The evolution of mission-oriented policies: exploring changing market creating policies in the US and European space sector

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Abstract

Market creation is moving to the centre of mission-oriented innovation policy in the space sector. Agencies such as the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) are developing market-creating innovation policies in response to (a) the increasing emphasis on societal grand challenges, (b) the rise of a new wave of space companies (often referred to as “New Space”) and (c) the global trend towards interconnecting and interlinking of industries (a trend referred to as Industry 4.0). In this paper we explore the changing nature of mission-oriented innovation policies for market creation for two agencies, NASA and ESA. For these agencies, earlier mission-oriented policies focused on clear challenges with identifiable concrete problems and directed by a strong centralised agency. Contrast this with today, with broadly defined grand challenges, decentralized innovation systems with mixed top-down and bottom-up problem definition. We describe the current drivers and pressures that are creating a window for policy change, and we present examples of how NASA and ESA are responding to these pressures and use this exploration to dig deeper into the evolving frames of market-creating innovation policy in the space sector to identify the challenges for such policies and to further articulate a research agenda.

Key words: market creation, mission-oriented innovation policy, grand challenges, Industry 4.0, directional failures

1 Introduction

Over the past six decades, the space economy has grown from a handful of space-faring nations to over 60 nations active in space-related activities worldwide – a trend that is growing. This international growth coincides with growth in the space private sector as well as non-space specialized corporate activity becoming entwined with the space sector. These developments are transforming the space economy, with a particular impact on incumbents, which are beginning to feel the pressure as more actors seek to enter the global space value chain and compete for a share of the space market (OECD, 2014).

While the private sector is evolving, so too is the public sector; space agencies are being tasked to respond to the evolving space sector while also considering broad societal goals during a time when public agencies are increasingly being asked to show their "economic value" in a time of budget reductions (Chapman, 2015; Balint et al. 2016).

Agencies such as the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) are challenged to develop market-creating innovation policies in response to (a) the increasing emphasis on societal grand challenges, (b) the rise of a new wave of space companies (often referred to as New Space) and (c) the global trend towards interconnecting and interlinking of industries (a trend referred to as Industry 4.0).

Approaches to tackling grand challenges through targeted innovation policies is becoming high on the agenda of many public agencies, in Europe and elsewhere (Georghiou, 2018; Fisher et al., 2018; Mazzucato, 2018). Therefore, understanding how public agencies are attempting this is of great interest, to learn about approaches and the challenges raised during these attempts.

In this study, we describe how the frames of innovation policy are changing in the civilian space context to (a) better understand the evolving innovation policies in the space sector, and (b) draw out broader lessons for public agencies wishing to address grand challenges through targeted innovation policies. We argue that a number of drivers such as Industry 4.0 (see below) has caused new types of actors and new types of relationships to be formed, with public space agency “missions” focused on fostering links between actors and sectors. We contrast Europe and the US (justification below) where there seems to be different responses to the “pressures”.

The role of mission-oriented policies is to translate broad challenges and political orientations (Barré et al., 2013) into “doable” problems to be solved (Fujimura, 1987). How then are mission-oriented policy approaches changing in response to grand challenges in an evolving innovation ecosystem of new actors, and how will this shape actual innovation activities? The space sector is a useful case study due to its long-term use of mission-oriented policies, and thus it is a perfect site to explore changes in mission-oriented policies and their consequences.

2 From fixing failures to shaping markets

Exploring innovation policy is important to understand the way in which public agencies are perceived, legitimized and evaluated (and thus also how they are organized and shape industries, the economy and society). Before exploring specific cases in the space domain, it is important to understand the variety of intervention rationales of public agencies. In the following we review three rationales for public agency intervention in innovation processes and markets: fixing market failures, fixing innovation system failures and fixing directional failures.

2.1 Fixing market failures

Governments have historically used market failure theory to guide interventions in the economy, justifying interventions only when they are geared towards fixing situations in which markets fail to efficiently allocate resources (Arrow, 1951, 1962). The market failure approach suggests that governments intervene to “fix” markets by investing in areas with “public goods” characteristics (such as basic research, or drugs with little market potential) and by devising market mechanisms to internalize external costs (such as pollution) or external benefits (such as herd immunity). Such government fixes are necessary for actions such as mitigating the effects of short-termism of risk-averse firms; this is particularly important for the space sector, where projects may last more than ten years.[1] Similarly, for the

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[1] Space manufacturing, which encompasses launchers, satellites and the ground segment, is a high-tech, high-risk and high-cost industry with long development times and a low rate of production (relatively low number of launchers and satellites).

space sector, which is well known for having a larger amount of spillover effects, markets will not take into account the diffuse (although often substantial) return on investment of space technology developments. Arguments for the market failure rationale for intervention is visible today in the space sector, for example, as David Haight, chief economist of the Canadian Space Agency put it, public agencies can “Correct market failure for innovation where lack of immediate returns diminishes private R&D investment” (Haight, 2016). Thus, the market failure rationale is justified under conditions of suboptimal investment in innovation, often owing to uncertainties on returns on investment due to unclear demand articulation, which may lead to waiting games (Robinson et al,. 2012; Lember et al., 2013).

While market failure theory provides interesting insights, it is most useful for describing a steady-state scenario in which public policy aims to put patches on existing trajectories provided by markets (Mazzucato, 2016). It is less useful when policy is needed to dynamically create and shape new markets; that is, “transformation” (Weber and Rohracher, 2012). Therefore, it is problematic for addressing breakthrough and disruptive research and innovation that has led to new technologies and sectors that did not exist before (the internet, nanotech, biotech, cleantech) areas where the potentially disruptive nature causes hesitation in the private sector (Robinson et al., 2012).

2.2 Fixing (innovation) system failures

Another rationale for public intervention in markets is to fix systems failure in national, regional or sectoral innovation systems. Such rationales take as the starting point the inability of the system to function efficiently due to faulty (or absent) links between elements of the ecosystem.

Systems of innovation have been defined as “the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies” (Freeman, 1994), and as “the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge” (Lundvall, 1992, p.2). National innovation systems are composed of different actors: government, industry (firms), research institutes (public and private), foreign companies, and universities (Lee and von Tunzelmann, 2005). Sectoral systems of innovation focus on the varied nature of production, firm types and organizations (users, producers and input suppliers), including non-firm organizations (such as universities, financial institutions, government agencies, trade unions or technical associations) (Malerba, 2002). Such sectoral perspectives broaden the firm- or supplier/assembler network-centric view of value chains to include development- and market-external actors. The assumption is that the factors impacting the diffusion of innovations are located within (a) innovation chains/networks, (b) the market place, and (c) the regulatory regime (including industrial, national or international authorities that can influence activities in the innovation system, the marketplace and/or the regulatory regime (Tilson and Lyytinen, 2004; Ansari and Garud, 2009). Innovation systems (whether sectoral, regional or national) embody dynamic links between various innovation actors and institutions (firms, financial institutions, research/education, public sector funds and intermediary institutions), as well as links within organizations and institutions (Freeman, 1995).

Therefore, the most important issue is how *actors* interact: what are the reasons behind certain research results being taken up, or certain innovation trajectories being followed? Innovation studies scholars have proposed the functions of the innovation systems approach (Hekkert et al., 2007) where a diagnosis of the various functions of innovation system can inform targeted innovation policy. However, this approach has some limitations. As most actors (public and private) do not have perfect knowledge of the future, their interaction with new knowledge can be described as iterative and tentative: responses and solutions are being sought. These actors are interacting along a complex landscape, forming new rules and routines, and they often follow “satisficing” behaviour rather than the maximizing behaviour that is assumed in traditional economic models (Nelson and Winter, 1982). The process of decision making that is pursued in this discovery of the landscape is crucial (Stirling, 2009; Smith et al., 2005; Robinson and Propp, 2008; Rodrik, 2004). Policy approaches that focus on technology transfer and technology clusters to connect elements of the innovation system are an example of the fixing systems failure rationale.

Innovation systems require the presence of dynamic links between different actors and institutions (firms, financial institutions, research/education, public sector funds, intermediary institutions) as well as horizontal links within organizations and institutions. Public agencies can play a role in fixing systems failure, and lead public organizations can galvanize the interests of relevant actors to stimulate the innovation process by shaping and creating technologies, sectors and markets. To do so, dynamic relationships must be developed

(Mazzucato 2017). Thus, the fixing systems failure approach focuses on optimizing the performance of the innovation system, which is related to the nature and quality of the interactions of innovation system actors.

While fixing market failures and systems failures may lead to optimization of current situations, creating new markets and industries requires a different rationale, what some have called transformative change (Weber and Rohracher 2012). This is visible in the next intervention rationale.

2.3 Fixing directional failures

Grand challenges, be they *sustainable development goals* (Griggs et al., 2013) or *grand societal challenges* (Cagnin et al., 2012), capture societal needs that are currently unmet and often require international and multisector solutions. The nature of grand challenges is complex, due to various interdependencies making approaches to solving them difficult to articulate (Amanatidou et al., 2014). Grand challenges have been described as wicked problems owing to their complex nature and their broad definition making it difficult to articulate specific manageable problems (Boden et al., 2010). Research and innovation policies targeted at societal grand challenges rather than purely economic growth has been argued to be a new type of policy for transformative change (Gassler et al., 2008, Weber and Rohracher, 2012) where policies contribute to facilitating innovation and socio-economic impact in a particular direction towards desirable transformative change (Mazzucato 2013, Kallerud, et al. 2013, Schot and Steinmueller, 2016).

Fixing directional failures requires articulation of broad societal and socio-economic challenges for which concrete actions can be supported to contribute towards desired transformative change. The challenge remains to translate broad challenges into concrete actions. Mazzucato (2017) proposes that challenges can be translated into concrete action through an intermediary layer of mission-oriented innovation policy for creating, shaping and directing markets that otherwise would not occur through fixing market and systems failures (Mazzucato 2017).[2]

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[2] A key aspect here is the level of articulation of issues to be dealt with and the location of action. A hierarchy of (a) broad challenge, (b) well-articulated mission, and (c) clearly identified problems to be solved allows connected innovation policy that can lead to market creation and fixing directional failures. The translation of grand challenges into "doable" problems (Fujimura 1987) is the key role for mission-oriented policy.

2.4 Mission-oriented policies: translating grand challenges into doable problems

Innovation scholars have emphasized the role of policies that have *actively* created markets rather than just fixing them, through “mission-oriented” objectives (Foray et al., 2012; Mowery, 2012; Mazzucato and Penna, 2015). Mission-oriented policies target the development of *specific* technologies in line with state-*defined* goals (missions); this differs from more horizontal policies aimed at institutional development in a systems of innovation approach (Ergas, 1987; Cantner and Pyka, 2001). Mission-oriented policies require support from specific sectors, but they are not sectoral policies; they are policies that get many sectors to work together in new ways.

Traditional *mission-oriented innovation policies* **(**we label as *Type 1***)** can be said to describe “radically-innovative projects which are themselves necessary for the pursuit of goals of national interest” (Ergas, 1992). The key features of such are a centralized decision-making process for pursuing goals, in a complex research and innovation system, where the goals are defined by the public agency. The key feature of a *diffusion-oriented innovation policy* is decentralization, where technology or innovation goals are not identified centrally and public agencies have a more restricted role, delegating these responsibilities to professional bodies or public research organizations (Foray and Llerena, 1996).

The mission-oriented literature contains many useful empirical studies, such as analysis of different technology policy initiatives in the US (Chiang, 1991; Mowery et al., 2010), in France (Foray, 2003), in the UK (Mowery et al., 2010) and in Germany (Cantner and Pyka, 2001); and studies of mission-oriented agencies and policy programmes, including military research and development (R&D) programmes (Mowery, 2010), the National Institutes of Health (Sampat, 2012), grand missions of agricultural innovation in the US (Wright, 2012), and energy (Anadón, 2012), among others. While mission-oriented programmes are intrinsically dynamic, with feedback loops between missions and achievements, the tools used to evaluate such public policies have remained *static*, coming from the market failure theory toolbox (despite the fact that many studies draw on the *dynamic* innovation systems perspective from evolutionary economics). Such mission-oriented investments have increasingly been found to be important for allowing innovation to take off in a way that generates long-term growth, and understanding the history of mission-oriented policies has been crucial for thinking around new policies needed to address grand societal challenges (Foray et al., 2012). In previous mission-oriented R&D projects, such as the Manhattan and Apollo programmes, all funding has been provided by public US Federal agencies. However, “for current societal challenges, publicly funded R&D, although vital, will be only one of a number of sources of R&D investment” (Foray et al., 2012, p.1698).

Recently there have been calls for a return to mission-oriented policies as a way to address grand societal challenges (Mazzucato 2018, Fisher et al., 2018, Georghiou et al., 2018). In the past, missions were often related to a well-defined outcome, such as putting a man on the moon, which mostly entailed technological challenges. However, modern missions, ranging from the demographic/ageing problem being faced by Western nations to the global challenges concerning climate change, are more complex because there are fewer clear technological challenges and outcomes are less clearly defined (Foray et al., 2012). Contemporary missions aim to address broader challenges that require long-term commitment to the development of many technological solutions and “a continuing high rate of technical change *and* a set of institutional changes” (Freeman, 1996, p.34). However, grand societal challenges concern the socio-economic system as a whole, which often implies large-scale transformations with multiple actors and elements (Kuhlmann and Rip, 2015; Geels, 2004). This is in stark contrast to the missions of the past, which were mainly technical and more “vertical” (Foray et al., 2012).

Visible in the current discourse about, and attempts to build, challenge-driven policy is what we label *Type-2 mission-oriented innovation policies*. Here, policies are not administered by centralized decision-making authority in a vertical structure (see Type-1 above); they are administered by public agencies engaged in decentralized and dynamic innovation systems that include bottom-up innovation and variation beyond the control of central administrations. Type-2 mission-oriented policies thus include diffusion policy characteristics too. Understanding the role of new actors required to confront missions that are socio-economic and not just technical, requires Type-2 policies with an “innovation ecosystems” viewpoint. These challenges also require changes at the societal/national systems level. The so-called Maastricht Memorandum (Soete and Arundel, 1993) provides a detailed analysis of the differences between old and new mission-oriented projects (Table 1).

Table 1: *Characteristics of traditional (Type-1) and challenge driven (Type-2) mission-oriented policies*

TYPE-1 Mission-Oriented Innovation Policy (MOIP) ***Examples include defence and nuclear***	**TYPE-2 Mission-Oriented Innovation Policy (MOIP)** ***Examples include environmental technologies and societal challenges***
Clear challenges with well-defined goals and specific objectives	Broad challenges with a complex mix of goals and objectives
Single source financing administered by a centralized authority	Multiple sources of financing stemming from a variety of innovation system actors
Centralized control within a government administration in clearly defined value chains.	Decentralized control with a large number of agents involved across many value chains and innovation ecosystems
The goals and the direction of technological development are defined in advance by a small group of experts.	The direction of technical change is influenced by a wide range of actors, including government, private firms and consumer groups.
Participation is limited to a small group of firms due to the emphasis on a small number of radical technologies.	Emphasis on the development of both radical and incremental innovations in order to permit a large number of firms to participate.
Diffusion of the results outside of the core of participants is of minor importance or actively discouraged.	Diffusion of the results is a central goal and is actively encouraged.
The mission is defined in terms of the number of technical achievements, with little regard to their economic feasibility.	The mission is defined in terms of economically feasible technical solutions to particular societal problems.
Self-contained projects with little need for complementary policies and scant attention paid to coherence.	Complementary policies vital for success and close attention paid to coherence with other goals.

Source: Adapted from Mazzucato and Penna (2015), which in turn is inspired by Soete and Arundel (1993, p.51).

3 Evolving innovation policy approaches in European and US public space agencies

The previous tour of policy rationales for intervening in markets provides a framework to explore the interventions of public agencies in the evolving space context. In the following sections, we explore how the two focus space agencies are changing their innovation policies and rationales for intervention in the space innovation ecosystem. But first we will articulate the changing context of space innovation, identify key drivers of policy change and locate the focal space agencies in a governance framework.

3.1 Pressures and drivers for (transformative) change of innovation policy

Amid budget cuts and pressures to show economic value, public space agencies are challenged to respond to changes and shifts in the space innovation system itself. This potential change in the stakeholders and innovation processes in the space sector is often labelled in the US and elsewhere as “new space”. While there are no clear definitions, we can offer the following comparison of new space and old space.

In “old space”, technology developments and applications are funded by governmental and institutional bodies often for bespoke low production activities, typically ten satellites or launchers (rockets) produced per year, and thus having a high cost per unit. There is an emphasis on high-end and high-reliability technologies, since the public sector are the funders and users of the technologies, the space markets are mainly composed of business-to-government or business-to-business services.

In “new space”, for projects such as launchers and complex satellites, large investments are provided by venture capitalists and large firms (Google, Apple, Facebook, Virgin). The model of “new space” brings an ethos of mass manufacture, and thus there is an emphasis on business models with high production rate and thus low cost per unit. In some of the “new space” approaches, reliability is less of an issue, for example PlaneLabs[3] is a firm that develops mass-produced shoebox-sized cheap satellites, which can easily be replaced if they do not function appropriately. The “new space” market is focused on business-to-consumer services, for example satellite imagery can be provided as a service to a client and arranged between a space firm and a big data firm to provide bespoke imaging data for any kind of

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[3] https://www.planet.com/ (accessed 19/12/17).

customer.[4] “New space” is particularly prevalent in the US and predicted to be a key driver in the global space economy, but it is also putting pressure on European space agencies to stimulate the European space industry to be competitive in global markets. [5]

Drivers such as “new space” have recently been placed at the heart of European space policy. In December 2016 at the ESA Ministerial Meeting, ESA Director-General Jan Wörner proposed his vision of Space 4.0 as a diagnosis of the global transformation of the space industry and the challenges and opportunities this poses for ESA’s new mission. Analogous to the notion of Industry 4.0 (see Box 1), which is the collective term for transformations across the value-chain of different sectors, Space 4.0’s focus is on “*interconnecting science, industry, politics and society”* in new ways. Space 4.0 includes downstream value creation as a key issue, with new roles for industry and agencies up and down the innovation chain[6]

Industry ‘waves’ (World Economic Forum)	**Space ‘waves’** (ESA)
Industry 1.0 – Use of water and steam power	**Space 1.0** – Astronomy
Industry 2.0 – Mass production through production lines and electrical energy	**Space 2.0 –** Space race, Apollo era
Industry 3.0 – Use of electronics for automation	**Space 3.0** – ISS era and integrated international initiatives
Industry 4.0 – Connected value chains (Internet of Things, smart factories, internet of services)	**Space 4.0** – More nations, more types of space ‘players’, spin-off, spin-in and spillover, meaning space is closer to consumers and society, space tourism

Figure 1*: Industry waves and space waves as viewed by ESA Director-General*

Source: Adapted from various presentations and blogs of ESA DG Jan Wörner (authors have added the term ‘spillovers’)

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[4] This is only part of the European notion of Space 4.0 which includes more heterogeneous value chains, greater global competition, the innovation effects of digitalization and the need for addressing grand challenges.

[5] There is a dedicated journal on the new space movement: http://www.liebertpub.com/space

[6] http://www.esa.int/spaceinvideos/Videos/2016/01/DG_s_media_brief_replay

As can be seen from Figure 1, Industry 4.0 implies new interactions between public sector and private sector organizations, both upstream and downstream.[7] In the space sector, this has meant that supply chains and services have become increasingly interconnected, for example through the use of big data in areas such as Earth Observation (EO) platforms and also in Block Chain Technology (Torben, 2017). Therefore, Space 4.0 represents a diagnosis and a vision from the director-general concerning the new space arrangements between (i) different space-faring nations, (ii) the public sector and the private sector, (iii) the interaction between the space industry and other industries and (iv) the space sector and society. At the same time, the space sector is trying to reposition itself along new societal challenges, ranging from climate change to immigration (McGrath et al., 2014; European Commission, 2013). Thus, there is growing recognition that the space innovation system is also part of a set of broader industrial transformations creating more interconnected industries cf. Industry 4.0, and the digital economy (see Box 1).

Box 1: Industry 4.0

Industry 4.0 emerged in Germany as an umbrella term capturing a vision of new technological manufacturing options and the growing interconnectedness of value chains. It has been picked up by a large range of firms and policymakers, indeed becoming the main motto of the World Economic Forum 2016. As a vision, the term has its origins with three physicists and engineers in 2011, but has been taken up by consultancies, intermediary organizations and governments (Pfeiffer, 2017; Deloitte, 2015). As a concept, Industry 4.0 describes a future vision of industrial production, where all aspects of value chains can be monitored as well as the lifecycle of products, all relevant information is available in real time, which is achieved by "interconnecting all instances that participate in the value creation processes the creation of dynamic, real-time optimized and self-organizing cross-company value networks by interconnecting humans, objects and systems, and their abilities" (VDI-VDE, 2016). A recent second round survey, of over 2,000 industrial actors, has shown that while in 2014 Industry 4.0 was a vision on the radar of industrial actors, in 2016 it is at the heart of their strategies and incorporated in the firm's missions (PriceWaterhouseCoopers 2016).

While there are changes occurring in the space innovation system, public agencies are experiencing budget cuts and are driven to justify their activities relative to the production of

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[7] A key topic of the World Economic Forum 2016. See the following link for more details: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

socio-economic value. This has meant that commercialization and market creation activities are prioritized more than ever, with agencies such as ESA and NASA targeting their activities closer to downstream applications, products and services, and having to show the effect of activities on indicators such as jobs, new company formation and economic growth (Besha and MacDonald, 2016). These activities have translated into demand for the growth of downstream utility of space technologies, midstream infrastructures and services, all of which are connected to the upstream activities that are at the heart of public space agency core competencies. Another pressure related to showing the socio-economic value of space agency supported activities is for agencies to respond to societal challenges such as migration, climate change and food security, translating into a pressure to respond to societal demands and needs.[8]

To summarize, a number of pressures and drivers are providing demands for policy change. Internal pressures are arising from budgetary limits and mounting competition from new non-European space-faring nations and space firms. The external pressures come from (a) new forms of innovation external to the space sector (spin-in), (b) broad industrial transformations creating more interconnected industries (cf. Industry 4.0 and the digital economy), and (c) greater needs from the demand side, captured through societal grand challenges (societal demands and needs). Both NASA and ESA have been challenged to address the pressures internal to the space sector to facilitate “value for money” amid “increasing global competition”, as well as the challenges and opportunities external to the space sector.

In the following, we shall consider some recent areas of change in space policy for both NASA and ESA. Such agencies act in a governance system between political authorities and innovation actors, creating innovation policies and programmes that connect the (broad) strategic aims of governments with the specific activities of innovation actors in the sector.[9]

The case studies are outcomes of two commissioned studies. Reacting to the pressures outlined above, the Office of the Chief Technologist of NASA commissioned a group of

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[8] See the European Commission grand societal challenges that guide Horizon2020 programme: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

[9] Both NASA and ESA sit in what Barré et al (2013) have called the “programming” functional layer of innovation system governance. The programming layer is sandwiched between the “orientation” layer (the realm of political authorities) and the “performance” layer (where concrete problems are solved, and knowledge and technology is produced by public labs and by firms). Such agencies are intermediaries between the two layers and have to work with (and within) both governance layers to shape innovation system processes (and directions of evolution).

economists to analyse challenges involved for NASA's involvement in creating an in-orbit space economy (Besha and Macdonald, 2016).[10] In a similar vein, and following shortly after the publication of this work, ESA's Space Economy group commissioned a study into challenges for market creation in the space sector (Mazzucato and Robinson, 2016).[11] That economists and innovation scholars are commissioned to provide policy advice is an indication of the existence of these pressures. The pressures that triggered the commissioning of the reports were very similar and thus triggered us to explore how these two, often complementary, space agencies located in different geographical regions address the pressures outline above. While focusing only on part of the portfolio of activities in each space agency has its limitations, we argue that they are illustrative of the policy challenges and responses that are taking place within these two public agencies that are important actors in their respective innovation systems.[12]

3.2 NASA: procurement and delegation

NASA has often been used as the prototypical mission-oriented agency, particularly through the Apollo Program's 'man on the moon' mission. NASA's mission-oriented programmes for innovation have historically been driven by security concerns and by the need to maintain technical leadership over other nations (Mowery et al., 2010).

The central position of NASA in the space "system of innovation" has meant that, for more than fifty years, NASA has directly financed technological innovation to achieve its missions, *setting the directions of change* and overseeing the private-sector companies that have been contracted to deliver the technologies. Today, the missions of technological innovation in space exploration are being broadened to include commercialization objectives.

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[10] For the NASA study, we conducted 15 semi-structured interviews along with analysis of the NASA internal archive.

[11] For the ESA case study, analysis of ESA documentation along with a number of semi-structured interviews with various representatives in the European space sector and the ESA itself.

[12] There are a number of limitations in this research activity. We have focused on illustrative areas of ESA and NASA activities based on small focused project research. An expanded study on all activities would provide more potential for comparisons of the portfolio of activities of each agency. In addition, another limitation is that we have only focused on Europe and the US although there are other space agencies of comparable size in Russia and China, with Brazil and India showing strong growth in space activities. Also, we miss out the military space activities. For the US, China and Russia, the military space activities play a considerable role in their national space innovation systems, thus an expanded study would factor in the role of defence.

In the past decade, NASA is seeking to create new markets, with a clear focus on fuelling a sustainable Earth low-earth-orbit (LEO)[13] economy – or, as International Space Station (ISS) Director Sam Scimemi put it, to "sustain economic activity in LEO enabled by human spaceflight, driven by private investments, creating value through commercial supply and demand" where the "destiny of LEO beyond ISS is in the hands of private industry outside the government box".[14]

According to a recent report from NASA's Office of the Chief Technologist, the 'drive towards a self-sustained low-earth-orbit ecosystem' has been positioned as a desirable objective for NASA's human spaceflight objectives (Besha and MacDonald, 2016). The report followed a wave of successive mission shifts and space policy directives that emphasize that the private sector should be given more power and be supported to stimulate space services. This shift towards an ecosystem approach is leading away from a 'market creation' approach to something resembling a 'fixing market failure' approach (Mazzucato, 2016).

In 2010, the US Congress directed NASA to create a cooperative agreement with a not-for-profit organization to manage the ISS US National Laboratory,[15] where in 2011 the Centre for the Advancement of Science in Space (CASIS) was awarded the management of 50% of the US National Laboratory, and associated up-mass (what is launched into space) and down-mass (what is returned to Earth). Operating costs for the organization were set at US$15 million per year from NASA to CASIS, including approximately US$4 million for technology development and demonstration projects. The new arrangement means that 50% of up-mass and 50% of scientific and operational activity of the national lab is mediated by CASIS to public and private actors. With CASIS acting as a broker with a strong decision-making role, with the power to decide how the US part of the ISS is used, it seems that, for the ISS, NASA is moving away from its role as the dominant *director* of innovation and development on the ISS and human space research and innovation in LEO (Foray et al., 2012) towards more diffusion-based policies (Chiang, 1991), where its role is to support the creation of the right

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[13] Low-earth-orbit (LEO) is the region of space stretching from 160 km to 2000 km from the Earth's surface. Besides the 24 astronauts that flew to the Moon during the Apollo Program, all human space activities have been restricted to this region of space. It is the location of the International Space Station.

[14] Presentation given by Sam Scimemi at NASA Headquarters Washington, DC December 10, 2014; http://www.nasa.gov/sites/default/files/files/NASA_Sam_Scimemi.pdf

[15] The US National Laboratory is a scientific module attached to the International Space Station where astronauts can conduct microgravity experiments.

conditions for markets to emerge. NASA generally foots the bill by providing access to space through its launches to the space station, as well as providing free access to the US National Laboratory. In conclusion, an examination of the relationship between NASA and CASIS reveals that there is a *delegation of control* over the use of the ISS from NASA to intermediary organizations that broker deals between NASA and potential users.

Another example of the shift in the US civilian space innovation system is visible in the new procurement approach in the US with regard to launchers (the rockets that take cargo and/or crew into orbit). In 2005, the establishment of the NASA Commercial Crew & Cargo Program Office (C3PO) resulted in two key programmes that provide a national private-sector capability of transporting cargo and crew to the International Space Station. The first programme was the Commercial Orbital Transportation Services Program (COTS), which was launched in 2006 to provide cargo transport to the space station. The second was the Commercial Crew Development Program (CCDev), launched in 2009 to provide the transportation of crew to the ISS, post Shuttle programme (NASA, 2014). The application of the Space Act Agreements (SAAs)[16] in COTS and CCDev has meant that more control of design and development has shifted *to* the contracted firm: the key milestones and the associated price are defined by the private contractor, which means they must deliver on time if they want to get paid.[17] By providing the company with freedom to define and deliver a service or technical capability in a way that it defines, NASA's involvement in the process is reduced with what is argued as a broader reduction in cost.

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Table 2: *Procurement contracts and agreements in crew/cargo transportation system*

Space Act Agreement or Federal Acquisition Regulations (FAR) Cost+ Contract	Awarded parties	Activity	Investment from NASA
Commercial Orbital Transportation Services (COTS)	Orbital and SpaceX	Orbital cargo delivery services to LEO	$891M Space Act Agreements

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[16] See this link for the Space Act Agreement concerning this partnership: http://www.nasa.gov/sites/default/files/files/SAA0-SOMD-11096_signed.pdf

[17] This is in stark contrast to the FAR-Cost+ form of contract, where NASA must foot the bill if there are delays or digressions.

Commercial Resupply Services (CRS)	Orbital and SpaceX	Cargo resupply services to the space station	$50M FAR Cost+ contract
Commercial crew Development Round 1 (CCDev1)	Blue Origin, Boeing, Paragon, Sierra Nevada and United Launch Alliance	Crew transport to LEO and new concepts	$315M Space Act Agreements
Commercial Crew Development Round 2 (CCDev2)	Blue Origin, Boeing, Sierra Nevada, SpaceX	Elements of a crew transport system	$1.1B Space Act Agreements

Note: This table is adapted from Mazzucato M. and Robinson D.K.R. (2017).

With this new mission of catalysing private investments into space infrastructures and services, NASA has led new forms of procurement to create a de facto market for private-sector-built and -operated launchers.[18] The two examples of launchers and use of the ISS imply that NASA is shifting from strong mission-oriented control of construction and operation of large public space infrastructures towards delegating the power to set the directions of the use and construction of publicly funded infrastructures to the private sector, with any profits made resting solely with the private sector.

3.3 The ESA: challenge-driven policy in a decentralized ecosystem

The European Space Agency is a pan-European public agency that coordinates a joint programme of research and development activities as well as providing infrastructures for European and other space operations. Mission-oriented policies are visible in ESA’s Convention, signed in 1975. A major mission of ESA was related to industrial policy on the space sector in Europe according to Article II.d of the Convention: “by elaborating and implementing the industrial policy appropriate to its programme and by recommending a coherent industrial policy to the Member States” (ESA, 2010). Article VII of the ESA convention explicitly places ESA’s mission with regard to industrial policy to build a competitive European industry by encouraging R&D and making maximum use of external contractors. It was mission-oriented investments such as these that coordinated public and

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[18] The US civil space budget is approximately four times larger than all of the European civil space budgets combined (national, ESA and FP7) (European Commission, 2013).

private initiatives, built new networks, and drove the entire techno-economic process, which resulted in the creation of new markets.

While 20th-century ESA activities focused on scientific exploration as well as supporting the European aerospace community through structured procurement, ESA's role was to provide a market for the nascent European aerospace sector (Petrou 2008).[19] ESA in the 21st century has seen commercialization activities increasingly prioritized, paying increasing attention to downstream applications, products and services in various space-based value chains. This is an outcome of the pressure to rethink European space innovation policy to provide not only science and spin-off technologies and services (the earlier model of innovation stemming from public-funded space activities) but to include products and services for consumers as well as public goods that address societal challenges. This shift is captured by recent debates in France on the position of France and Europe in the global space sector. Then French President Francois Hollande stated in January 2016: "French and European leadership in space exploration, satellites and launch vehicles is subject to tough international competition, especially from the United States, which gives massive support to NASA's science programs as well as to private-sector companies, notably SpaceX, which benefit from a high level of both private and public backing" (de Selding, 2016).

On this platform, former French Prime Minister Manuel Valls assigned Mrs Genevieve Fioraso with the task of identifying the decisions to be made to reinforce the strength and competitiveness of the French space sector. Preliminary results presented in 2016 by Lieutenant-Colonel Vincent Dedieu (rapporteur to Mrs Fioraso) revealed that:

> After the commitment in 2014 to ensure the "core" for space activities, Europe has to make the employment in downstream activities a priority ... Europe cannot just sit, watch and wait, as we first did with launchers. Europe has to be ready for the battle, which means coherence and coordination within Europe and to consolidate the launchers and address "New Space" (Dedieu, 2016)

This focus on the downstream (services and applications), rather than the supply (satellites, launchers and other technologies and infrastructures) is a radical shift in European space

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[19] A key element of the ESA procurement system is the principle of *juste retour* (fair return principle), where the Member States' national industries must be awarded contracts with a value almost equal to their respective contributions to the ESA budget .

policy. For this shift to occur, European civil space agencies such as ESA have to define desirable services and applications, seek strategies to support the creation of value chains stretching from upstream, through midstream to downstream, and create this in such a way as to combine providing public goods as well as creating a strong and globally competitive European space industry that brings jobs, growth and other benefits to European citizens (a mission clearly stated in its founding convention).

3.2.1 From supply chain innovation policy to intervention along the value chain

Exploring different ways of creating markets and supporting upstream, midstream and downstream parts of different space value chains has become a core element of ESA innovation policy. One of the key areas in which ESA is operationalizing its active innovation policy is in Earth Observation satellite technologies.

The European EO industry is still in its nascent stages; until relatively recently, EO with satellite activities has been fully funded by the public sector, particularly for defence purposes. For example, for Spot Image,[20] the first five EO satellites were fully financed by the public sector with the public sector as the key customer, meaning that the public sector took all the risk. However, Spots 6 and 7 became the first fully private-sector-financed EO satellites (Astrium). Furthermore, there was no prior agreement that the public sector would purchase Spot 6 or Spot 7 images, which meant that the private sector took the full risk.

DigitalGlobe, based in the US, is now the main private sector EO image provider globally, following a merger with GeoEye. A large share of DigitalGlobe’s sales come from contracts with public agencies, particularly the National Geospatial-Intelligence Agency (NGA), which is part of the US Department of Defence. Largely owing to this sizeable domestic market, DigitalGlobe has become the world leader in images from space. In Europe, the major players are Astrium and e-GEOS (controlling approximately 70% of the market), while the other relevant market players are companies such as RapidEye, DMCii and Elecnor Deimos. Thus, the EO industry has been dominated until recently by a handful of firms, primarily financed by the public sector.

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[20] Spot Image is a French company that started in 1982 as a public limited company owned by CNES (the French National Space Agency), the Institut géographique national (the French mapping agency) and a number of space companies including Alcatel and Matra.

Large players from the technology industry are becoming increasingly involved in space activities and have the capability to provide significant investments. Elon Musk and Space X are the best-known examples, but as Table 3 shows, there are a large number of technology entrepreneurs investing in what is being called New Space.

Table 3: *Billionaires investing in space*

Name	Net worth (billion $)	Source of wealth	Notable space affiliation
Bill Gates	79.2	Microsoft	Kymeta, Teledesic
Jeff Bezos	34.8	Amazon	Blue Origin
Larry Page	29.7	Google	Planetary Resources
Charles Ergen	20.1	Satellite TV	DISH Network
Paul G. Allen	17.5	Microsoft	Scaled Composites, Startolaunch Systems, Vulcan Aerospace
Ma Huateng	16.1	Internet	Satellogic, Moon Express
Sheldon Adelson	13.0	Casinos	SpaceIL
Elon Musk	12.0	Paypal, Tesla Motors, Solar City	SpaceX
Eric Schmidt	9.1	Google	Planetary Resources
Ricardo B. Sainas	8.0	Retail	OneWeb
Richard Branson	4.8	Virgin	OneWeb, Virgin Galactic
Subhash Chandra	4.2	Media	Teledesic, ICO
Lynn Schusterman	3.7	Oil and Gas	Space IL
Yuri Milner	3.2	Facebook	Plane Labs, SETI
Peter Thiel	2.2	Facebook, Palantir	SpaceX
Kavitark Ram Shriram	1.9	Venture Capital	Planetary Resources
Craig McCaw	1.8	Telecommunications	Teledesic, ICO
H. Ross Perot Jr.	1.8	Computer Services	Planetary Resources
Charles Simonyi	1.4	Microsoft	Planetary Resources
Kenji Kashara	1.4	Social Networking website	Astroscale

Moriss Kahn	1.0	Software	SpaceIL

Source: Tauri Group, 2016

In June 2014, Google Inc. made two major announcements. The first was an agreement to buy Skybox Imaging for US$500 million in cash and the second was a US$1 billion investment into SpaceX, with eyes on SpaceX's plans to build a large constellation of satellites to provide internet access from space. In March 2014, Mark Zuckerberg confirmed that Facebook's Connectivity Lab was working on Free Space Optics, a form of infrared laser that transmits information via light. The most significant initiative is OneWeb, which involves a massive constellation of several hundred small LEO satellites providing high-speed connectivity.

Whether they are from start-ups or major actors, these initiatives have some commonalities. They are launched by private actors, even when supported by public money or public orders. Even if these actors are not based in California, they apply the Silicon Valley approach. They are all fast and agile, are proposing scalable systems, and are convinced that their dream will become a reality. One example is Planet Labs, an American company that operates a number of new business models in satellite imagery that break the mould of traditional approaches. Planet Labs creates shoebox-sized satellites that launch through piggy-back launches and paid launches and are even launched from the ISS through the NanoRacks cubesat launcher. The business model is to create many small and cheap satellites, which are easily replaceable if they fail. However, Planet Labs has now acquired a key European satellite firm (which has EO platforms in orbit) – RapidEye (Marshall, 2015).

What is clear is that a global value chain is emerging with more players and a diversity of business models and includes firms that do not brand themselves as space firms but as information technology or media companies – where space is one means to deliver their products and services to clients. Here we can see the different service providers at each link in the value chain. The key growth area in New Space is occurring in the midstream, where data processing and dissemination and delivery are being conducted by rapidly growing start-ups, financed by dot-com billionaires and building new ideas for using EO data.

The ESA's Copernicus Programme adds to this mix and is likely to spur a variety of big data business activity (European Commission 2015).[21] The Copernicus Programme is the outcome

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[21] http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus

of combined efforts of ESA, the European Commission and the European Union to build a constellation of world-class EO satellites and instruments to monitor the Earth. The objective of the Copernicus Programme is to guarantee continuous access to data on environmental and security issues through dedicated state-of-the-art space-based EO platforms, known as Sentinels. Currrently six Sentinels have been launched so far. Copernicus plays a key role in observing land, sea and the atmosphere to help understand climate change as well as the European environment. In this way, it is designed to support climate change policies, contribute to prevention of climate change and its management, and support humanitarian aid and the general well-being of European citizens.[22] The Copernicus Programme also promises to open up opportunities for private sector usage of Sentinel data.

Copernicus provides its data for free and any user anywhere in the world can have access to images coming from the Sentinels. While ESA provides the data, the use of those images requires the development of application-specific algorithms to add value to the image – converting data into business.

Although EO programmes such as Copernicus are essential strategic assets for decision making, they require large investments, while the return on such investments remains unclear and open-ended. Copernicus promises high spillover effects into other industries, where other sectors benefit from different forms of high resolution imagery that can enable innvoation in areas such as urban planning, digital agriculture and block chain-based finacnial transactions (Torben 2017). ESA is facilitating the spillover effects by seeking ways of combining EO with the thematic demand-side areas.[23] ESA is facilitating innovations around using Copernicus data, such as through the Copernicus Masters initiative, a challenge-led competition run as a collaborative endeavour by ESA, the German Aerospace Agency (DLR), T-Systems International GmbH, Satellite Applications Catapult Ltd., the German Federal Ministry of Transport and Digital Infrastructure (BMVI) and Stevenson Astrosat Ltd. With a fund of approximately EUR600,000, prizes are awarded for proposing solutions to specific challenges set by the organizers that promise to lead to downstream solutions.

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[22] Copernicus, formerly GMES, has a legal basis that makes it a European strategic asset (see European Union 2010, p.1) , http://www.copernicus.eu/sites/default/files/library/Regulation_911_2010.pdf

[23] For example in ESA's ARTES Integrated Applications Programmes, dedicated to the development, implementation and pilot operation of integrated applications. https://artes.esa.int/iap/overview

As the Copernicus Programme begins to come fully online amid an emerging value chain of upstream, midstream and downstream, there are concerns that free images provided by Copernicus will undermine the growth of an EO market. In mid-2013, a group of commercial European midstream players jointly submitted a formal letter to the European Commission, in which they expressed their concerns about the potential effects on their businesses of Copernicus's proposed free and open data policy (Space-Tec Partners, 2013). These include price pressure, which would affect all commercial data providers. The availability of free Copernicus data could take market share away from the data providers offering similar products and services. In addition, there is downward pressure on the price of data expected from the influx of free data from Copernicus. There is also an argument that the free and open availability of Copernicus's services will raise awareness of the range and utility of EO products, and thus increase the demand for similar offerings, such as higher-resolution imagery or different product "bundling" and – further downstream – value-added products. Diversity and variety of relationships between the space sector and other sectors should be recognized, and there is a growing recognition in European space policy that the connections between downstream use, midstream actors and space supply chains should be catalysed, perhaps through the creation of demand articulation forums to facilitate demand-side policies (Edler and Boon 2018).[24]

3.2.2 Regional innovation ecosystems linked to societal challenges

In 2009, the Sixth Space Council meeting highlighted the need to think in terms of interventions into regional, national and European innovation systems as well as to connect the space value chain with other non-space value chains to build a stronger and more sustainable European space economy. In particular, the meeting emphasized "the need to mobilise existing innovation support mechanisms at European, national and regional level, and consider new support instruments to ensure cross-fertilisation of knowledge, innovation and ideas between space and non-space sectors, and between space industry and leading research organisations and universities" (ESA 2009).

The ESA's answer to this is to refocus part of its innovation policy on regional innovation ecosystems coupled with the idea of creating, or reframing existing, smart specialization strategies (Foray et al. 2009). This policy is to create programmes that create regional

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[24] Demand articulation forums are situations where *downstream industrial actors* and *users* meet potential *supply chain actors* to (a) define areas where value can be created, and (b) align interests and activities to be able to create potential ways forward, whether they are new partnerships, contracts or joint ventures.

expertise that can compete globally on elements of the space innovation value chain, including upstream, midstream and downstream segments as described above. Regional innovation ecosystems in this approach combine smart specialization in space supply chains with links to socio-economic needs and/or sustainable development goals,[25] for example, focusing on grand challenges such as food security and more recent challenges, particularly for Europe, regarding migration.[26]

In Europe, there have been a number of initiatives to link with the downstream of value chains. One example is the ESA Business Incubator Centre (BIC) network, currently located in 16 European locations focusing on the spin-out of ESA space technologies through a supply-push approach. While there has been significant success over the last ten years of activity, with growth in the number of centres, there is a tendency to think in terms of local specialities in the region of the BICs and potential demand-side activities. Hubs are emerging, both alongside and in conjunction with the establishment of the BICs. In the UK, for example, a focus on satellite production and applications is developing, with the colocation of the Satellite Applications Catapult, the new ESA European Centre for Space Applications and Telecommunications (ECSAT), along with the BIC. ESA makes use of a network of brokers that act as intermediaries between potential users and the technology offerings stemming from ESA activities. These brokers are spread across 15 countries and have heterogeneous experience; some are tightly focused on the space sector and some have a much broader portfolio of sectors to cater to. ESA also uses these brokers to assess the market needs in which there is potential for spin-off (Winch and Courtney, 2007; Klerkx and Leeuwis, 2009).

3.4 Synthesis of the two evolutions in innovation policy

Agency	Activity	Evolution in mission-oriented policies.
NASA	Development of crew and cargo launch capability *(COTS)*	An evolution from *Type-1* mission-oriented policy towards a combination of *Type-1* and *fixing market failure* approaches using demand-side instruments (procurement).

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[25] http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/ESA_and_the_Sustainable_Development_Goals

[26] http://www.esa.int/Our_Activities/Preparing_for_the_Future/Space_for_Earth/Space_and_migration_jam_session

NASA	Market creation using the International Space Station *(CASIS)*	An evolution from *Type-1* mission-oriented policy towards a combination of *Type-1* and *fixing market failure* approaches delegating 50% to an external private intermediary organization.
ESA	Earth Observation system *(Copernicus)*	An evolution towards a combination of grand challenge-driven *Type-2* mission-oriented innovation policy and fixing *system failure*.
ESA	Network of Business Incubator Centres *(BIC)*	An evolution towards a combination of grand challenge-driven *Type-2* mission-oriented innovation policy and fixing *system failure*.

Table 4: Summary of the four space activities and the policy evolutions.

Table 4 summarizes the evolutions in mission-oriented policies for the four space activities described above. Earth Observation is just one example of how ESA is shifting from an innovation policy. In the 20th century ESA has focused on fixing market failures by providing a stimulus to create a European supply chain through upstream initiatives through procurement, contributing to the growth of many of Europe's largest aerospace companies dealing with space. This has achieved its original goal outlined in its constitution of creating a globally competitive supply chain. However, its new policy is not only to focus on the high investment and high risk upstream activities, but also to seek ways of intervening in supporting and directing downstream space applications for the benefit of European citizens, and in the case of EO and freely available data, the benefit of the whole globe. ESA is also shifting towards supporting challenge-driven regional innovation ecosystems, to nurture and grow hubs that can compete globally upstream, midstream and downstream in global space value chains, and to shape the direction of these regional innovation ecosystems in desirable ways.

EO has been heavily financed by the public sector to provide images from space for national needs. Where the private sector has taken over, it has been with the public sector as anchor tenant, guaranteeing purchase of images and services from the private sector, thereby de-risking the endeavour. An emerging private-sector value chain is developing, as can be seen in the emergence of big data firms, aggregating and adding value to images from space, as well as the emergence of private manufacturers of EO satellites.

The Copernicus Programme, which provides free and high-quality EO imagery, has created opportunities across the globe to build value-added services that are based on, or augmented by, space-based images of the Earth. Despite some concerns about the free images undermining a nascent supply chain of EO imagery, it can also be argued that the availability of high-quality imaging stimulates added-value service creation, which will increase the demand for EO imagery and space-based services. This is already visible in New Space, as can be seen in companies such as Orbital Insight, which is solely based on transforming EO imagery into strategic intelligence, and Planet Labs' purchase of Rapid Eye satellites and launch of its own "disposable" satellites. It is clear that the growth of big data analytics, with firms specializing in EO big data, there is already a diversification in the value chain. This is captured in a recent report showing that both midstream and downstream segments of the EO chain are emerging and consolidating (Space-Tec Partners, 2013).

For ESA and other European space agencies, the issue is not about whether to provide Copernicus images free of charge but about how to create an ecosystem of thriving EO-enabled innovations and services that can capitalize on the Sentinels and other platforms to provide globally competitive value propositions.

Thus, the trade-off is between mission-oriented innovation policy and a more catalytic role for facilitating diffusion style bottom-up activities. The right mix of policies and public–private partnerships is needed in order to create a competitive European EO industry.

Table 4 summarizes the innovation policy applied by NASA. In this case, the degree of decentralization is different for various parts of the US space innovation system, for example, with its new procurement approach for launchers, NASA places the design and delivery responsibility on the private sector, at the same time as providing loans and guaranteeing sales in advance. Thus, NASA is shifting away from a strong directing role, where the design and development was tightly directed by NASA, towards a looser and more facilitating approach where the private sector is becoming a prominent actor, not only in producing technologies and services under contract, but also in deciding on the direction of technology development and the *direction* of parts of the space innovation ecosystem – visible in the US around launchers.[27]

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[27] This is already the case for cargo to LEO, where SpaceX and Orbital-ATK have benefited from the Space Act Agreements as a simpler procurement approach. The SSAs<should this be SAAs?> have been described as a new way of fostering interaction between NASA and the private sector, beyond traditional Federal Acquisition

Thus, NASA is combining a mission-oriented innovation policy (Type-1) goal of creating a strategic asset (launchers) by fixing market failures, but leaving the direction of development and the decision to continue providing launch services to the private sector. For the US segment of the ISS – the National Laboratory – providing free for the private sector (and any other actors) 50% of launcher payload, 50% of their astronauts' scientific time aboard the ISS and 50% of their return payload delivery, without any need to provide a return to NASA, shows a shift from a mission-oriented innovation policy seeking guaranteed returns on investment (achieving the mission) to a looser market fixing approach, with benefits appearing in a more dispersed way through having an active private space sector.

There is a clear and striking difference in the evolution of innovation policy framework of NASA for low-earth orbit activities and that of ESA for its Earth Observation activities. In the following section we draw out some of the challenges (and opportunities) that arise through these differently evolving innovation policy frames.

4 Diagnosis of the evolution and challenges for space innovation policies

The Space 4.0 vision challenges ESA to create and shape markets, along with other key international partners. This includes using a mission-oriented objective function, where commercialization objectives do not get confused with the mission but are seen as key to the *spillovers* which are created in the long run. For NASA, the hybrid nature of the "mission" of creating a sustainable economic zone in Low-Earth Orbit, with the practice of applying "market fixing" opens up a number of issues of sustainability and directionality. Below we outline some of the issues, challenges and opportunities that are emerging for both ESA and NASA.

4.1 Fixing directionality failures

While ESA is evolving towards a *challenge-driven* innovation policy approach, NASA seems to be evolving towards a *market-driven* innovation policy. By delegating much of the directionality of innovation on the International Space Station to an intermediary organization, and also reducing its role in directing development and ownership of the next

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Regulations cost-plus contracts. SpaceX already has non-NASA contracts for launching communication satellites, which means that, for cargo, US launchers are fully privately designed, built and operated.

generation of space launch vehicles, NASA is moving towards an increasingly *fixing market failure* policy, leaving it to the private sector to direct innovation systems. A key challenge for NASA is whether to make clearer the desirable directions for the low-earth orbit economic zone and further detail *how* its policies will benefit the US innovation system.

4.2 A dynamic combination of horizontal and vertical policies

With its motivation of facilitating and intervening in the value chain, not only upstream, but also mid- and downstream, ESA's industrial policy must be targeted across the entire innovation chain, including demand-side policies, via procurement, which are especially key in triggering the business sector to market opportunities in space.[28] Mission-oriented vertical (direct) policies need to work hand in hand with horizontal framework (indirect) policies. Both types of policies should be targeted at different stages of the innovation chain. Mission-oriented policies can actively create new landscapes that increase the expectations in the private sector for new growth opportunities. For NASA's and ESA's objectives of market creation, both the European and US space innovation systems would benefit not only from support policies that facilitate innovation, but also from active mission-oriented public agencies built on public–private partnerships that help the ecosystem to grow, flourish and compete in global value chains. This will require both vertical and horizontal policies. Vertical policies are more *directional* and "active", focusing on directing change, often through missions that require the active creation and shaping of markets. Horizontal policies are more focused on the background conditions necessary for innovation, correcting for different types of market and system failures, such as the need to fund infrastructure and the creation of intermediary organizations between science and industry. When enacted alone, horizontal policies assume that the direction of change is set by the private sector, with the public sector only "enabling" and "facilitating". Innovation policy in an era of Space 4.0 must be under no illusion: it requires both types of policies. The public sector can strongly direct upstream policy through vertical measures, in areas where the potential for growth is not yet visible, and where the private sector is hesitant to take risks. Downstream policies can support and promote the involvement of the private sector through horizontal measures.

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[28] The innovation chain comprises chains of development of new technology or service innovations. The stages include research, concept/inception, early-stage development, product development and production/marketing.

4.3 Bottom-up experimentation connecting regions and challenge-driven innovation policy

A dynamic mix of vertical and horizontal policies should focus on achieving bottom-up experimentation, where new sources of value and growth are explored and catalysed by new forms of public–private partnerships. Lessons can be learned from space districts such as Harwell (UK) for satellite applications and Aerospace Valley (France). With the European flagship programmes such as Copernicus, there is great potential to connect these platforms to specialized districts to drive innovation, jobs and growth. Vertical and horizontal interventions should be linked to ESA's mission, which can then invite private sector interactions based on these missions, through specific projects, and through instruments, such as prizes, that reward success on key metrics. In the US, we see that CASIS has refined its strategy to connect with specific thematic regional hubs, for example lifesciences in the Boston area. While there are some emerging space districts in Europe, there is potential for further consolidation of these space districts through coordination approaches with regional actors and ESA. It is particularly important, for connecting regions to societal challenges, either to connect space districts to existing non-space ecosystems in order to leverage existing synergies or to stimulate hybrid ecosystems where strong ties between space and other sectors are connected early on. For example, connecting space ecosystems to pan-European application-oriented ecosystems such as the European Connected Health Alliance might be an interesting route to explore.[29] This would facilitate pan-regional ecosystems similar in character to the smart specialization strategy – creating a joined-up approach that can compete in global value chains.

4.4 New forms of partnerships and relationships

Various forms of relationships between ESA and the private sector and different options can be pursued. Brokers and intermediaries are emerging as players in the transfer of space technologies from ESA space programmes to other sectors (spin-offs). However, for such activities to be fruitful, *demand-pull initiatives* and *spin-in* opportunities must be explored. Historically, although ESA activities rely on contracts with the private sector, ESA has maintained in-house scientific and technical expertise that allows for good relationships with the private sector, guaranteeing high-quality services. This means that demand-side policies

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[29] https://echalliance.site-ym.com

should be harmonized with space-centric *supply-side policies* to seek alignments (and misalignments), which require more active engagement with other sectors and perhaps the pursuit of demand articulation forums. Alternative approaches can be part of this mix through initiatives such as prizes and crowdfunding, which would stimulate supply of innovations directed through demand-side competitions.

4.5 Symbiosis and mutualism in risks and rewards

Space agencies could seek mechanisms for public–private partnerships that involve co-investment and sharing of risks and benefits. Ecosystem thinking can provide a means of assessing case-by-case degrees of risk/benefit sharing where symbiotic ecosystems are targeted, to refuel public funding sources and generate the greatest amount of spillovers to the public. Sharing risks and benefits requires dedicated policies. Using the Copernicus Programme as an example, the world benefits from images from the Sentinels, but various areas of the world are *better prepared* to exploit these images than others. This situation is most evident in the US, and not restricted to imaging, with the rise of New Space companies such as Planet Labs, Space X and Nanoracks. Therefore, it is not a matter of whether assets such as publicly funded imaging data are free or not, it is a matter of the ability of the public agencies that have invested in the costly spacecraft and infrastructures to capitalize and benefit. Different modes of exploitation and innovation need to be explored in Europe to be able to compete in exploitation. Alternative risk- and benefit-sharing mechanisms can help. Examples that could be explored include the capping of prices on services using publicly funded infrastructures and applying these to private-sector services that exploit assets such as Copernicus. Other ideas could be a percentage payback by the private sector, which profits from downstream innovations, into an “innovation fund” directed at future upstream missions.

4.6 A general challenge of dynamic evaluation and assessment

Public policies often rely on static approaches to assessment such as cost–benefit analysis. For transformative change, more dynamic measures are needed in order to measure the socio-economic impact of space. Such measures should be focused on the entire innovation chain, with spillovers being the focus upstream and formation of high-growth innovative companies downstream. If missions are to be combined with horizontal policies, then the growth of the companies might also be measured in terms of the value of the products and services they produce. In this way, societal challenges can help steer the metrics so that public funds produce public value. Evaluation processes should be linked with agency's core missions, connecting directly selected *challenges*,[30] which can be used to guide interactions with the private sector and guide the process of public and private development of the downstream sector. Furthermore, if bottom-up experimentation is an objective, then horizontal policy success can be based on the extent of downstream private sector experimentation with space application development. For NASA this is less clear, since challenge-driven innovation policy is not visible in its market-fixing framing of US civilian space innovation policy. Finally, to achieve symbiosis, metrics should be developed that capture the degree to which both the risks and the rewards of innovation in space are socialized.

5 Conclusion

In this paper, we argue that there are new types of mission-oriented policies that we have called Type-2 mission-oriented innovation policies. In contrast to the centralized Type-1 missions such as the Apollo Program and the Manhatten Project, Type-2 mission-oriented policies need to be enacted in a decentralized and distributed innovation system, connecting broad, complex and often contested challenges with concrete problems to be solved by innovation actors. Type-2 policies can capitalize on bottom-up activities (common to diffusion-oriented policies), but the agencies that facilitate them also must connect with political authorities. We have shown that a number of pressures have triggered policy changes in both NASA and ESA. For NASA, the response has been to evolve strong Type-1 approaches towards a mix of Type-1 approaches and a fixing market failure approach, delegating much of the "directioning" of the innovation system to private actors. For ESA, the response has been a combination of fixing system failures and attempts at Type-2 missions linked with sustainable development goals.

In the previous section we have used these two case vignettes to draw out challenges for innovation policy, particularly around market creation, which is a going concern for both agencies. Global industries are becoming more connected and interlinked, as epitomized by the idea of Industry 4.0. At the same time, industrialized nations are also seeking to connect industrial transformations with grand societal challenges. Challenges such as migration, food

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[30] Note that ESA is already actively engaged in linking its activities with these sustainable development goals. The issue here is to find measures of socio-economic impact that stem from these sustainable development goals. 'THESE sustainable development goals' ? which SDGs? you don't mention them in this subsection

security, ageing, climate change, terrorism, urbanization and poverty are being connected to innovation-driven "smart growth" agendas, as in the European Commission's Horizon 2020 and the upcoming Horizon Europe.[31] These opportunities allow the *direction* of innovation to receive as much importance as the more traditional focus on the *rate* of innovation. The combined objective of achieving growth that is more inclusive and challenge-led, and growth that is led by the opportunities posed by Industry 4.0, gives European and US public agencies an opportunity to consider how to use mission-oriented policies to tackle societal problems. In the case of space, this dual objective can help to better define, develop and operate publicly funded space infrastructures (such as the International Space Station) in ways that develop new types of partnerships with the private sector, with the goal of developing new technologies and services that can help companies compete in global value chains, while also addressing the *direction* of innovation. This has to be achieved in an era of growing competition between regions, where more actors, global value chains and decentralized innovation processes motivate agencies to focus on improving global competitiveness.

Public space agencies play an important role in both the US and European space sectors; specifically, their role is to (a) create linkages between non-space innovation systems and the space innovation system, (b) coordinate long-term infrastructures with "public good" characteristics,[32] and (c) to catalyse and govern space-involved innovation systems. In Europe, these three elements are complementary to the activities of other public agencies (such as the European Commission) and industry associations (such as the European Association of Remote Sensing Companies). ESA combines this with an industrial and innovation policy that focuses on the European space innovation *eco*system, which frames public–private partnerships as symbiotic relationships directed towards a competitive European space sector in line with sustainable development goals.

The US situation is less clear. While a broad aim of stimulating new markets in low-earth orbit is announced as a key mission, the approach to doing so, as described above, seems counterintuitive. A special issue of *The Economist*, "Remaking the Sky", dedicated to the emerging new role of the private sector in space, states: "Even if for now most of the money being spent in space remains with old government programmes and incumbent telecom

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[31] http://ec.europa.eu/horizon-europe

[32] A large share of space investments can be said to have public good characteristics, where the socio-economic benefits are wide-ranging and extensive. Examples such as Copernicus and Galileo are space investments that have a large public good element.

providers, space travel is moving from the world of government procurement and aerospace engineering giants to the world of venture capital funded start-ups and business plans that rely on ever cheaper services provided to ever more customers” (Economist, 2016).

Similar predictions of *The Economist* and other fans of the “free market” around innovation have proved simplistic. Some of the greatest advances in Silicon Valley’s IT revolution have been and continue to be co-funded by government – from the grant behind Google’s algorithm, to the technologies inside the iPhone, to the large guaranteed loan (by the US Department of Energy – DoE) provided to Tesla (Mazzucato, 2013, Mazzucato and Penna 2015). The green technology revolution is today being fuelled by risk-taking government investments in countries such as China, Denmark, Germany and the US. Indeed, it was the DoE’s ARPA-E (Advanced Research Projects Agency – Energy) that recently attained the “holy grail” of energy – the next-generation system of battery storage (Goldberg, 2016) . The future of space will be determined by breaking down the dichotomy between “old” government and “dynamic” entrepreneurs. What is needed is an “entrepreneurial” innovation ecosystem that involves a network of public and private actors to work together in new and dynamic ways.

The innovation policy challenges for NASA and ESA reflect challenges faced by other mission-oriented public agencies around the globe. Mission-oriented organizations can be viewed as driven more by the willingness and ability to shape and create markets, rather than just fixing markets. At the same time, failures in both markets and systems continue to plague the landscapes in which such agencies operate. Hence, agencies that seek to use industrial policy to tackle key challenges facing space technology face the dual challenge of highlighting different types of “failures” that need to be corrected, for example *directional* failures, while also retaining a challenge-driven approach that seeks to do more than fix existing markets and systems. The latter requires more attention to be placed on the multi-layered ecosystem of public and private actors along with third parties such as organized critical groups, which can shape and create a new type of space system driven by “big thinking” along grand challenges and also connect to concrete actions through mission-oriented innovation policies. This creates challenges at the organizational level of mission-oriented public agencies: how to organize such focal functions and deal with the high pressure of being the person-in-the-middle, on whose functioning every ecosystem actor has an opinion? This is the challenge of *implementing* mission-oriented policy and should be the focus of further research by scholars and practitioners exploring mission-oriented research and innovation policy.

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