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Future Issues for Commercial Space Sustainability Suggested by Space Industry Socio-Economic Trends

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Abstract

As the space industry continues to mature and diversify in both structure and applications, considerable effort has been made in recent years to research and describe the underlying trends that are supporting and enabling this growth. These studies include:

- Efforts to quantify and characterize the total size of the space economy, such as the annual Space Report, published by the Space Foundation.
- Efforts to quantify and map investment capital and sources flowing into the space industry, such as the Start-Up Space study published by the Tauri Group in February 2016.
- Efforts to understand linkages between technology trends and economic returns, such as the Global Trends in Civil and Commercial Space study published by the Science and Technology Policy Institute in October 2015.
- Efforts to size and forecast specific segments of the space-sector value-chain such as Earth observation and satellite communications market forecasts regularly published by consulting firms such as Euroconsult and NSR.
- Efforts to quantify satellite launch rates and service types, such as the annual small satellite launch forecast published by SpaceWorks.

While these studies provide actionable quantitative data to guide market and investment approaches; what is often missing is cross-cutting analysis between studies focusing on qualitative trends and issues uncovered by the quantitative datasets. Comparison of data contained in these efforts can provide important insights into the policy and environmental issues and challenges that will affect the future development of a functioning and sustainable space economy. This paper will present findings from a comparative analysis of trend data focusing on identifying cross-cutting issues that affect the continuing sustainability of the space operating environment. Continued economic development of, and return from, the space industry requires a space environment that remains accessible to all industry actors. Maintaining this environment will require collaborative attention and action from all of those involved in the space industry, including companies, regulators, and investors. Through a literature review of the published studies mentioned in this abstract, and others, this paper presents a comparative analysis that: compares multiple studies; identifies common themes, topics, and issues suggested by the datasets, and analyzes them for policy and strategy aspects that pertain to space sustainability.

Keywords: commercial space, space commerce, space sustainability

Acronyms/Abbreviations

ADR	Active Debris Removal
COTS	Commercial Off the Shelf
LEO	Low Earth Orbit
OECD	Organisation for Economic Co-operation and Cooperation
RPO	Rendezvous and Proximity Operations
SIA	Satellite Industry Association
SSA	Space Situational Awareness

1. Introduction

The commercial space sector is currently undergoing rapid expansion. New and innovative business approaches are bringing new services and applications to market, changing access to use and of space; and disrupting traditional industry approaches [1]. Considerable analytical effort has been devoted to describing, quantifying and projecting this activity with the intent of informing business strategy, government policy, and investment decisions.

The rapid development is creating new complexity in the operating environment, and in how operators interact with each other and with the regulatory system. Continued economic development of, and return from, the space industry requires a space environment that

remains accessible to all actors. The expansion of the commercial space sector poses new challenges to maintaining a safe operational environment in space, and to sustaining the benefits of space applications here on Earth. Addressing these challenges will require collaborative attention and action from all of those involved in the space industry, including companies, regulators, and investors.

While analytical efforts aimed at describing the commercial space sector are typically aimed at describing market or economic trends; comparison of data contained in these efforts can provide important insights into the policy and environmental issues and challenges that affect the ongoing development of a sustainable commercial space sector. In fact, many of the same market and economic trends that are enabling the current wave of commercial space expansion; when analyzed in a cross-cutting fashion suggest a number of challenges that impact the continuing sustainability of the space operating environment.

2. Approach

This paper, and its conclusions, is based upon a literature review of space industry analysis studies, reports, white papers and other related work. It includes work published by industry consultants, think tanks, and governments. Media and trade press articles were not a focus of this analysis. The literature review was based solely upon publications available in public domain, which means that for several studies (produced on a commercial basis by consulting firms) only executive summaries were available for review. A complete listing of publications included in the literature review is included in Appendix 1. The literature review identified common trends and issues, which were then mapped to a notional space industry value chain to identify areas of impact. From there space sustainability issues are postulated.

3. Qualitative Trends and Challenges

In the general the studies and reports reviewed for this paper fell into one of three different types:

1. Analysis focusing on characterizing and describing Industry Structure elements. This type of analysis focuses on identifying who is acting (e.g. firms, investors, customers); what activities they are engaging in; and how they are interacting which each other. In general, these studies are qualitative in nature, although they may include quantitative information.
2. Studies which focus on Market Sizing and/or Forecasting, typically focused on specific application (e.g. remote sensing, communication services, launch services). These studies aim to quantitatively assesses the size (in potential sales, revenue, or value terms) of a particular market segment and may forecast the expected future growth of that market. While quantitative in nature, these studies generally include qualitative trend information to support the numerical analysis.
3. Efforts which focus on characterizing and describing Technology Trends and/or Forecasts. These types of analyses focus on describing the underlying trends of development, adoption, and use architectures for specific technologies or systems being developed and deployed across commercial space applications. These studies typically include both quantitative and qualitative information.

The literature review conducted for this analysis reviewed a cross sampling of studies from these types, covering a cross section of applications and technology areas including remote sensing and communications market analysis, small satellite and launch technology studies, and finance and global space trend focused industry structure analysis.

While the literature review cannot be characterized as exhaustive it does reveal a number of trends and challenges present in the commercial space industry, that are discussed consistently across the different study types. As consulting firm Avascent writes:

> "Change is hitting the industry from all sides, and it's not just technology that's advancing, although in many ways it is leading the upheaval. There's also a transformation in manufacturing systems, business models, customer engagement, and management processes. [2]"

3.1 Current Commercial Space Development Trends

Commercial Space Development Trends (listed in Table 1, and described, on the following page): are those things that are characterizing, enabling and supporting the current wave of activity in the commercial space sector.

Table 1. Trends Identified in Studies

Study Type / *Trend*	Industry Structure	Market Size	Tech Trends
Agile Aero	✓	✓	✓
COTS		✓	✓
Commoditization		✓	✓
Constellations	✓	✓	✓
Consumer Market	✓	✓	
Diversification – Operators	✓	✓	
Diversification – Users	✓	✓	
Legacy Role	✓	✓	
Lower Costs		✓	✓
New Apps	✓	✓	✓
New Capital	✓		
Spin-In	✓		✓

A number of trends are consistently reflected in industry studies analyzing the growth and development of the commercial space sector:

- Agile Aero: Many of the firms commonly in described in industry reporting as "disruptors" or "NewSpace" have adopted a business and operations philosophy known as "Agile Aerospace." This approach entails "making continual incremental improvements to hardware and software to ensure that operations can be rapidly configured to satisfy changing markets demands [3]." Agile aerospace firms may be characterized by a higher level of vertical integration, faster development cycles, and higher technical risk tolerances that legacy firms.
- Commercial-off-the-Shelf (COTS): The use of commercial-off-the-shelf parts, subsystems, and software are now "commonly used to build small satellites at the lower end of the cost range [4]." This is one of several factors that is driving lower costs in many areas of space development.
- Commoditization: Related to COTS, commercial space firms are increasingly leveraging the commoditization of "computing, solar cells, batteries, SDRs, sensors,…" and other subsystems/components [5]. The advent of smallsats, and activities towards dedicated smallsat launch vehicles are acting towards making those technologies themselves commodities, in turn threatening the traditional value proposition of the satellite manufacturing and launch segments [6, 7, 8].
- Constellations: Both the Earth observation and broadband communications segments are currently characterized by a notable number of business plans and system architectures based on constellations of 10s to 1000s of small satellites, operating in competition/conjunction with traditional satellite systems [e.g. 9, 5]. This trend has many implications, including the introduction of economies of scale into the satellite manufacturing process, impacts on the way satellite operators interact with each other, and potential expansion in consumer access to space applications and services [7].
- Consumer Market: Traditionally the space industry has focused sales of goods and services to government and large enterprise customers; however, the current wave of commercial space development is increasingly focused on end-users and a "more widely utilized consumer/commercial set of sectors" as target customers [6]. This has implications for the ways space business interact with customers, how business risks are defined and mitigated, and how governments engage with industry as customers [7, 10].
- Diversification – Operators: Enabled by expanding markets, lowering costs, and new sources of investment, the number and types of space, satellite, and launch vehicle operators is diversifying, including commercial, governmental and academic actors. This has the effect that "portions of the space sector are transitioning from a monopsonic-oligopoly to a more globalized mainstream sector [7]."
- Diversification – Users: As consumer markets become more prevalent; new user communities become associated with space applications, services and goods. Space is becoming more accessible, increasing the number and types of stakeholders in applications, operations, and governance [5, 11]. There is a shift towards more commercial activity, away from government dominance [5, 6]. A key driver of this diversification is a shift towards selling of package solutions and/or value-added services instead of raw data or product [12].
- Legacy Role: Despite the number of start-up companies and amount of investment activity in the "NewSpace" community, "the traditional players are still in the driver's seat [2]." The established and legacy space companies retain the institutional relationships, technical capabilities, and financial scale to drive change and expansion in their segments. The interaction between new actors and legacy firms – how each responds and adapts to innovations, applications, and services produced by the other – is an

important dynamic in today's commercial space industry.

- Lower Costs: Across the space supply chain, firms are taking advantage of lower cost parts, components, and technology to develop lower-cost applications and products. [6,9]. This trend is closely interrelated to other trends including Agile Aero, COTS, and Commoditization; the result is that commercial space firms are "focusing on affordable, scalable systems vs. exquisite capabilities [5]."
- New Applications: Industry is developing, and basing business plans on, a number of "non-traditional" applications and services, outside of traditional approaches to communications and optical remotes sensing. These applications often rely on novel sensors, analytical methods, and/or operations concepts, and pose regulatory challenges to governments [6,9].
- New Capital: A key driver of current commercial space activity is that "Space is attracting increased attention in Silicon Valley and in investment communities world-wide. Space ventures now appeal to investors because new, lower-cost systems are envisioned to follow the path terrestrial tech has profitably travelled: dropping system costs and massively increasing user bases for new products… [13]"
- Spin-In: Space companies are increasingly "incorporating technology from other sectors" in the development and fielding of services and applications. Examples include: "inertial measurement units, from video games; radio components from cell phones; processors meant for automobiles and medical devices; reaction wheels meant for dental tools, [6]" and data analytics methods from the software industry. Spin-in also is acting in the form of human capital moving into the space industry from other segments – most notably the IT/software industry; and through the influence of venture capitalist (and other investors) in the Boards and executive suites of many space start-ups.

3.2 Current Commercial Space Development Challenges

Commercial Space Development Challenges (listed in Table 2, and described, below) are barriers which the industry faces in achieving sustained economic success from current development.

Table 2. Challenges Identified in Studies

Study Type / *Trend*	Industry Structure	Market Size	Tech Trends
Investment Bubble	✓		
Launch Access	✓	✓	✓
Market Size/Share		✓	
Regulatory Scale & Certainty	✓		
Spectrum	✓	✓	✓

A number of challenges are consistently reflected in industry studies analyzing the growth and development of the commercial space sector, although most of the reviewed works (given their nature and target markets) focus on market challenges, rather than policy or governance challenges:

- Investment Bubble: A noted caveat in analyzes and discussion of the influx of new investment sources into the space sector is questions over the long-term sustainability of the new funding, concerns over demonstrating exits and moving to instructional and equity funding, and comparisons to the failed investments in large-LEO telecommunications constellations in the 1990s [6].
- Launch Access: The availability of reliable access to dedicated and affordable access to launch has oft been noted as a "potential choke point for further growth" for smallsat and CubeSat operators [8]. While rideshare opportunities exist, access to dedicated vehicles enables operators to access orbits of their choice, which is key to support business plans [1]. In response "many small launch vehicles are being developed to meet the growing demand. [14]." Most of these vehicles have not yet flown, and the long term development of the small launch vehicle market remains unclear, however the area is seen as attractive for commercial development [2, 15].
- Market Size/Share: Much of the activity in the space start-up community is driven by new applications, targeting new markets, for which the long-term size and viability is simply put., unknown. As Avascent writes, "Realistically, there are so many new projects hoping to deploy innovative smallsat technologies, it's clear they can't all succeed [2]." Even in traditional applications competition is growing more intense. The Satellite Industry Association (SIA) noted in its June 2016 State of the Satellite Industry Report, that at least 20 different firms have operational or announced plans for commercial

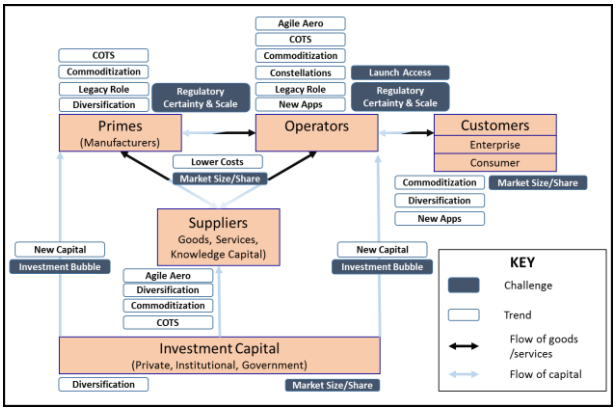
Earth observation satellite services. [9]. The long-term evolution of the commercial space industry, its size, scope and scale, is, as Lisa Porter, Executive Vice President and Director of CosmiQ Works at InQTel, writes, dependent "upon the success of several market sub-segments. [5]"

- Regulatory Scale & Certainty: The scope of most existing regulation on space activities focused on launch, remote sensing (particularly electro optical), and telecommunications services. Many new commercial applications do not fit cleanly within the existing regulatory frameworks, forcing governments to re-evaluate regulatory approaches as investors seek certainty in the legal and regulatory environment for new space ventures [11]. Areas such as remote sensing licensing approaches; the legal regime for space resources development, commercial space stations, and on-orbit servicing; and space traffic management; and others all pose questions to the existing regulatory frameworks [6]. A related issue is the ability of governments to efficiently and effectively operate licensing processes in an environment of rapidly increasing activity.
- Spectrum: With the growth in operators, increased competition with terrestrial uses, and increased uses of LEO communications and Earth observation constellations "management and allocation of radio frequencies for space-based stations will become more challenging with increasing demand for spectrum/orbit usage for practically all space communication services [3]."

4. Trends and Challenges Cross Cut the Space Value Chain

The trends and challenges that have been identified through industry studies are "affecting all parts of the value chain and most customer segments. [2]" By mapping these trends to a notional space industry value chain (based loosely on that described by the OECD Space Forum [4]) their cross-cutting nature is illustrated.

Figure 1: Trends and Challenges Mapped to Impact Area(s) in Notional Space Industry Value Chain



It is worth noting that one of the consequences of current development in the commercial space sector is that this traditional value chain is becoming less characteristic, as for example agile aerospace business practices contribute to vertical integration and as traditional lines between operators and manufacturers blur.

5. Future Issues for Commercial Space Sustainability

It is through this cross-cutting value chain impact that the identified trends and challenges pose future issues for commercial space sustainability – outside of questions about long-term business success or market viability. In this sense commercial space sustainability refers to the collective operating environment and context in which the growing space industry interacts; the impacts of that industry on that environment, and the continued ability of that environment to support business operations.

An illustrative list of these issues can be identified, and discussed in terms of the trends and challenges described previously:

- The introduction of operations concepts involving large constellations of satellites (numbering in the 100s or greater), operating in coordinated networks, and possibly operating in similar orbital configurations as competitor constellations.
- Increased numbers of smallsats and CubeSats flying.
- The emergence of new, 'non-traditional' applications (e.g. space resources development, on-orbit servicing, commercial space stations) that do not fit existing regulatory frameworks.
- A growing number of new actors (both commercial and governmental) in the space sector.

- An influx of investment and human capital from outside the space sector, which might not be as familiar with the traditional operational practices in the field.
- Increasing pressure on maintaining environmental factors such as space debris remediation and electromagnetic spectrum coordination.

These issues are themselves cross-cutting and interrelated, as the illustrative case studies below showcase.

5.1 Increase in Prevalence of Small Satellites and Cube Satellites

An unmistakable dynamic in the current evaluation of commercial space activities is the increased use – and utility – of small satellites. Euroconsult forecasts more than 3,600 smallsats to be launched between 2016 and 2026 [15]; and SpaceWorks' latest annual forecast of nanosat and CubeSats (below 50kg in mass) projects that "as many as 3,000 nano/microsatellites will require a launch from 2016 through 2022. [14]" Other studies forecast similar magnitudes of activity [12, 16]. As of June 2016 slightly more than 1400 satellites (of all mass types) are currently operating in orbit [17], so clearly the projected launch rates would represent a fundamental change.

The move towards smallsats is driven by many of the trends identified in the earlier analysis, including the use of COTS components, the commoditization of supply chain elements, and spin-in of technology and human capital from other industries – in particular software. Smallsats are at the forefront of the agile aerospace philosophy, helping to drive lower costs and supporting rapid manufacture and system improvement while distributing risk across multiple platforms rather than low numbers of exquisite platforms [6, 7, 12]. Smallsats enable constellation architectures and support consumer market driven solutions [7, 12, 14].

The increase in deployment of small satellites raises challenges for space situational awareness (SSA), which is our ability to characterize information about the space environment and its effects on our activities in space. SSA includes tracking of space objects, characterization of those objects, and identification of threats to space objects – including potential collisions between satellites [18]. CubeSats pose tracking challenges, both in that their size approaches the lower limit of capabilities for many existing sensors and in that it is difficult to individually identify and track CubeSats when launched in large groups. Small satellites are trackable by existing sensors, however the prospect of large constellations of them operating in the same orbit creates the potential for significantly increasing the number of potential conjunctions that must be analyzed. Accompanying the increased use of commercial smallsats and CubeSats is increased commercial interest in the development of dedicated small satellite launch vehicles. As these systems are deployed, they will challenge the efficiency and operating tempo of existing launch ranges. Collectively, as the commercial character of these activities (and actors) increases relative to the government share, questions are raised as to whether the appropriate provider of SSA functions should be a military organization (as it currently) or a civil organization, and about the role of commercial systems and operators vis-à-vis government capabilities.

5.2 New Actors

170 countries have a financial interest in one or more satellites [6]; and over "over 80 angel- and venture-backed space companies have been founded since 2000 [13]." The space sector is growing and diversifying, and as it does so new actors – both governmental and commercial – are entering. Diversification is driven by lower barriers of entry (e.g. lower costs, commoditization, COTS) and measured in terms of new countries, companies, and customers investing in space applications, services, and products – a trend sometimes referred to as the 'democratization' of space [11]. It is reflected in the role of spin-in technology and human capital in enabling space business and present in the role that non-traditional and 'new' investment capital sources are play in driving the entrepreneurial space community. New actors bring innovation, motivation and new business models that help provide new benefits and advancements in space technology; but at same time may lack familiarity with common norms and best practices in the space sector.

The challenge posed is how does the community help maximize the benefits from new actors entering the space sector by ensuring that there is awareness of the fundamental principles, laws, norms, and best practices for safe, predictable, and responsible activities in space. Will new space actors experience the same "learning curve" as the legacy actors? What sort of national policies and regulations should new spacefaring countries be adopting? How do new commercial actors, new government actors, and the established actors interact?

5.3 Operator Coordination in an Increasingly Complex Environment

A natural consequence of the expansion and diversification of the space sector, is that the operating environment (in orbit) is becoming more complex – and that the nature of the most prevalent operators (measured by number of satellites in orbit) is shifting from government to commercial [3, 14, 15]. Smallsat-based mega-constellations may operate at the same altitudes as constellations operated by competitors. Commercial on-orbit servicing and active debris

removal (ADR) concepts will require operators to coordinate with each other as satellites conduct rendezvous and proximity operations. The dramatic increase in the number of satellites in operation will place additional pressure on spectrum coordination and avoidance of interference, even as terrestrial competition grows at the same time.

This complexity in the operating context, and in how operators interact with each other will require collaborative action to ensure that the space environment that remains accessible to, and usable by, all actors. Recognizing this, a number of industry-led or driven initiatives are underway, including:

- The U.S.-based Satellite Industry Association has issued a white paper covering "Responsible Space Operations" which represents "the consensus views of the members of SIA with respect to space situational awareness and best practices for responsible space operations. [19]"
- Efforts within the Commercial Spaceflight Federation to develop voluntary industry consensus standards for human space flight safety.
- The recent establishment of the Commercial Smallsat Spectrum Management Association which is intended to be an industry-led group for the pre-coordination of spectrum issues for small satellite operators.
- DARPA's recently announced plans to facilitate the establishment of an industry-led consortium to develop norms for on-orbit servicing activities.

There will be a continued need for initiatives like these to develop norms and principles for responsible space operations as the industry continues to expand.

5.4 Regulatory Fit

New and innovative business approaches are bringing new services and applications to market – such as commercial space stations, on-orbit servicing, and space resources development –and are bring disruptive approaches to existing markets – such as reusability in launch or newly commercialized sensors and data types in Earth observation. Governments must consider how they will satisfy their supervision and oversight requirements for these new applications. As they do existing regulatory frameworks originally developed for communications, electro-optical remote sensing, and space launch services will not be sufficient. Investors, governments, and industry alike are looking for regulatory certainty to define the legal context for new developments [20].

Governments are also challenged to keep pace with the agile aerospace philosophy and approach. Licensing and filings processes must both keep pace with accelerating technical change and increased licenses application volume. Governments are challenged to resource their licensing procedures so as to satisfy their due diligence obligations while not imposing undue delay on commercial business plans. New commercial actors are in some cases establishing operations in states which have not traditionally had a space sector – challenging those governments to put into place a regulatory regime from essentially scratch. Through all of this governments and industry must work in collaborative fashion to find and operate a balance between regulatory requirements and industry-led self-governance.

6. Conclusion

This paper conducted a literature review of a cross-section of industry analysis studies to identify trends and challenges, that collectively suggest space sustainability issues raised by the expansion of the commercial space sector. The illustrative set of issues identified through this analysis will require collaborative action by government and industry to help support the continued expansion of the commercial space activities, and associated benefits that they bring.

Appendix A (List of Works Reviewed)

	Publishing Organization	Title	Date	Format	Type of Study
1	Avascent	*Space Market Disruption: How to Succeed in Today's Hunger Games Arena,*	October 2015	White Paper	Industry Structure
2	Avascent	*Space Market Disruption: The Smallsat Revolution,*	October 2015	White Paper	Technology Study
3	Avascent	*Smallsat Market Projections*	October 2015	White Paper	Market Sizing
4	Euroconsult	*$22 Billion Market Value for Small Satellites over Next Ten Years*	July 2016	Executive Summary (Report)	Market Sizing
5	European Association of Remote Sensing Companies (EARSC)	*A Survey Into the State and Health of the European EO Services Industry*	September 2015	Report	Industry Structure
6	European Space Policy Institute	*Space Policies, Issues and Trends in 2014—2015*	November 2015	Report	Industry Structure
7	InQTel	*"Commercial Space,"*	February 2015	Conference Presentation	Industry Structure
8	Institute for Defense Analysis, Science and Technology Policy Institute	*Global Trends in Space*	June 2015	Report and Presentation	Industry Structure
9	Institute for Defense Analysis, Science and Technology Policy Institute	*The CubeSat Ecosystem: Examining the Launch Niche*	October 2016	Conference Paper	Technology Study
10	Japan Science and Technology Agency	*A Comparative Study on Space Technology in the World*	March 2014	Report	Technology Study
11	Organisation for Economic Co-operation and Cooperation	*The Space Economy 2014*		Report	Industry Structure
12	RAND Corp.	*The Democratization of Space*	March 2016	Whitepaper	Industry Structure
13	Satellite Industry Association	*2016 State of the Satellite Industry Report*	June 2016	Report	Market Sizing
14	SpaceWorks Enterprises	*2016 Nano/Microsatellite Market Forecast*	March 2016	Report	Market Sizing
15	The Tauri Group	*Start-up Space*	January 2016	Report	Industry Structure

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