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A Snapshot of Commercial Space

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An EU Fellowship Report

by Augusto González

Center for Science and Technology Policy Research
Cooperative Institute for Research in Environmental Sciences
University of Colorado Boulder

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This report addresses space commercialisation as perceived by the people connected to the aerospace sector who I had the chance to meet, talk to or just listened to during a semester as an EU Fellow and visiting research scholar at University of Colorado – Boulder. It is indeed a snapshot of commercial space. In its final section, the report examines the relevance of some of the key findings from a European space policy perspective.

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CONTENTS

1. INTRODUCTION

Colorado has a vibrant aerospace sector and tightly knit community of dynamic aerospace stakeholders from academia, government and industry, which provides an excellent environment to investigate the subject of this report. The report is based primarily on input gathered through face to face interviews, informal discussions and attendance at several relevant events, from August 15th to December 15th, 2016.

In so far as possible, I have tried to identify the sources for specific input reflected in the report. However, this is not always possible as, at times, the same idea has been echoed by several people or it has emerged from one of the numerous informal conversations.

There is, of course, a little bit of my own observations and perceptions, as well as a personal attempt at organising the main ideas emerging from my discussions. The final section reflects exclusively my own personal views.

There are excellent descriptions of the Colorado aerospace sector in the web pages of the Metro Denver Economic Development Corporation[1] or those of the Colorado Office for Economic Development and International Trade[2].

In order to put this report into context, I would highlight that Colorado has nearly 170 businesses classified as aerospace companies, and more than 400 companies and suppliers providing space-related products and services. Direct employment in the aerospace cluster totals 25.120 private sector workers. Colorado ranks first in the U.S. in terms of aerospace employment as a percentage of total employment and second in total private-sector employment (Metro Denver Economic Development Corporation 2016).

Colorado boasts world-class universities and research intuitions that provide highly skilled workforce to aerospace industry and play a role of their own in designing, developing and running space missions. University of Colorado ranks first in the U.S. in terms of funding received from NASA.

Last but not least, the presence of several aerospace defence facilities and federal agencies contribute to the development of the aerospace industry as well as to the positive synergies between academia, industry and government.

In the words of Maj. Gen. (Ret.) Jay Lindell (2016a), Colorado's Aerospace and Defence Champion, *the key to the attractiveness of Colorado for aerospace companies is the favourable business climate (a notion that encompasses all elements that determine cost as well as ease of establishing and operating a business). Colorado competes well with Silicon Valley in terms of access to talent and living conditions in Colorado (not least its natural environment) are attractive to the highly educated type of people aerospace industry employs.*

To conclude this introduction, I would like to pay special tribute to Dr Max Boykoff, Director of the Center for Science and Technology Policy Research[3] (CSTPR), who was my faculty

1 http://www.metrodenver.org/industries/aerospace
2 http://choosecolorado.com/key-industries/aerospace
3 The Center for Science and Technology Policy Research (CSTPR) is part of the University of Colorado

host during my stay in Boulder. CSTPR provides a unique cross-disciplinary space where researchers can pursue science-technology-policy endeavours to fulfil that mission to improve how science and technology policies and politics meet societal needs. As Dr Boykoff points out, data obtained from space is critically important for environmental sciences and essential in science-based policy formulation and decision making for environment as well as for climate change mitigation and adaptation; he believes it is important for CSTPR to reinforce its capacity to tap the potential of remote sensing big data analytics. Dr Boykoff concurs with the opinion that the demand for interpretative data products and services, many of which may have environmental applications, will continue to grow and this is likely to have a positive impact in the development of commercial space.

2. OBSERVATIONS ON THE EXPRESSION "COMMERCIAL SPACE"

The 2010 National Space Policy stated that *"commercial," for the purposes of this policy, refers to space goods, services, or activities provided by private sector enterprises that bear a reasonable portion of the investment risk and responsibility for the activity, operate in accordance with typical market-based incentives for controlling cost and optimizing return on investment, and have the legal capacity to offer these goods or services to existing or potential nongovernmental customers* (The White House 2010).

Beyond this definition, there are different interpretations as to the meaning of commercial space[4]. There are voices that consider this notion of "commercial space" too broad and not one that adequately conveys the evolution in space activities. As one of my interlocutors put it *"commercial space" is a misnomer*. U.S. space manufacturing companies are all commercial. However, most of these companies have traditionally done most of their work under federal government contracts. Therefore, to speak of commercial space does not necessarily convey a clear idea of what it is that the expression actually refers to (O'Neil 2016).

For decades, space infrastructure has been manufactured by companies in a process that would fall within the above definition of "commercial". Even if mission design and funding were primarily public, private capital has historically been present in the space sector and continues to co-exist alongside governmental funding.

If "commercial space" were to be equated with space activities that are non-dependent from public funding (or publicly owned infrastructure), then the remit of actual "commercial space" would be limited to Satcom companies and suborbital flight[5]. It would be perhaps more telling to look into what has changed in the way space business and activities are being conducted.

Cooperative Institute for Research in Environmental Sciences (CIRES).

4 The spacepolicyonline.com provides a good overview of "commercial space" http://www.spacepolicyonline.com/commercial.

5 Telecommunications is the one space subsector that is purely commercial and non-dependent from public funding support. Suborbital flight has not benefited from the same governmental funding that traditional launcher manufacturing companies have and are primarily commercial ventures. Remote sensing systems first emerged and developed to meet defence and scientific needs; there is an increasing number of privately-owned remote sensing satellites, but these rely heavily on government sales. Satellite navigation systems are still primarily the result of massive public investment and space transportation systems are all dependent on government funding to a lesser or greater extent.

In recent years space activities have been characterised by an increasing recourse to off-the-shelf technology, serial production and changes in manufacturing processes that have lowered costs and make space generally more accessible, on one hand, to companies willing to develop activities in this sector and, on the other, to end customers for space-based products and services.

There is an ongoing change driven by improved manufacturing processes, improved material characteristics and more reliable and readily available triple E (Electric, Electronic and Electromechanical) parts. Nowadays, the reproducibility and reliability of triple E components is such that, in many instances, it is no longer necessary to have components specifically made for space. Space is no longer a self-contained industrial sector and there is no clear divide between space and non-space companies. Non-space companies are capable of delivering high precision design, high purity materials and excellent production quality controls which are up to par with those of traditional space companies (Miller 2016). This is also true for many small aerospace companies, which provide high-precision responses for big or small space missions. Their strength lies in their capacity to provide solutions within short deadlines. From a technological standpoint they can match and even better quality standards of much larger aerospace companies; however, these large companies cannot compete with the small ones' capacity for customised response and product/service delivery times (Kennedy 2016). Another aspect to consider is that a growing number of companies offer customers the possibility of saving significant amounts of time and money through their modelling, simulation and testing capacities; as a consequence, the need for in-orbit demonstration and validation for space components is significantly less of a constraint than it used to be.

Some non-space companies identified a need for spacecraft components and found that it was relatively easy or worthwhile to certify for space use products that were already being produced for terrestrial use, becoming suppliers for space systems[6] (Simpson 2016; Simpson 2010). Another aspect is that the space sector has entered a new phase where the private sector innovation cycle is faster than the government acquisition process.

Commercial space development has been linked to new approaches in federal government spending in space. NASA's Commercial Orbital Transportation Systems approach[7] is a novel way of engaging with industry and is proving to be quite effective in both stimulating competition in the space sector and in containing costs (O'Neil 2016). NASA has become less directive and increasingly driven by commercial considerations (Mazzucato and Robinson 2016).

When confronted with the need to work with limited budgets, private companies are clearly better at sticking to those budgets than governmental organisations. A view often repeated in U.S. space circles is that the U.S. is lagging behind in innovation because most technological challenges have been overcome by throwing unlimited government funds at them. NASA's commercial space support schemes clearly seek to address that criticism.

It is worth noting that NASA openly admits its part of responsibility in the confusion around

6 ABSL Power Solutions, now part of Enersys, a company specialised in lithium-ion cells and batteries is a good example of this.

7 https://www.nasa.gov/content/cots-program-approach

the expression "commercial space". For NASA, commercial space is primarily about human space flight and space cargo transportation. 95% of NASA funding for commercial space development is destined to human space flight and cargo, compared with 5% to science and technology developments with potential commercial applications (Scimemi 2016). In NASA's own words, *commercial Crew and Cargo Program is the critical enabler for further American space economic development* (NASA 2014).

New Space or New Space Economy are expressions that are being used by some authors to refer to this evolving space landscape which is characterised by new entrants, changing production methods, new business models and novel government procurement approaches. I have noticed, however, that these expressions were rarely used in the many conversations I had. For the sake of simplicity, I will stick to "commercial space" and "commercial space activities", which, for the purpose of this report, are to be interpreted in the broadest sense, i.e. including activities where a company sells goods or services to private consumers (even though the satellite infrastructure is owned by government) as well as activities where a company provides goods and services primarily to government customers.

3. PRIVATE AND PUBLIC FUNDING IN THE DEVELOPMENT OF COMMERCIAL SPACE ACTIVITIES

The development of commercial space activities is associated with the affluence of venture capital. The 2015 *Start-Up Space* report by The Tauri Group provides excellent insight into facts and trends in private investment in space start-ups; it reveals that there has been an exponential increase in various types of private investment since 2000 (The Tauri Group 2015). Although there are no precise figures that may give an indication of what private funding for space looks like at a global level, it seems plausible that as space activities expand, space will become increasingly attractive to private investors.

Private investment in space is not a new phenomenon; there has been private investment in space for decades. Many companies, with a perhaps less flamboyant leadership than Space X, have been investing in space money made in areas that have little to do with aerospace. Ball is a case in point.

The Tauri report also provides a good insight into private investment motivations. The key to attracting investors' interest in ambitious space ventures is the combination of new, truly disruptive ideas and solid business plans. Greater availability of components, lower cost of access to space, growing importance of software and the tremendous progress in ground simulation which saves years of testing that were necessary in the past are factors that do not escape private investors and contribute to stimulate commercial space development (Juverston 2016).

The vast majority of companies in the aerospace sector are small companies. The U.S. does not lack support schemes targeted at those companies, such as NASA's Small Business Innovation Research/Small Business Technology Transfer[8] or, at state level, Colorado's Advanced Industries Accelerator Programs[9]. What emerges from the field is that accessing

8 http://sbir.nasa.gov

9 http://choosecolorado.com/doing-business/incentives-financing/advanced-industries

appropriate funding does not appear to be a significant obstacle for space start-ups needing up to $2,5 million. Business associates, family support and angel investors are generally not difficult to find for investments of that size. It seems to be significantly more difficult for established small companies (often employing 10 to 15 people) to get the $5 to $15 million they typically need to scale up their business to 50 to 55 people. Scaling up means access to larger contracts, but these contracts often require them to demonstrate the capacity to carry out the project, which can only be done if they have secured access to additional funding prior to bidding for the contract. The problem is not lack of private investment sources but rather the competition that small aerospace companies face from advanced technology industry (such as ICT or biotechnology) that can generate a return on investment sooner than space companies (typically 3 years as opposed to 5 to 7 years)[10] (Lindell 2016b). From a state policy standpoint, sustained information and awareness raising efforts as well as reaching out to potential investors are the key to unlocking private investment[11].

Private investment in space has not meant a decline in public funding; it is often associated with it. Governmental investment in space activities has not on average diminished in the last decade or so in any of the major space faring nations. On the contrary, it is on the rise. On a world scale, public funding for space activities is higher today than has ever been and the expectations are that investment will continue to grow (Euroconsult 2015).

The widespread view in the U.S. aerospace community is that government funding is essential for the development of commercial space. There is no question that U.S. space policy (and federal government funding) is the motor behind commercial space development. The drive to promote commercial space is closely linked to the need of containing cost for space developments, widening and strengthening the U.S. space industrial base and technological leadership, and maintaining at least two major launch systems. Civil space missions are a means to contribute to maintaining space strategic capacities.

NASA's support schemes for the development of commercial crew and cargo space transportation capacity[12] seek to achieve two key objectives: lower transportation costs and transportation capacity security of supply (Sowers 2010). However, while emphasis is also on encouraging industry to be competitive in a commercial market, actual market success is not a criterion that NASA applies in determining which of the various projects continue to get funding. As the Shuttle retirement neared, NASA's approach sought the International Space Station to be serviced by private companies on *fixed fee* basis. The expression "commercial" is not in any of the contracts for these services (Scimemi 2016). Under NASA's award schemes for technology development (led by Space Technology Mission Directorate), proposals' commercial potential is evaluated in a rather light way, NASA deliberately avoiding to be too judgemental in this respect; in general, the existence of private funding is considered enough evidence of market potential (French 2016).

As regards Earth observation capacities, the tendency is for government agencies to have greater recourse to commercial remote sensing operators (Foust 2016). The widespread

10 Despite technological progress, there is also greater risk involved in space than in other advanced technology sectors. Another interesting consideration is that, private investors interested in space seem to be found either on the East or the West Coast. Silicon Valley is a known investor hub, however, funding is often provided on condition that companies establish their business physically close to investors so these can monitor progress.

11 In Colorado, the Office for Economic Development and International Trade is spearheading these efforts.

12 https://www.nasa.gov/exploration/commercial/index.html

view is that the future of Earth observation lays in a combination of public and private capacities. Public funding is likely to remain essential for the development of cutting edge new sensors. In turn, the private sector is likely to find ways to carry out Earth observation activities better, cheaper and faster than government agencies. Weather data is a good example. However, it is reasonable to assume that there will not be sufficient market for unlimited numbers of commercial remote sensing operators (Busalacchi 2016).

Defence programmes are critically important to this sector. It is a matter of national priority to maintain the space industrial base. There is overt recognition that the usefulness of some space defence-related programs may be questionable but they are funded because they keep people at work in areas that are considered strategically important from a defence standpoint. Contrary to what has happened in some defence areas, budgets for core space programs involving R&D have not been reduced. Preserving the space industrial base remains an overriding consideration. Another important consideration from a defence standpoint has been providing a line of funding to two large manufacturing primes: this leads to competition and cost reduction. Investing in space, keeping the main companies in the sector in operation saves the government money in the long run (Lindell 2016a).

The key issue for industry is budget consistency. Industry can adapt to high or low level of funding; however it has greater difficulty with variable budgets. Government funding is the guarantor of a strong space sector. Twenty years ago there was in the U.S. a much longer list of big aerospace companies than today; this situation was not sustainable and there has been significant concentration in the sector, alongside the emergence of some new companies. Yet, the financial health of these companies is not necessarily guaranteed. Aerospace ecosystems need to be watered regularly with government funds (Abdalati 2016).

Despite space market growth, there does not seem to be, as yet, sufficient market for companies in this sector to live exclusively off commercial activities. In most cases, a commercial-only business model is not enough. Arguably, if government did not provide funding, companies would shrink their activities to whatever they can sell to commercial customers. However, if only commercial considerations are applied to space activities a good portion of their societal value would be lost and it may result in serious prejudice to society. Government funding is not a subsidy; it is a response to essential needs that could not otherwise be satisfied. It is a reflection of the fact that space data is essential in many domains and nobody other than government is likely to pay for acquiring such data. Space research will remain fundamentally government funded. Ultimately, government investments in space generate economic value and make the space market grow; however it is not always possible to draw a straight line from one to the other (Abdalati 2016).

Notwithstanding the importance of public funding and determined efforts to increase it, there is a general sentiment that it is necessary for the space sector to reduce the dependence on it. The key to less dependence from public funding is affordable technology, additive manufacturing being perceived as key to this[13], and marketable products (Kappes 2016).

13 Additive manufacturing not only allows design of very complex components in a manner that traditional manufacturing does not; it also allows using the same manufacturing equipment to produce a whole variety of components without having to redesign the production lines, as traditional manufacturing would have to. This allows for great flexibility and has an obvious impact on production costs and delivery times.

Supply chains are much shorter than those of traditional manufacturing, which would normally require different materials to be used and subparts to be assembled. In additive manufacturing, the essential component is the

4. SPACE EXPLORATION AND SCIENCE MISSIONS DRIVE COMMERCIAL SPACE DEVELOPMENT

Federal government investment in space exploration is a powerhouse that enables space companies' growth and maintains U.S. technological leadership. Federal government investment in the International Space Station (ISS) has been determinant for the emergence of companies like Space X and is critical to maintaining jobs in companies like Lockheed Martin or Boeing which have been traditional contractors for NASA.

In a recent conference[14], Dr Charles F. Bolden Jr., NASA Administrator, underlined the potential of ISS for commercial market, not just for human or cargo transportation but also as a testing ground to prepare future private space stations. He pointed out that over one thousand companies contribute to the effort of opening up space transportation in low Earth orbit to commercial ventures and that thousands of companies and research institutes are involved in different ways in research on board the ISS.

The growing international interest in human travel to Mars forebodes a world of opportunities for commercial space development through the technological and life support challenges that it will pose.

NASA's investment in space exploration has been at the origin of much of the emerging commercial space activity in low Earth orbit, which over the next decade is expected to become self-sustaining. NASA intends to facilitate this transition following a path identical to that followed since early space missions: support for the design, development and testing of new technologies which are then turned to the private sector while NASA can turn to new ventures and deep space exploration (Bolden 2016).

For NASA, market development in LEO means *bringing the economy in the ground to LEO*. There are two dimensions to this: the supply side (which includes transportation capacity), and demand side (which is about transforming ISS in a National Research Laboratory, the objective being opening-up ISS to non-NASA users). The move towards private industry as a supplier of ISS is not going to stop. However, NASA is aware that in this process there are important considerations to factor in: the need to maintain the existing international partnerships and the maturity of the industry to provide services (Scimemi 2016).

Public funding remains absolutely critical to cutting edge technologies. NASA's funding for exploration and science missions and projects, including in novel areas such as asteroid mining (which may not seem to have immediate practical application) benefit big and small companies alike, often resulting in technologies that end up being marketed by those companies.

Government funding, in particular funding for small companies, present industry with technological challenges and allows them to push the technology boundary; the desire to stay in business once government funding is over is what drives companies' search for

alloy/s powder that will be used to produce the component. Shorter supply lines mean potential cost savings, efficiency gains and less exposure to supply shortages.

14 American Institute for Aeronautics and Astronautics Forum and Exposition, Long Beach, California, September 13th 2016.

marketable applications (Cheetham 2016). Space missions do not generate a great deal of recurrent business and, for some small companies, do not even have a big financial impact. However, short term space projects can be exciting for engineers; they often pose tough technical problems and help companies sharpen their technological capability which later result in better products that the company can market. When a company does contract work for space missions it is saving its own money on research (Miller 2016).

5. COMMERCIAL SPACE DEVELOPMENT OUTLOOK

Launchers

Small launchers, reusable launchers and suborbital vehicles are likely to see a significant growth in the next decade. The generalised use of CubeSats will generate demand for smaller, more frequent and less expensive launchers. Research activities may also benefit from cheaper launcher and suborbital flight opportunities. Commercial spaceflight industries are a strong vector for the development of commercial space. Investment in this sub-sector is on the rise; however, investors are shopping around, as demonstrated with Firefly[15] (which did not manage to secure critical investment for the next development phase of its Firefly Alpha light satellite launcher).

Payload delivery will be perhaps commercially more important than tourism for suborbital flight business in the medium term. Suborbital vehicles could, in a not so distant future, share airport runways with reusable spacecraft like Sierra Nevada's Dream Chaser, for now the only space transportation system currently under development in the U.S. capable of runway landing (Roth 2016). There will be mounting pressure on aviation authorities to establish regulations for these emerging activities.

As regards heavy launchers, the landscape in the U.S. has changed in recent years. Lockheed Martin and Boeing used to have the monopoly for the provision of government launcher services in the framework of a very specific regulatory regime that did not allow these companies freedom to operate commercially. Space X challenged this legal monopoly, and, as a result, government procurement practices have changed. U.S. government and agencies are now putting Space X and ULA in competition. This competition may become even more acute as other entrants in this market emerge.

The U.S. access to space policy has traditionally been based on the existence of two independent launcher systems; up until recently, U.S. government was financially supporting United Launch Alliance (a 50-50 joint venture owned by Lockheed Martin and Boeing) to maintain both systems. This has now changed. Apart from the financial consequences of this change of approach, ULA no longer has the need to maintain its two systems, Atlas and Delta, and is now moving towards a single System, Vulkan. It is also looking into ways to become more streamlined and have greater presence in the commercial market (which at present represents only 10% of its sales), both domestic and international – the objective being that one third of its sales be commercial.

The arrival of companies like Space X and the more commercially aggressive orientation of

15 http://www.fireflyspace.com

a launcher giant like ULA are likely to make waves in the international launcher business, possibly contributing to worsening the imbalance between supply and demand and driving launcher prices down. While there is little doubt that launchers in the U.S. and elsewhere will continue to be subsidized to greater or lesser extent, the current U.S. government fixed-fee, more competitive procurement approach is forcing efficiency gains and bringing down prices, which affects developments elsewhere, including in Europe.

As part of the strategy to drive costs down, launcher companies in the U.S. and others around the world have developed or are developing rideshare programs allowing multiple possibilities for auxiliary and secondary payloads.

Heavy launchers will coexist with small launchers, with or without subsidies; the most commercially successful launchers will be those that can prove to be available, cost-effective and overall reliable and trouble free. However, prospective customers for the initial launches of the new Space X's Falcon Heavy, ULA's Vulkan and Arianespace's Ariane 6 will have to make choices based on parameters other than reliability, which these launchers will have to demonstrate in coming years (Sirangelo 2016).

Satellite manufacturing

The key to the future development of commercial space is the accessibility and availability of space data at increasingly lower prices. The proliferation of companies (generally small companies) that are capable of delivering, within short deadlines, relatively cheap, high-precision, high-performance pieces of engineering can contribute to lowering the price of spacecraft and launcher manufacturing; this, together with an overall decrease in launcher costs due to efficiency gains, can facilitate access to space and ultimately reducing the cost of acquiring space data. Advanced manufacturing technologies (such as additive manufacturing) will also help reduce costs. Space data at a lower price is likely to generate more demand for spacecraft and rocket manufacturers, creating a virtuous circle.

There is a widespread view in the space sector that there is a strong potential for commercial development in small satellites, CubeSats and flight formation. CubeSats, for example, will get prices down for satellites and will provide access to space activities to traditionally non-space private and public customers. CubeSats are already being used by private companies to do radio occultation work and sell data to government.

Small satellites could, in theory, pose a certain threat to the high resolution business model in the medium term, but this is still to be seen. Clearly there is a growing interest in temporal resolution versus optical resolution; however, high resolution is still going strong (Harford, 2016). More difficult seems to be predicting the true market capacity of a particular data stream.

Satellite manufacturing industry has identified two areas of major potential growth: Earth observation and, more importantly, broadband services. Industry seems confident that the current trend of private investment in the sector, which peaked in 2015, will remain stable; however, it is reasonable to assume that some investors may want to see whether the return from those investments materialises. Despite the potential for commercial space development, federal government and agencies remain fundamental customers for the satellite industry[16] (Grush 2016). Satellite manufacturing industry representatives overtly recognise that manufacturing industry prefers to sell to government because profit margins are larger than those obtained through commercial sales (Stroup 2016).

While there is no controversy regarding satellite manufacturing prospects for the provision of broadband services, public sector representatives seem to be less upbeat than space manufacturing industry representatives regarding the outlook of remote sensing systems. There are ample opportunities to leverage existing commercial capacities, but commercial remote sensing companies are still largely dependent on government acquisition for survival. There also seems to be enough remote sensing capacity for downstream applications and service development that non-government and government users may want to buy. It seems difficult to find new business models and new customers whose needs cannot be satisfied with existing capacities, at least for now[17].

One of the areas of perceived significant potential for commercial development is satellite navigation tracking. This is not just about positioning but also the capacity to locate and track multiple moving transmitting units, which involves either ground or, most likely, satellite communication capacity. There are endless applications to satellite navigation/tracking that will emerge in the near future in a wide variety of domains which may generate not just demand for applications and service development[18] but even for dedicated new space infrastructure (French 2016).

Downstream market development

On the downstream side, data analysis and interpretation is clearly an area of tremendous potential growth. The same can be said about GNSS localization and timing services (GSA 2015). There is a strong market potential for geospatial industries providing interpretative services which rely not only on Earth observation but also on in situ sensors combined with positioning services. Natural synergies are constantly and rapidly emerging between traditional aerospace industry and non-aerospace advanced technology industry. Unmanned Air Vehicles are an example of this[19].

Value adding companies face the competition of data providers and always run the risk of being subsumed by them. Adding value to a particular set of data has limitations, whereas

16 NASA has taken steps to support small satellite industry.

17 See also The Tauri Group (2016).

18 For an exhaustive GNSS market development outlook, see the excellent GNSS Market Report, Issue 4, published by the European Global Navigation Satellite Systems Agency. Numerous GNSS-based applications in a variety of fields involve tracking (GSA 2015).

19 UAVs will provide solutions which are complementary to those provided by Earth observation satellites. The criteria to determine which solution would be the most appropriate are scale, accessibility and cost. Scale refers to the area to be covered, which in the case of UAVs can be very small to relatively large, though not as large as what a satellite could possibly cover. Accessibility has to do not only with the actual availability of UAV versus satellite when a particular job needs to get done, but also with the possible combination of sensors that a UAV can put together versus the need to obtain multiple satellite data streams for a particular survey. Accessibility includes the ability to access certain types of sites and coverage over determined precise periods of time; UAVs may be able take images at angles (such as vertical surfaces) that are virtually impossible for satellites and hover for long periods over a particular spot in a manner that satellites are not designed for. Cost is always an obvious factor. Satellite data may be used in a manner that is complementary to data gathered by UAVs. UAVs have their natural niche and fill a gap that exists between satellite and aerial data services (Oliver 2016).

real time data is an area in which private sector (notably data providers) can easily make money. For value adding companies it is commercially interesting to add value to different types of data, from different sources including from GNSS and non-space sources (be it ground-based, ocean-based or airborne). It is not just adding value it is also about adding value to added data (Busalacchi 2016). Easy access to big data volumes and enhanced processing capacities will be part of this.

For market to grow, it is necessary to widen the customer base. The difficulty lies in that downstream potential users do not necessarily know what is possible or what is on the horizon. It is necessary to bridge the gap between the end users' needs and what space technology can provide; to achieve this, a more strategic approach will be necessary as well as some sort of institutional setting[20].

The emergence of a variety of ecosystems, where there are increasing interactions between data producers and providers, marketable application developers, geospatial service providers and users, will make commercial space activity grow. These ecosystems can be left to their own devices so that they grow out of natural synergies or, preferably, can be encouraged and supported through public policies which will likely accelerate growth (Gail 2016).

Social demand will also be a driver for future demand of space-based services. One example is climate change. Climate change may have a geo political destabilising effect; countries suffering the consequences of phenomena such as severe drought will be under political stress. Global environment space systems can help better predictions and therefore potentially contribute to pre-empting instability through better policy making (Rayder 2016).

The prospect for space resources

Space mining, including asteroid mining, and the acquisition of space resources does not seem to be as remote as it once was[21], as proven by the emergence of a number of companies like Planetary Resources[22], Deep Space Industries[23], Shakeltonnergy[24] and Moon Express[25], with clear business ambitions in this domain, notably with a view to supplying materials to support life and economic activity in space (Larson 2014).

Space mining would be, in many ways, similar to terrestrial mining. Typical mining phases - prospection, drilling and excavation, extraction, processing and utilisation - would apply in space as they do on Earth.

The Colorado School of Mines has been a pioneer in this front, setting up a Centre for Space Resources in the early years of the last decade. Studies on the economic value of space mining carried out at that time concluded that mining for space resources, particularly water, and making them available for applications in space does make economic sense. Water could be broken down into oxygen and hydrogen to be used as propellants and to sustain human presence in space. In those days, the idea was to return to the Moon and NASA

20 In this respect the EU is one step ahead of the U.S.
21 Early works on space mining include John S. Lewis (1996).
22 http://www.planetaryresources.com/#home-intro
23 https://deepspaceindustries.com
24 http://www.shackletonenergy.com
25 http://www.moonexpress.com

developed an active interest in and devoted funding to space resources projects (Abbud-Madrid 2016). A few years later, the revision of the U.S. space policy put aside that idea and some of the momentum of space resources was temporarily lost.

However, in the last three years the interest in space resources has bounced back, notably connected with a renewed interest in a human lunar settlement (See Hubbard 2016). 2015 was a key year for space resources as the U.S. adopted the (somehow controversial)[26] Space Resource Exploration and Utilization Act of 2015[27] (a subset of the U.S. Commercial Space Launch Competitiveness Act 2015) with a view to promoting the exploration and utilization of space natural resources by private companies and to removing governmental barriers to the development for the space resources industry. Interestingly, the 2015 Luxembourg initiative on space resources[28] had a strong echo in the U.S. and an inspirational impact on the space resources community (de Selding 2016).

From a technological standpoint, space mining does not pose unsolvable problems[29]. The real issues are cost and sustainable demand. United Launch Alliance (ULA) has provided a first response to the question of demand in its Cislunar Space Economy concept (ULA 2016). The core of this concept is that the development of a space economy is dependent on cheaper access to space and key to this would be reusable transportation and the in-space availability of liquid oxygen and liquid hydrogen propellant obtained from water mined in asteroids and in the moon. ULA has worked out the cost that would be economically advantageous to pay for propellant made available in Lagrange point 1 or in lunar low orbit and is approaching companies that could undertake mining water in asteroids or in the Moon with its proposition (Sowers 2016). ULA could potentially become the first commercial client for space resources.

The development of space resources has two different avenues: one is commercial (lunar and asteroids mining), which is led by the companies mentioned above, and the other is governmental (mining in Mars). On the governmental side, NASA is again active in space resources. There are two missions planned for 2020, the first is the Resource Prospector mission[30] that will be the first demonstration to obtain water in the Moon; the second will be the Mars 2020 mission[31] that will explore how to produce oxygen from carbon dioxide in Mars' atmosphere, identify other resources (such as subsurface water) and determine the habitability of Mars for humans. It will be interesting to watch future developments on both fronts.

6. THE ROLE OF LEADING RESEARCH UNIVERSITIES IN SPACE

University education plays a key role in the development of space activities in general and commercial space activities in particular. Leading research universities, notably those strong in engineering, physics, optics and computer science, have been key players in space and

26 See section 9 of this report.
27 https://www.congress.gov/bill/114th-congress/house-bill/1508
28 http://www.spaceresources.public.lu/en/index.html
29 For technological details see, for example, Lewis 2015.
30 https://www.nasa.gov/resource-prospector
31 http://mars.nasa.gov/mars2020

received, for decades, continued support from NASA and other government agencies.

In some of these universities, engineering departments have achieved a level of excellence which is high enough for NASA to entrust them with the design and operation of full space missions; that is the case for University of Arizona and the Osiris-Rex Mission[32] and the University of Colorado for the Maven mission[33]. Missions are the most visible part of NASA's and other agencies' massive funding to universities for space related education and research.

Research universities are also leading in both CubeSat technologies and in software development for spacecraft and data analytics (essential for downstream applications).

Aerospace industry is investing money into leading research universities because these universities can train for in-demand technologies but also carry out research essential for the space sector, particularly at low Technological Readiness Level, at a fraction of the cost of what it takes for that research to be carried out by industry itself[34]. Through their research projects, universities bring in creativity and innovation contributing to reinforcing the company's leading position. In return, industry can concentrate in applied research of immediate use to its projects.

Universities feed talent into highly innovative companies and many are actively building bridges to attract such talent[35] through research projects and internship programmes. Funding university research promotes companies' image as potential employers amongst students and also gives companies the possibility to identify the brightest students (Harford 2016).

It is generally accepted that the first, most important factor that attracts aerospace industry to states like Colorado is access to a well-educated workforce (Colorado Office of Economic Development & International Trade 2016).

University of Colorado (CU) provides a perfect illustration of the important role that leading research universities play in the development of the space sector in the U.S.. CU ranks first in the U.S. in terms of funding received from NASA and leads in aerospace engineering nationwide. CU's Laboratory for Atmospheric and Space Physics (LASP)[36] is an elite space institution, unique in many ways and the largest of its kind in the U.S., with a capacity to design, develop, implement and operate multiple space missions.

32 http://www.asteroidmission.org

33 http://lasp.colorado.edu/home/maven; MAVEN is designed to orbit Mars and explore the state of the Martian upper atmosphere, the processes that control it, and current atmospheric loss. The CU Laboratory for Atmospheric and Space Physics proposed, designed and leads the mission on behalf of NASA. NASA provided the $600 million necessary for the mission. Lockheed Martin built the spacecraft, LASP designed and manufactured the instrumentation, with University of California at Berkeley and ULA provided the rocket. All of the main players in this mission are based in Colorado.

34 For example, Lockheed Martin will provide $3 million to University of Colorado for teaching and research on radio frequency systems (Lockheed Martin 2016). The $3 million will be spread over 4 years and will establish new academic programs focused on radio frequency (RF) systems. RF fields address commercial, civil and military needs for communications, radar and photonics. Engineers in this field will develop innovative approaches for tracking, navigation and control of spacecraft as well as next-generation global navigation technologies.

35 Space X and Ball Aerospace provide good examples of internship programmes for university students: http://www.spacex.com/careers/list; http://www.ball.com/aerospace/about-ball-aerospace/careers/college-internships.

36 LASP has impressive capacities and an equally impressive record of achievements. For further info see http://lasp.colorado.edu/home.

LASP integrates undergraduate and graduate students into all working teams providing them an unparalleled opportunity to experience hands-on the various stages of a space mission. Students may lead instrument development under academic and research supervision. Undergraduate students are trained and certified to perform mission operations together with professional staff.

There is a strong collaboration between LASP and industry. LASP not only carries out research projects for industry (for a fraction of the cost the industry itself would incur); it also tests and calibrates instruments for space missions and in some cases operates missions on behalf of industry (Johansson 2016). LASP currently operates four satellites – QuikSCAT[37], SORCE[38], AIM[39], K2[40] - and over 100 instruments.

CU is also leading in the field of Earth Observation, with the Cooperative Institute for Research in Environmental Sciences (CIRES)[41] playing a leading role in this domain.

The university's AeroSpace Ventures[42], provides a good example of the university's own proactive approach to marketing its assets, coordinating interdepartmental efforts to attract funding for space projects and facilitating career opportunities in the space sector for students. University of Colorado's efforts to promote commercial space career opportunities for students include a postgraduate course on Commercial Space Operations designed to better prepare students to deal with the business side of space activities[43].

Another excellent example of the close collaboration between industry and academia supported by government is the Alliance for the Development of Additive Processing Technologies (ADAPT)[44]. ADAPT is an R&D consortium that helps industry to improve the additive manufacturing process using data obtained though highly sophisticated tests and analysis carried out at the ADAPT Center hosted by the Colorado School of Mines. The lab is a unique facility that was set up thanks to the initial contribution of the founding partners (Fouston – a small, high precision machining company, Lockheed Martin, Ball Aerospace and the Colorado School of Mines) and a grant from the Colorado Office for Economic Development and International Trade (Kappes 2016).

Metropolitan State University of Denver and Colorado State University are also active in the aerospace sector and both boast intense collaboration with industry (Metro Denver Economic Development Corporation 2016.

37 http://lasp.colorado.edu/home/missions-projects/quick-facts-quikscat

38 http://lasp.colorado.edu/home/sorce

39 http://lasp.colorado.edu/home/missions-projects/quick-facts-aim

40 http://lasp.colorado.edu/home/missions-projects/quick-facts-kepler

41 CIRES predates the creation of NOAA by a few years. NOAA has nowadays 60 cooperating institutes of which CIRES is the largest. http://cires.colorado.edu.

42 http://www.colorado.edu/aerospaceventures. Set up in 2012, Aerospace Ventures (ASV) is a University of Colorado service that provides practical assistance with project proposals, particularly when these involve several departments; it carries out outreach activities so that numerous space-related activities at CU are better known; and it facilitates contacts between researchers, students, industry leaders, government partners, and entrepreneurs. ASV organises an annual ASV Day, at the time of writing, the latest held on October 27, 2016 (http://www.colorado.edu/aerospaceventures/ASV2016).

43 The course is run by instructor Bradley Cheetham.

44 http://inside.mines.edu/ADAPT-Home

It is worth noting that universities, like many other stakeholders in the aerospace sector in Colorado, carry out a significant number of outreach activities promoting STEM education and space science among elementary through high school students.

7. A CONCERTED EFFORT AT STATE LEVEL TO PROMOTE THE SPACE SECTOR

States play a key role in the development of the space sector in the U.S.. Colorado provides a good illustration of this. The state boasts a strong and effective for-space alliance between academia, industry and government that reflects the importance that the sector has for the economic development of the state.

The State of Colorado Office of Economic Development and International Trade[45] (OEDIT) is state's arm to promote Colorado industry domestically and internationally and promote Colorado as the right place for companies to set up their businesses. Within OEDIT, Maj. Gen. (Ret.) Jay Lindell is Colorado's Aerospace and Defence Industry Champion, a position created following the publication of the Brookings Institution report "Launch! Taking Colorado's Space Economy to the Next Level" (Muro et al. 2013). The report advised the state to "brand and relentlessly market Colorado's space economy" suggesting the a dedicated *sector champion…can further these efforts while at the same time spearheading space cluster development and ensuring regular dialogue with stakeholders*. He plays a pivotal role in fostering Colorado's for-space alliance.

The Colorado Space Coalition (CSC)[46] provides a good illustration of how the alliance works in practice. The CSC is a group of stakeholders – including aerospace companies, military leaders, academic organizations, research centers, and economic development groups – that cooperate to advance the aerospace sector, market existing assets and carry out legislative advocacy. The CSC works closely with Colorado Senators and Congressional Delegation in seeking federal funds and influencing legislation that can be of benefit to the sector. Its role is to identify areas of potential interest for the aerospace sector and provide the rationale and precise data to support action at a political level. This is particularly important when existing jobs are at stake, but also with regard to key legislation (regarding which the main preoccupation is that regulations meet the standards needed to keep up with industry development and that industry has the necessary legal certainty to conduct their businesses) (Lea 2016). ITAR reform is credited to be the result of a strong bipartisan lobby in Washington from Colorado Senators and Congressmen.

When the Constellation programme[47] was shelved, pressure from Colorado Congressional Representatives was key to ensure the survival of Orion Multi-purpose Crew Vehicle[48], whose prime contractor is Lockheed Martin, a company with a strong presence in Colorado.

The Colorado Space Coalition brief Senators and Congressional Delegation during the new Administration transition with a view to, on one hand, enlist, at an early stage, the new

45 http://choosecolorado.com
46 http://www.spacecolorado.org
47 https://www.nasa.gov/mission_pages/constellation/news/index.html
48 https://www.nasa.gov/exploration/systems/orion/index.html

Administration's support for Colorado aerospace priorities; and, on the other hand, avert the danger that an Administration insufficiently aware of the significance of certain top projects may put them at risk when new policies and budget priorities are established (CSC 2016).

For the most ambitious stakeholders of the Coalition, the ultimate objective is to create a more united front that helps the sector not only take advantage of existing opportunities but rather create opportunities and shape the political agenda to its advantage.

Other state for-space advocate organisations include the Colorado Space Business Roundtable (CSBR)[49]. CSBR is a non-profit corporation which carries out numerous outreach and networking activities, notably aimed at strengthening relationships across the Colorado aerospace community and reaching out to non-space private and public organisations across the state.

The Colorado-based Space Foundation[50] has made a tremendous contribution to Colorado's international projection as a hub for aerospace activity through its annual Space Symposium, a space event of global renown.

It is worth noting that the influence and lobbying of individual states have contributed to the dispersion of space activities (including NASA and NOAA centers) throughout the country. Because of that influence, space in the U.S. is rather "decentralised", much in the same way that space is "decentralised" in the EU (where space remains largely a matter of national competence). Decentralisation, however, is not perceived as a disadvantage as it often induces healthy competition, new approaches and original ideas (Simpson 2016).

8. THE IMPORTANCE OF NETWORKING FOR THE SPACE SECTOR

States play a key role in the development of the space sector in the U.S.. Colorado provides a good illustration of this. The state boasts a strong and effective for-space alliance between academia, industry and government that reflects the importance that the sector has for the economic development of the state.

Intense networking is quintessential to the commercial development of the space sector in the U.S.. Colorado provides good examples of this. The previous section gives a glimpse into the formal, concerted action at state level to promote the aerospace sector. However, networking happens in a variety of ways and is often informal, with frequent social events organised and sponsored by industry.

Colorado is a small state hosting a tightly knit industrial aerospace cluster. Companies compete but they also cooperate in many ways. Networking between companies as well as networking industry, government and academia is one of the keys to the success of the aerospace sector in Colorado.

There are four main reasons often invoked by stakeholders to explain why networking is so important:

49 http://www.coloradosbr.org
50 https://www.spacefoundation.org

a. Facilitating contacts and sharing of experience between companies in the space sector. Networking activities bring together representatives from large and small companies. Ideas for collaborative ventures that build on the respective strengths of different companies, or ideas for supplying contracts often emerge through these networking activities; they provide opportunities for new entrants to make themselves known and get direct access to well-established companies.

b. Connecting (generally small) space and non-space industry suppliers with large space manufacturing companies. As it was pointed out earlier in this report, there is no longer a clear divide between space and non-space companies on account of the latter's capability to deliver components that are on par with those produced by traditional space companies. There are also non-space companies that may spin-in products not originally conceived for space use or become otherwise suppliers for space activities. Networking can serve to reach out to these companies[51].

c. Raising awareness among state legislators and congressional representation regarding the social and economic importance of space in general, including legislative issues that may affect space activities[52] and the need for financial support for specific space projects.

d. Connecting academia, industry and government and providing a favourable environment for synergies to emerge. Section 6 and section 7 of this report cover different aspects of the structural connections between these three set of actors. Frequent, informal networking activities contribute to creating, reinforcing and oiling those structural connections as well as less formal, personal relations that are at least as important as the formal ones.

Graduate and undergraduate students with an interest in space are encouraged to participate and often present in such networking activities which is one of the multiple ways in which they build their paths into professional life including, for some, the setting up of their own start-up aerospace company. For these, networking may facilitate both access to future contracts as well as access to private funding.

9. REGULATORY ASPECTS LINKED TO COMMERCIAL SPACE DEVELOPMENT

Security concerns, notably export control related, are omnipresent in the space sector in the U.S.. As a rule, companies in this sector do not hire foreign nationals and, as I experienced first-hand, do not easily open up to foreign interlocutors unless they have a good reason to do so.

51 Examples of the way this is being done in Colorado are the road trips organised by the Colorado Space Business Roundtable. These road trips, whose participants include representatives from academia, industry and government, are informal, creative ways to connect with non-space companies based in state regions that are not geographically close to the major aerospace areas.

52 One good example of successful outcome of networking and awareness raising campaign among State legislators was the 2014 Colorado House Bill enacting a sales and use tax exemption for qualified property used in space flight. Up until the adoption of the Bill, Colorado tax legislation imposed sales taxes on space flight property (a satellite, for example) that needed to be stored until delivery for launch; this situation provided an incentive for companies to store such property in states which had already passed tax exemptions and was perceived as detrimental to Colorado aerospace industry's interest. Networking and awareness-raising helped enlisting the support for the Bill of many state legislators, including legislators from constituencies with no direct interest in aerospace.

Yet, the general perception among aerospace companies and authorities I came in contact with is that, following to the International Traffic in Arms Regulations (ITAR) reform, which U.S. government recognised as having adversely impacted space industry's competitiveness (see USDOC 2014), necessary export controls are no longer a matter of concern.

Some voices point out that ITAR was never a problem for big companies, which could afford paying for all the paperwork involved in getting authorisations. They benefitted from the fact that ITAR prevented small companies from exporting due to the costs involved. Reform has made exporting easier and cheaper for small companies – mainly suppliers and support companies. Authorisations through the Department of Commerce cost generally a few thousand dollars, while authorisations through State would be tens of thousands. Another positive impact of ITAR reform is that foreign customers are now more confident about buying U.S. components.

Beyond ITAR, the consensus seems to be today that there are no serious obstacles for U.S. companies to export or engage in international collaboration, or that existing obstacles, like government protectionism are inherent to space activities. In this respect, there are views that argue that the competition between the U.S. and the EU is not about exporting to each other, but rather about who conquers emerging space markets (Harford 2016) - which means identifying which are those with greatest potential and who gets there first (see Peeters 2010).

However, the growth of commercial space does pose new regulatory issues. For example, the increased recourse to small satellites (either for science or for commercial purposes) is bringing with it a growing demand for smaller launchers, which the established launcher industry is not designed to fully accommodate. The likely increase in launcher and other space activities requires a new regulatory framework.

There is a widespread view that good space situational awareness is essential for the safe and sustainable use of space. In particular, low Earth orbit requires a revision of the existing, outdated legal framework. International partners have the obligation to monitor, track and share data of what they see in space. It is necessary to establish a space traffic management system, like it exists for air traffic. Responsible behaviour alone will not solve the problem (Slazer 2016).

The Federal Aviation Authority (FAA) is being asked to look into some of these issues (see FAA 2015). FAA does not have as yet, the formal authority, the money and the immunity to take this regulatory work forward, although there are proposals to move in this direction (Sloan 2016).

Industry also has the responsibility for developing norms for how it operates systems in space. Standards are necessary for industry to build and operate spacecraft in order to make, for example, spacecraft more easily tracked, to determine orbits to be used so to as to reduce collision risk, and to ensure an adequate capacity for manoeuvring spacecraft once in space (Pulham 2016).

There is consensus that while there is a clear framework for launch and re-entry activities, there is still a great deal of uncertainty as to what is legally possible while in space. Legal ambiguity can have two opposing effects on space commercialisation: it can be perceived as an opportunity and stimulate new ventures or it may deter them due to the risks connected with it.

One important consideration is that the growth of commercial space activities is likely to change the perception of tolerable risk, financial and otherwise, associated with them. It is generally accepted that space commercialization is desirable because it is more efficient than government subsidized programmes. However, in the pursuit of efficiency and profits, mistakes will be made (Griffin 2016); commercial space development will go hand in hand with increased tolerance towards risk and recognition that failure will indeed occur, be it commercial or technical. This has repercussions, for example, on the insurance for space activities and legal liability issues. The 2015 U.S. Commercial Space Launch Competitiveness Act[53] amends the Commercial Space Launch Act[54] clarifying licensing arrangements and third party liability issues; further clarification is still necessary, for example as regards insurance of spaceports[55].

The exploitation of space resources is one the areas where the U.S. has taken legislative action seeking to remove legal uncertainty in order to promote the commercial exploration and utilization of space natural resources and the development for the space resources industry. There is certain legal controversy stemming from the fact that the Space Resource Exploration and Utilization Act of 2015 has been adopted unilaterally by the U.S. (von der Dunk 2016) and concern that it may give rise to international litigation (for example where U.S. and non-U.S. companies compete for the same source of space resources) (Simmon 2016). How effective this Act actually is remains to be seen.

U.S. businesses are in general regulation-averse; the space sector is no exception. With the exception of the need of space traffic management and norms, the general sentiment is that given the changes in policy and regulatory framework for space activities in recent years, stability is necessary to allow the sector to adapt and grow within that framework.

10. CONSIDERATIONS FROM A EUROPEAN PERSPECTIVE

There is no doubt that, in the last 15 years of so, some things have changed in the way space activities are conducted in the U.S.. One could say that there has been a democratisation of space; space technology is no longer the monopoly of government agencies and well-established, generally large aerospace companies; there is a plethora of new entrants in the space business with the ambition to make profit selling services and products to private and public customers; private investment has taken a growing interest in space; long-standing monopolistic contractual relations with government have been brought down; government space procurement is now less directive, and encourages competition and cost-efficiency. Government is becoming more like the customer that many in the private sector wanted it to be.

Space commercialisation results from the convergence of a bottom up trend driven by a growing accessibility of space technology and a determined top down policy to encourage

53 https://www.congress.gov/bill/114th-congress/house-bill/2262/text
54 https://www.congress.gov/bill/98th-congress/house-bill/3942
55 One case in point is commercial space transportation. See, for example, GAO 2016.

a more market-oriented approach to space activities.

These changes are certainly not exclusive to the U.S.. The European space sector is experiencing similar trends. The European Commission adopted on October 26, 2016, a key policy document under the title *Space Strategy for Europe* (European Commission 2016a); in this document the Commission points out that *the overall international space context is changing fast: competition is increasing; new entrants are bringing challenges and new ambitions in space; space activities are becoming increasingly commercial with greater private sector involvement; and major technological shifts are disrupting traditional industrial and business models in the sector, reducing the cost of accessing and using space*.

What follows are considerations on the relevance of some of the salient findings in this report from a European perspective, notably in the light of the European Commission's *Space Strategy for Europe*.

Public support to space commercial development

One of the main foundations on which space commercialisation is being built in the U.S. is government funding. Federal support for space is the result of combined defence as well as civil scientific and economic considerations, which, in the U.S., are inextricably linked in a manner that, in Europe, are not.

There is no indication that the development of commercial space will entail a significant change in the strategic importance granted to space in the U.S. and that it may bring about a significant reduction in federal financial support for it. The expectation is rather that the development of commercial space, particularly in low Earth orbit, will allow NASA to shift its focus towards other areas, like deep space exploration, in the course of the next decade. This shift will continue to feed the development of commercial space. From a U.S. public policy standpoint, encouraging commercial space is not about spending less, it is about spending differently.

Commercial space will offer federal agencies a wider choice of services or products that may be contracted out to private suppliers. Government funding to maintain and develop the space industrial base represents, in the medium to long term, potential cost savings and efficiency gains.

From a European perspective, there are two immediate conclusions regarding space commercialisation that can be drawn from the U.S. example: the first is that public funding for space activities remains essential if Europe is to keep pace with space commercialisation in the U.S.; the second is that, beyond other security considerations, commercial space development would greatly benefit from increased synergies at a European level between the civil and defence space dimensions. In this last respect, the natural institutional environment for these synergies to be reinforced is the European Union, which has its own competence in space[56] as well as common foreign and security policy[57], the latter including specific provisions on common foreign and defence policy.

The *Space Strategy for Europe* confirms the Commission's commitment to the financial

56 See Article 189 of the Treaty on the Functioning of the European Union.
57 See Title V of the Treaty on the European Union.

stability and the strengthening of the EU space programmes – Copernicus, Galileo, EGNOS and the R&D space strand Horizon 2020 – and suggests avenues for further activity development, notably in the field of space situational awareness. The Strategy makes a strong case for the reinforcement of the synergies between civil and security space activities, pointing out that *most space technologies, infrastructure and services can serve both civilian and defence objectives. Although some space capabilities have to remain under exclusive national and/or military control, in a number of areas synergies between civilian and defence can reduce costs, increase resilience and improve efficiency*. Reinforcing these synergies will be central to the European defence action plan presented by the European Commission and endorsed by Member States (European Commission 2016b).

Private funding

There is a generalised perception in Europe that access to private funding for space ventures is generally easier in the U.S. than in Europe. The same perception prevails among companies in the U.S. that have tried to venture across the Atlantic, namely that access to private funding is indeed more difficult in Europe than it is in the U.S..

The reality, however, is not monolithic on either side of the Atlantic. The Tauri Group report shows that there is a significant presence of private investors in the EU with a track record of investing in space start-ups. Europe venture capital is no longer a backwater that it once was and, surprisingly, as regards the ratio of exit value to capital commitments, European venture capital now outperforms the U.S. (Hixon 2016). Whether this evolution affects the space sector is another matter. The difficulty does not seem to be the lack of capital, but rather a different more conservative attitude towards the space sector in general and lower risk tolerance among European investors.

Access to funding in the U.S. for established small companies to scale up their businesses is not easy either, as the ongoing efforts referred to in section 3 demonstrate.

In the EU, there are ample funding opportunities being offered to start–ups and small and medium size companies (SMEs), including the COSME programme[58] and the Horizon 2020 R&D programme[59]. The European Commission's Startup Europe website[60] is an excellent starting point for companies in search of funding opportunities. In 2016, the EU took action with a view to reviewing existing legislation on European Venture Capital Funds and European Social Entrepreneurship Funds[61], and thereby improving the accessibility to funds supporting young and innovative companies, or enterprises with the intention of generating positive social impact, which may include, in both cases, space sector companies.

However, specific measures are needed for the space sector. The *Space Strategy for Europe* outlines a series of measures aimed at creating *the right ecosystem and a favourable regulatory and business environment that incentivises the private sector to be more risk-prone and encourages businesses to develop innovative products and services*. These measures include supporting space companies to scale up their business and facilitating

58 http://ec.europa.eu/growth/smes/cosme_en
59 https://ec.europa.eu/programmes/horizon2020
60 http://startupeuropeclub.eu
61 http://ec.europa.eu/finance/investment/venture_capital/index_en.htm#maincontentSec1

access to finance for space, notably in the context of the Investment Plan for Europe[62] and Union funding programmes.

The European Commission also intends to *strengthen the use of innovative procurement schemes to stimulate the demand-side of innovation and explore new approaches to leverage private sector investments and partnerships with industry*.

In the same vein, the European Space Agency (ESA), in its recent Resolution *Towards Space 4.0 for a United Space in Europe*[63], refers to *supporting private investment and entrepreneurship, in particular through start-ups and SME* as well as *promoting public-private partnership schemes that include the sharing of risks and rewards, prioritising pre-operational space activities with a potential for industrialisation and commercialisation* as a means to optimise its industrial policy.

Space exploration and science

The real powerhouse for commercial space development in the U.S. is, unquestionably, federal-funded space exploration and more specifically the commercial space cargo and crew transportation system development. The whole launcher landscape in the U.S. has changed as a result of NASA's new approach to it and is affecting developments on a global scale, including Europe. NASA's investment in space exploration has been essential for the emergence of commercial space in this century through support for the design, development and testing of new technologies which have then been turned to the private sector.

NASA's funding for exploration and science missions and projects, including in novel areas such as asteroid mining, remains critical to the development of commercial space, favouring the emergence of new companies, and stimulating technological developments that are being transformed in marketable products and saving companies their own money in research.

ESA is leading European efforts in the field of space exploration and space science missions and the research linked to them is determinant in encouraging the development of commercial space in Europe. This is both a reality and a policy message that comes across strongly in ESA's resolution *Towards Space 4.0 for a United Space in Europe*.

Space research under Horizon 2020 has a very strong industrial orientation that the *Space Strategy for Europe* vows to sustain, maintaining a particular focus on the development of critical space components, systems and technologies that contribute towards the technological non-dependence of the European space industry and reinforce its capacity to respond to the challenges that those missions present. The *Space Strategy for Europe* also recognizes the need for space research to support new production processes as well as new manufacturing technologies that have been determinant in the emergence of commercial space contributing, in particular, to shortening time to market.

The importance of space exploration in the development of commercial space and as a

62 https://ec.europa.eu/priorities/jobs-growth-and-investment/investment-plan_en
63 Resolution adopted at ESA Council meeting at Ministerial Level meeting of December 1st 2016 (ESA 2016).

source for technological innovation connects with the European Union's top priority on economic growth and employment and efforts to stimulate innovation. It would be natural for ESA and the EU to join forces in promoting further the potential for commercial space development of space exploration and science.

Commercial space development outlook

Launchers

In the U.S., changes in the launcher landscape were brought about by NASA's commercial space cargo and crew transportation system development, with NASA gradually behaving more like a traditional commercial customer with respect to launcher service acquisition. While developments in Europe are not identical to those in the U.S., they are equivalent in that the European Space Agency and Member States are committed to ensuring that European-built launchers, notably the future Ariane 6, maintain their competitive edge. This is to be achieved inter alia through a novel governance approach of the European launcher sector which includes greater sharing of responsibility, cost and risk by ESA and industry than has been the case in the past[64]. The emergence of the EU as a space actor and the launcher requirements generated by the EU Copernicus and Galileo constellations (30 satellites to be launched in the next 10 to 15 years) has turned the EU into the largest European institutional customer for launchers. In the *Space Strategy for Europe*, the European Commission vows to leverage the potential impact of its aggregate launcher demand in support of European reliable and cost-effective launch solutions.

There is no doubt that a greater commercial presence of a launcher giant like ULA, alongside that of ILS, Space X and other new entrants will affect the global launcher business stiffening competition and possibly bringing launcher costs further down, which is generally good news for the development of commercial space.

There are exciting prospects in commercial space development linked to the growth of the small satellites and CubeSats business, the increased demand of small and suborbital launchers linked to it and the likely surge of suborbital transportation for people and cargo. Europe is not foreign to these developments and the *Space Strategy for Europe* bids support to Member States, ESA and industry in developing low-cost access for small satellites, encouraging commercial markets for small launchers as well as commercial space flight and suborbital space tourism.

Satellite manufacturing

It was not within the scope of this study to explore in depth trends on satellite manufacturing, but rather collect impressions as to the prospects in this domain. What emerges from discussions is the perception that there is a strong potential for commercial development in small satellites, be it for remote sensing or telecommunications, including navigation tracking. This potential is driven by a virtuous circle of increasingly less expensive satellite development and launch as well as a growing demand for cheaper and more readily available data from space.

64 http://www.esa.int/Our_Activities/Launchers/Launch_vehicles/Ariane_6

In so far as remote sensing is concerned, there is in the U.S. a growing interests in temporal resolution (favouring the recourse to larger constellations and smaller satellites), which is not to say that high precision remote sensing is in decline. There seems to be a consensus regarding the good prospects of telecommunications satellite manufacturing, including in order to cater for the ever growing possibilities offered by GNSS-enabled tracking applications.

There are similar echoes in Europe regarding the prospects for small satellite manufacturing. The *Resolution on ESA programmes: outlook and way forward*[65], acknowledges that *as reliance on satellites and the services they offer continues to grow, […] the number of spacecraft in orbit around the Earth is increasing substantially, a phenomenon which will be stimulated further by the expanding commercial use of space, the growing interest in CubeSats and nanosats, and the potential arrival of mega-constellations*.

The European Commission's *Space Strategy for Europe* points out the increase in space activity fuelled by the reduced costs of developing and launching satellites and underlines the need to facilitate low-cost access to small satellites. The Strategy emphasises the role of satellite communications to improve connectivity for Europe's digital society and economy and bids support to *promote the efficient and demand-driven use of satellite communications, so as to foster ubiquitous connectivity in all Member States*.

Space downstream market development

Europe and U.S. share the perception that there is an enormous potential in the development of the downstream market, data analysis and interpretation, GNSS localization and timing services; both sides of the Atlantic are particularly upbeat regarding market prospects for geospatial industries providing interpretative services which combine data from multiple sources (be it remote or in situ) with positioning services. These prospects go hand in hand with public policy efforts to ensure ease of access to and use of big data volumes.

Europe is ahead of the game with regards to identification of users' needs and bridging the gap between the demand and the supply side. Public and private users' needs have been engrained at every stage of the development of programmes like Copernicus and Galileo, including the downstream service and application development and is central to the entire European Commission's *Space Strategy for Europe*, while in the U.S., the general sentiment is that not enough is being done in this respect.

The *Space Strategy for Europe* states that *the Commission's aim is to optimise the benefits that space brings to society and the wider EU economy. Achieving this means boosting demand among public and private users, facilitating access to and use of space data, and stimulating the development and use of innovative downstream applications. It also means ensuring the continuity and user-driven development of EU space programmes*. Such aim is largely shared by the EU and ESA, as their October 26, 2016, *Joint Statement on Shared Vision and Goals for the Future of Europe in Space* reflects[66].

65 Resolution adopted at ESA Council meeting at Ministerial Level meeting of December 1st 2016 (ESA 2016).
66 http://www.esa.int/About_Us/Welcome_to_ESA/Shared_vision_and_goals_for_the_future_of_Europe_in_space

Space resources

There is growing interest in the U.S. regarding space mining. The acquisition of space resources is perhaps not as remote as it sounds and a number of companies have emerged that believe in the market potential of mining for space resources. In 2015, the U.S. adopted the Space Resource Exploration and Utilization Act, with a view to setting a national legal framework for U.S. companies wishing to do business in this domain. One European country, Luxembourg, has taken action to become an international hub for space mining companies. The European Space Agency has taken a hands-off approach in this matter[67], at least for now. At EU institutional level, the European Commission and the European External Action Service do recognize that there may be international legal issues around space mining that may test the limits of existing UN space conventions. If current trends regarding space resources prove to be sustained over time, Europe will have to devote greater attention to the technological, economic as well as the legal aspects linked to this activity in order to keep pace with developments in the U.S..

Universities involvement in space

Leading research universities and government funding provide industry the brain power and financial fuel for the development of commercial space in the U.S.. Needless to say, private investment is also key to such development, but it comes afterwards. Leading research universities have been determinant for making space-grade technology developed with government funding accessible to industry, big and small, thus facilitating access of new entrants to the space sector and bringing down barriers between space and non-space industry. Graduates from these universities join industry or government agencies having acquired not only scientific and technological knowledge but also hands-on experience in all phases of space missions, from design to operations. Strong university/industry partnerships bring down space research and development costs for industry, fuel innovation and build professional pathways for talented graduates.

Europe is well aware of the importance of University education for space development and numerous industry/university partnerships do exist at national and European level. Both ESA and the EU have encouraged these partnerships under various schemes, notably under the space strands of the EU R&D framework programmes.

However, speaking from personal experience, there is nothing comparable in Europe to the intense, structural for-space university/industry/government collaboration that I have witnessed in the U.S..

ESA's resolution *Towards Space 4.0 for a United Space in Europe* does acknowledge the importance of greater *cooperation between academic institutions and research establishments together with industry and end-users, in order to allow for uninterrupted, rapid development from idea to product or service and sustain competitiveness in an efficient manner*, and the need to ensure availability of skilled staff *including through exchanges of personnel and secondments to and from industry, academia and other national and European institutions.*

67 See European Space Agency's Director-General's quote in the article by de Selding (2016).

In its *Space Strategy for Europe*, the European Commission envisages launching, as part of the New Skills Agenda for Europe, *a dedicated sector skills alliance for space/Earth observation gathering key stakeholders from industry, research, universities and public authorities to tackle new skills requirements in the sector*. In that context, and as other EU institutions engage in the discussion of the strategy proposed by the Commission, it may be worth exploring the potential for a dedicated, EU for-space university/industry cooperation scheme that builds on the combined, highly successful traditions of EU programmes supporting curriculum development, student and researcher mobility as well as industry placements in the framework of transnational consortia.

For-space lobbying

Although the U.S. state-*versus*-federal reality is not directly transposable to Europe, there is perhaps inspiration to be found in the way states lobby the federal level in support of space sector interests. The same can be said about networking and the important part it plays in facilitating business contacts, notably new entrant industry access to contracts, for-space awareness-raising among policy makers and reinforcing connections among the whole spectrum of space stakeholders, including actual and potential private investors.

There is, however, no *one size fits all* approach and the diverse reality at European and national levels require multiple-design approaches and formats. The key points here are, on one hand, that the defence of space interests requires constant attention and a persistent, concerted effort by all stakeholders and, on the other hand, that, like in any other activity sector, nothing works better than face to face contacts and human interaction. It is worth noting that in the *Space Strategy for Europe*, the European Commission does recognise the need to undertake such effort, and in particular bids support to *awareness-raising and outreach activities to inform the space industry and local financial intermediaries about the opportunities offered by EU initiatives and programmes*.

Regulatory aspects

From a regulatory standpoint, commercial space development has been determinant in bringing about ITAR reform. While there was a consensus that ITAR was excessively restrictive, U.S. companies are in general satisfied with the current reform and tend to perceive obstacles to international trade or to international collaboration as inherent to space activities. This complaisant attitude regarding international trade can be partly explained because of the relatively lower importance that international trade represents for U.S. space companies than it does for their European competitors. Europe does perceive a need to ensure a level playing field and greater convergence as regards dual use export controls, as the European Commission *Space Strategy for Europe* points out.

Notwithstanding this seemingly different take on international trade, Europe and the U.S. share similar concerns regarding the need to ensure the sustainability and safety of space activities. Transatlantic collaboration will be crucial in dealing with issues such as the development of international space standards, space traffic management or legal issues linked to the exploitation of space resources.

11. CLOSING REMARKS

Against the backdrop of an evolving space sector, space development in the U.S. remains unquestionably and critically dependent on combined space exploration, space science and space-related defence government funding, including as a means to leverage private investment. However, there has been a key shift in government procurement approach – now driven by competitive considerations - that is fuelling commercial space activity to a degree never seen before.

Tapping the full upstream and downstream economic potential of space is central to current European space policy, alongside societal and strategic considerations. While Europe is devising its own policy recipes to achieve this, it is worthwhile to keep in sight and perhaps find inspiration in certain key aspects that contribute to the U.S. dynamic commercial space development, such as the commercial dimension of space exploration and science, the synergies between space civil and defence components, the deeply rooted, structural collaboration between university and industry and the open mindedness towards the commercial potential of activities such as space resources.

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