, laboratories and universities in fundamental research and development. This is, for example, the case for the United States, with several NASA and Department of Defense research centres, for France with CNES, ONERA and DGA centres, and India with major ISRO centres distributed throughout the country. These R&D capacities under governmental control have still important impacts on employment and future public innovation capabilities for the space sector that should not be underestimated.

So as economies get more interdependent and interconnected, all countries and all firms have the opportunity to participate and benefit from global value chains in the space sector. However, this situation puts new competitive pressures on governments to adopt reforms that enable their producers to find or to try retaining niches in which they may make the most of their capabilities. There is a need for complementary policies, such as those that boost education and skills, as well as ensuring long-term investments in research and development capabilities, leading to future innovation (OECD, 2014).

Space is still not a “business like others”, despite the many globalisation patterns it follows. The more countries are investing in space, the more the global market will be stimulated, and global value chains will be strengthened. Even if companies involved in

space activities seem to be freer than ever to pursue growth strategies internationally, many countries will unsurprisingly keep a level of control over sovereign interests and strategic technologies. In order to benefit from global value chains, countries will increasingly have to balance their strategic and industrial interests with further growth. Economies willing to develop and sustain an active national space programme in a more competitive world will need to remain key driving forces, as reliable customers and R&D enablers of their national space industries, as well as be promoters of more open markets for the industry as a whole.

Dynamic innovations in the space sector

The section briefly presents some of the new dynamic innovations within the space sector. Technological innovation and new industrial processes are particularly impacting the space industry in OECD economies. More globally, a new space era seem to be opening up with the development of “small satellites for all”.

A revolution pending in industrial processes?

A number of innovations are currently taking place in the space sector that may impact the strategies of many incumbents and newcomers in the industry: the promotion of new production processes, the rise of advanced manufacturing in the space sector, and the launch of new all-electric satellites.

Industrial organisation is an essential element of competitiveness and quality for all economic sectors. It is of course also true for the space manufacturing sector, which has been for decades a highly specialised industry, where precision and verification procedures remain essential, since once a spacecraft is launched there is no way to service it. In that context, satellites and expendable launchers have been treated like prototypes for decades, even if over the years standard platforms have been developed by many manufacturers to gain processing efficiencies and reduce production costs.

To further lower costs, adaptation of new industrial qualification procedures are being pursued, to try and use existing experience and data from high volume industries to mass produce spacecraft and launchers (e.g. automobile, aeronautics). This process has been promoted by SpaceX, a California-based U.S. company. The billionaire Elon Musk, founder of PayPal, funded a few years ago a new space manufacturing company SpaceX. The business model is based on vertical industrial processes (i.e. more than 70% of each Falcon launch vehicle is manufactured at the SpaceX production facility) and mass production, inspired by the automobile sector, not used before in the space industry. It has also benefited from supportive US institutional contracts to develop the activity. The company's fabrication volumes are constantly increasing, with production to grow more than five times year-over-year, with 2 Falcon rocket cores produced in 2012, 3 in 2013, and 17 to be produced in 2014 and 2015 as discussed during a recent OECD Space Forum workshop. The company's factory is configured to achieve a production rate of up to 40 cores annually. These new industrial processes and governmental support allow the company to sell space launch services of its Falcon rocket for around USD 60 million, at a price less expensive than its established competitors.

The European Ariane launcher currently dominates the market for commercial satellite launches (see 7. *Space launch activities*) and its production supply chain is spread out on 25 industrial sites throughout Europe. As a reaction, major actors in the European space industry decided in spring 2014 to merge some of their activities to gain in efficiency. Airbus Group, the prime contractor for the Ariane European rocket and Safran, which produces its engines, signed a memorandum of understanding to create a joint venture that could facilitate the development of the Ariane launcher and make it more competitive.

Other established actors in the United States are also reorganising their activities to adapt to increased competition. Overall, streamlining space manufacturing production and concentrating it in a few places follows a rational economic model, but it may impact incumbents over the next couple of year in terms of R&D and industrial employment.

In addition to these evolutions in the space sector's industrial processes, new developments in information technologies, computing power and molecular research in materials are all contributing to advanced manufacturing, an anticipated new chapter in industrial revolution. Additive manufacturing, or three-dimensional (3D) printing, is increasingly used in the space industry, and direct-write technologies may also have major impacts for several space applications.

Additive manufacturing is one mass production technique currently under study in several space agencies and industrial actors alike. The technologies have been tested for almost a decade in the space sector, mainly to produce models and prototypes. However space agencies and industry are looking at integrating fully these capacities in industrial processes, testing different metal alloys to build parts and full equipment. A large number of space-related components have been already produced in North America and Europe with various types of 3-D printers, and they continue to grow in size and complexity.

Despite stringent need for quality control, the first tests seem to indicate significant time- and cost-savings, with expected repercussions on the industry as a whole. In the United States, Lockheed Martin and its RedEye contractors manufactured in late 2013 a couple of two-meter long fuel propulsion tanks to test a new satellite design, by printing independently polycarbonate pieces and bonding them together. The process took approximately three months, or half the time Lockheed Martin anticipated for traditional space manufacturing techniques, and only one-fifth the price (RedEye, 2014). Further research and development in metal alloys and use of 3-D printing may also have long-term impacts on space exploration, as future generations of astronauts may be able to "print" equipment they need, out of material taking less mass at launch. Experiments took place already on the International Space Station, and more are planned by late 2014 to produce and test plastic parts with a new 3-D printer.

Another advanced manufacturing advance is based on direct-write technologies, also known as digital printing or digital writing. Using this process, it is possible to print or rather deposit on the surface of equipment a nano-scale structure with mechanical and electrical properties, which can be controlled. In other words, it becomes possible to place sensors on almost any surface including hard-to-reach places. This opens entire new fields of applications for many sectors, including the space industry for which sending low mass to orbit is critical. Being able to detect and even control changes in structures, and in the environment of commercial satellites and space stations opens up many development axes.

Finally in terms of innovation, according to many industry actors, the market for commercial satellites will be divided by 2020 between satellites with conventional chemical propulsion and satellites with electric hybrid propulsion. In 2012, two relatively new satellite telecommunications operators (Mexico's Satmex, bought by France's Eutelsat since then, and Hong Kong's Asia Broadcast Satellite) bought four commercial fully-electric satellites, developed by Boeing Space and Intelligence Systems. The first two satellites were launched in late 2013.

Electric propulsion technologies are classified into three categories: electrothermal, electrostatic and Plasma. These are types of propulsion that have been under study for more than thirty years in several countries, particularly the United States, France and the Russian Federation to save mass on interplanetary probes. On a satellite, the propulsion

system aims to ensure the transfer of the satellite from its injection orbit to its final orbit. Once the satellite has reached its position, the propulsion system is necessary to modify the orbital moves induced by natural disturbances, and correct the orientation of the satellite when needed. Satellites often carry several propulsion systems, using solid propellant (i.e. chemical system) for transfer manoeuvres, and using electric thrusters for more precise control of orbit and orientation. The main constraint for electric thrusters is that the thrust force is less important, compared to chemical engines, so it takes more time to move a satellite or an interplanetary probe. The first probe to use an ion engine for main propulsion was NASA's Deep Space 1 launched in 1998. NASA's Dawn probe, which is currently exploring the asteroid belt, also uses one. The European Space Agency's satellite SMART-1, launched in 2003 to orbit the moon, used a Hall thruster, a type of ion thruster in which the propellant is accelerated by an electric field.

As much R&D has been conducted over the years, it is not surprising to see fully-electric commercial satellites becoming available. The main advantage of electric propulsion used for commercial satellites is that due to the relatively lower weight of the satellite an operator can embark more marketable capacity (i.e. transponders on board telecommunications satellite to lease to its customers), in place of the fuel the satellite would have needed if it used a classic chemical propulsion system. Since the satellite's mass to be launched is also smaller, it reduces the launch costs. Several space manufacturers are now offering or planning to offer all-electric satellites or hybrid solutions for satellite operators. But the market is still nascent, as despite the lower costs, an important constraint from using fully-electric propulsion for operators is the length of time it takes to reach the satellite's final operating orbit (several months) before being able to start commercial operations.

The era of small satellites for all?

As a possible result of some of the innovative trends seen in previous sections, small satellites have become in the past five years very attractive, due to their lower development costs and shorter production lead times.

There is still a natural trade-off to be made between a satellite's size and its functionality, i.e. the smaller a satellite is, the fewer useful instruments it can carry, and the shorter its lifetime will be since it carries less fuel. However advances in both miniaturization (e.g. increased utilisation of micro-electromechanical systems or MEMS; reduction of Attitude Determination and Control components) and improved satellite integration technologies have dramatically diminished the scope of that trade-off (NASA, 2014). Small satellites are also becoming much more affordable. Commercial off the shelf (COTS) components and consumer electronics are now commonly used to build small satellites at the lower end of the cost range. Several commercial companies fabricate structures for a large variety of small satellite missions, and it is even possible to buy online most of the components and subsystems to build a nano-satellite in-house (e.g. Pumpkin, ISIS and SSTL lead the market). The main cost barrier remains the access to space, although significant progress may occur in that domain.

There are different types of satellites, mainly sub-categorised by their mass. Developers increasingly work on complex system architectures, to get small satellites to interact in constellations. Whole new classes of missions for navigation, communications, remote sensing and scientific research for both civilian and military purposes are being designed in universities, research centres and industry.

Table 1.3. **Types of small satellites**

Type of spacecraft	Mass
Mini satellite	100-180kg
Microsatellite	10-100kg
Nanosatellite (Cubesat)	1-10kg
Femto and picosatellite	Less than 1kg

Cubesats are very popular in universities, as technology demonstrators. They are less than twenty years old, with their standardization realized in 1999 by academics at CalPoly and Stanford University in California. The US Defense Advanced Research Projects Agency (DARPA) was one of the first promoters of these satellites as technology demonstrators, contracting out American universities (Woellert et al., 2011). Usually it takes years, even a decade or more, for major scientific missions to actually move from paper studies to operational satellite missions. In that context, the use of small satellites by universities can help students put into practice much faster their engineering and scientific competences, and small satellites can be launched when excess capacity is available on diverse rockets.

As of spring 2014, almost a hundred universities worldwide are pursuing cubesat development. Some 200 cubesats have been launched. The first launch occurred in 2002. From 2009 to 2011, there have been around 10 per year, but more than 100 were launched in 2013 alone. Twenty six countries have developed cubesats so far, with the United States launching over half of the satellites, followed by Europe, Japan, Canada, and several South American countries.

In terms of future developments, fractionated mission architectures are being studied in several countries. This involves research in networked systems of distributed, co-operating small-satellites, away from the current traditional, large, multifunctional satellites. Some experts see this as an evolution similar to computers, i.e. large mainframe computers of the 1970s have evolved into networks of small computers connected via Internet. This is leading to new commercial ventures. The firm Skybox Imaging, launched in 2013 its first satellite (SkySat-1) of a planned constellation of 24 small satellites, is focusing on making cheap high resolution satellite imagery available, with continuous refreshed data. In January 2014, the company Planet Labs launched the “Flock 1” constellation, with 28 nano-satellites in low-earth orbit, with also the aim to provide frequently updated satellite imagery. As a potential indicator of commercial interests linked to these small satellites’ developments, Google acquired in spring 2014 the Skybox firm for some USD 500 million.

Small satellites are thus attracting a lot of interest around the world, and this interest will probably increase as lessons learned are shared in scientific conferences by hundreds of developers. Many countries have decided to fund their first space programmes with the development of small satellites. Overall, aside from the mandatory requirement to secure a launch seat for these satellites on current commercial and governmental rockets, one major challenge will concern the issue of space debris, especially if some systems are not following best practices and end-up in wrong orbits. As the population of small satellites in low earth orbits augments, particularly in the sun-synchronous belt, a very busy orbit for commercial satellite constellations and institutional missions, so will the inherent risks need to be addressed more effectively by the international space community.

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