Space Technology under NASA and SpaceX

The relationship between public and private innovation

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I. Introduction

Space in social context

We stand at the dawn of a new age for humanity’s place in the universe, the age of space exploration. From the 1950s to the 2050s, we are set to have taken the path of a century-long leap from the confinement of our Earth into a multi-planetary species. Today, it is within this social context that innovation in space technology must be considered (Fig. 1).

![Space Exploration Timeline](image)

Fig. 1 - Space exploration timeline from Sputnik to Mars. Source: Bartu Kaleagasi

It is on October 4th, 1957, that the Soviet Union (USSR) launched the first ever artificial satellite into orbit around the Earth. Sputnik was small metal sphere with four antennas, relaying basic radio transmissions. This event would kick-start a decade of unprecedented research and development into space technology, forming the basis of the famous Space Race between the USSR and the United States, competing for spaceflight supremacy as rivals in the all-encompassing Cold War of the 20th century.

As a reaction to what President Eisenhower called the “Sputnik Crisis”, the United States promptly established the National Aeronautics and Space Administration (NASA) in 1958, starting with a historically low budget of $89 million (0.1% of federal budget), 3 major research laboratories, and 2 testing facilities.\(^2\) That same year, the United States had launched its own satellite into orbit, Explorer 1. Using instruments on board, it measured radiation levels around the Earth and discovered the existence of the Van Allen radiation belts.\(^3\)

![NASA Budget as a Percentage of Federal Budget](image)

**Fig. 2 – NASA funding from 1958-2012. Source: United States Office of Management and Budget**

After a series of developments, including the first animal in orbit with Sputnik 2 (USSR, 1957)\(^4\), the first rocket in Moon orbit with Luna 1 (USSR, 1958)\(^5\), the first photograph of Earth with Explorer 6 (USA, 1959)\(^6\), and the first satellite to reach the Moon with Luna 2 (USSR, 1959)\(^7\), everything changed on April 12\(^{th}\), 1961. The USSR had just

\(^7\) "Luna 2." NASA. Web. 8 Jan. 2017.
launched their Vostok 1 capsule, carrying the first human ever to be in space: Yuri Gagarin.8 This propelled the space industry into a paradigm shift akin to Thomas Kuhn’s theory in The Structure of Scientific Revolutions, opening the first page of manned spaceflight and marking the beginning of an astronomical rise in NASA’s public funding (Fig. 2).9

Awarded with 3-5% of the federal budget in the mid-1960s, NASA went through the golden age of its advancements in space technology. Having concluded Project Mercury in 1961, sending Alan Shepard into space just a month after Yuri Gagarin, the United States was ready to announce its grandest endeavour yet; the Apollo programme.10 It was in 1962 that President John F. Kennedy, addressing the nation, gave his historic speech: “We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard”.11 In the meantime, the USSR sent the first probe ever to land on the Moon, Luna 9, in anticipation of their own efforts against NASA’s new objective.12 The implications were not only scientific, but extended well into the public’s perception of the United States and the USSR’s technological abilities in the event of a potential war.

On July 20th, 1969, Apollo 11 successfully landed on the Moon and Neil Armstrong became the first man ever to step on a celestial body beyond the Earth. Although the Cold War would continue until the USSR’s collapse in 1991, the United States was declared the de facto winner of the Space Race. Despite a substantial decline in public funding after the 1960s, NASA and its competitors continued to innovate on all fronts of space technology. Developments to this date include the first probe on Venus with Venera 7 (USSR, 1975),13 the launch of deep space probes Voyager 1 & 2 (USA, 1977)14, the first reusable space shuttle

10 “The Apollo Missions.” NASA. Web. 8 Jan. 2017
12 “Luna 9.” NASA. Web. 8 Jan. 2017
13 “Venera 7.” NASA. Web. 8 Jan. 2017
(USA, 1981), the first probe to enter Jupiter’s atmosphere with Galileo (USA, 1995), the launch of the International Space Station (ISS, 1998), Curiosity rover’s landing on Mars (USA, 2012), the first soft landing on a comet with Rosetta (ESA, 2014), and the first reusable rocket with Falcon 9 (SpaceX, 2015).

This brings us to the modern landscape of space technology, which is formed by a multitude of both public and private competitors (Fig. 3). The industry’s leading players now include national organisations NASA (USA), Roscosmos (Russia), ESA (Europe), CSA (Canada), CNSA (China), and ISRO (India), as well as commercial entities SpaceX (Elon Musk), Blue Origin (Jeff Bezos), United Launch Alliance (Lockheed & Boeing), Arianespace (Stephane Israel), and Orbital ATK (David Thompson). This essay will focus on NASA and SpaceX, reviewing their respective achievements in space technology, as well as analysing the relationship between public and private innovation in that sector.

Fig. 3 – The 8 sectors of space technology. Source: NewSpace Global

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15 "Space Shuttle Era." NASA. Web. 8 Jan. 2017
17 "International Space Station." NASA. Web. 8 Jan. 2017
19 "Rosetta." ESA. Web. 8 Jan. 2017
20 "Falcon 9." SpaceX. Web. 8 Jan. 2017
Innovation theories

For the purposes of this analysis, it is necessary to consider the space industry’s dynamics through the scope of various innovation theories. The most relevant ones in this case have been determined as: (i) theory of disruption, (ii) systems and salients, (iii) research & development, and (iv) national innovation.

Theory of disruption will be related to SpaceX’s recent entry into the sector as an organisation which offers commercial spaceflight rather than focusing exclusively on scientific missions. Systems and salients will be related to SpaceX’s progress in overcoming the reverse salient of reusability in rockets, which is one of the greatest challenges facing the sector’s commercial feasibility and profitability. Research & development will be related to both NASA and SpaceX’s investments in space technology, with specific focus on the contrast between public and private incentives. Finally, national innovation will be related to the way in which policies are used to achieve technological progress, whilst also considering whether SpaceX can fill that gap by either overtaking NASA with commercial spaceflight, or working together with them a public-private basis.
II. Literature review

Theory of disruption

The theory of disruption, most prominently developed by Clayton Christensen in his Harvard Business Review article *Disruptive Technologies: Catching the Wave* (1995), is now a cornerstone of modern innovation theory.\(^{21}\) Although it has a relatively wide scope of application, its constituent elements must be carefully observed in order to ascertain its relevance to each case.

![Christensen's theory of disruption. Source: Harvard Business Review](image)

First of all, Christensen draws a distinction between disruptive innovations and sustaining innovations. The latter is characterised as technologies which “give customers something more or better in the attributes which they already value”, whereas the former refers to technologies which “introduce a very different package of attributes from the one mainstream customers historically value”. Second, the theory contains an element of “low-end disruption”, which refers to the fact that disruptive technologies tend to enter the market at the lower end of its performance and price spectrum. Thus, in Christensen’s scenario, the

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incumbent has often left a gap in the market, which the disruptor uses to capture its first customers as a new entrant, even if profit margins are not substantial (Fig. 4).

Finally, the disruptor’s entry is often followed by further innovation, which allows it to increase profit margins as well as fundamentally change the sector’s landscape by re-defining the customer base’s expectations of which attributes are both desirable and available. The classic example given by Christensen is the advent of Hard Drive Disks (HDDs), whereby high-end suppliers were focusing on the needs of governments and businesses (storage capacity and retrieval speed), thus overshooting the needs of low-end consumers. As smaller, more portable, and lower-cost HDDs entered the market, those new technologies disrupted the playing field and eventually overtook the market share of most specialised producers at the time. However, as observed by Harvard professor Jill Lepore, some companies including Seagate were actually able to survive this disruption and retain their position as market leaders.²²

**Systems and salients**

Systems theory, within the context of technological innovation, analyses the interactions and interdependences between various components of a technology. In his publication *Networks of Power: Electrification in Western Society* (1983), Thomas Hughes emphasises the significance of the systems approach as a tool to understand why progress happens when it does, and which conditions serve as its catalysts.²³ As per Jonathan Liebenau, these factors can be classified as (a) interconnectedness, (b) agency of artifacts, (c) momentum, and (d) salients.²⁴

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Out of those conditions, salients are the most pertinent to space technology. The term *salient* is used to describe a scenario whereby a certain sub-technology has progressed beyond its complementary components, whereas the term *reverse salient* expresses the opposite case. As per Hughes, a reverse salient “appears in an expanding system when a component of the system does not march along harmoniously with other components”. Thus, as the system evolves towards an objective, a certain sub-technology falls behind and hampers the entire sector’s continued growth. Reverse salients are often applied to analyse the progress of sectors derived from general purpose technologies (GPTs), although that is not always the case. Notable examples include braking technology in railways, battery technology in mobile phones, and battery technology in electric cars.

**Research & development**

Research and development, commonly referred to as R&D, can be divided into 3 distinct stages: (1) investment, (2) output, and (3) returns. Unlike many other forms of investment, R&D entails a high degree of both scientific and financial uncertainty, as well as a non-fixed rate of return and undetermined payback period. R&D output can take many forms, which may be classified from most abstract to most tangible as: scientific knowledge, intellectual property, upstream products, and downstream products. Whilst the first three types of output can be re-used as inputs for further R&D, the fourth type is usually sold as an industrial or commercial product. However, as per Aurora (2001), intellectual property such as patents and licenses can also be considered as products, forming what is referred to as “markets for technology”.

Finally, the different forms of returns from an R&D project include (a) direct financial returns, (b) indirect financial returns, and (c) social returns. Economically, social returns can

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be characterised as the result of any technology or product which has a positive externality that exceeds its market equilibrium, thus justifying the provision of public funding and subsidies (Fig. 5). It is important to note that social returns can manifest themselves directly (ex: aerospace technology), indirectly (ex: scientific advancement), or even intangibly (ex: public inspiration).

Fig. 5 – Positive externality for space technology. Source: Bartu Kaleagasi

This distinction is particularly significant when analysing the space industry, as national organisations focus primarily on social returns, whereas commercial firms are often required to prioritise financial returns as a means of maintaining liquidity and profitability. This has interesting implications with regards to the different sets of incentives and objectives at play, as well as how they affect R&D investment decisions in space technology. Another concept of particular relevance to this industry is “mission-oriented finance for innovation”, whereby Laplane (2015) observes the importance of technology management in mission-based projects, stating that “public agencies in charge of defence or space programmes
usually have experience in using technology management tools, unlike most public agencies in other areas”.

**National innovation**

National innovation, as a broad term, involves such concepts as the military-industrial complex, innovation policy instruments, complex innovation, and public-private partnerships. As per Nelson & Rosenberg (1993), national innovation systems can be defined as “a set of institutions whose interactions determine the innovative performance of national firms”.

The military-industrial complex, which was coined by President Eisenhower in 1961, refers to the relationship between a nation’s military forces and the technological institutions which support it. Within the context of the Space Race, NASA was an essential part of this ecosystem, particularly with regards to aerospace technology, ballistics, and surveillance capabilities against the USSR. Innovation policy instruments are any measures which can be taken by government to incentivise innovative processes. As per Edler & Georghiou (2007), these can be divided into a taxonomy of supply-side and demand-side measures. According to Kuhlmann & Smits (2004), this involves systemic policy instruments with the objective of preventing lock-ins, building spaces for interaction, and supporting creativity. Complex innovation refers to the fact that innovation often happens within a “complex system”, involving a large number of companies, knowledge institutions, financial institutions,

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regulatory agencies, and sociocultural developments, which is highlighted by Lundvall (2004) in his paper on national innovation systems.\textsuperscript{31}

Finally, a public-private partnership (PPP) is any venture in which national and commercial institutions cooperate to achieve a common objective. As per Hodge and Greve (2016), this can involve any combination of joint financing, common management, risk allocation, and strategic alliance.\textsuperscript{32} PPPs can result in a significant synergetic effect, combining the strengths of a governmental organisation (public funding, access to knowledge, low liquidity requirements) with those of a private firm (private financing, creative potential, flexibility). However, if the two parties’ objectives are misaligned, it can also lead to significant difficulties related to the allocation of resources, acceptable levels of operational risk, and public relations.

III. NASA technology

NASA’s contributions to space technology cover almost all stages and sectors of the industry. Its main activities include: (i) satellites, (ii) probes, (iii) launch capabilities, (iv) manned spaceflight, (vi) rovers, and (vii) astrotechnology. Relevant divisions include the Space Technology Mission Directorate (STMD) and the Jet Propulsion Laboratory (JPL).

Satellites

NASA’s satellites fall under the STMD’s Small Spacecraft Technology Program (SSTP). In the last few decades, it has launched several dozen satellites, mainly used to support the Earth Sciences division’s research on geophysics and climate change (Fig. 6).33

One of the earliest missions was Explorer 6, which was the first satellite ever to take a photograph of Earth from orbit.34 Today, the SSTP’s various projects include (a) Nodes: satellites which display swarm-like network capabilities; (b) OCSD: high-speed optical

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33 "NASA’s Earth Observing System." NASA. Web. 8 Jan. 2017
34 "Explorer 6." NASA. Web. 8 Jan. 2017
transmission of data; (c) ISARA: increased downlink data rates; (d) CPOD: proximity operations and docking using CubeSats; (e) PTD: propulsion, stabilisation, and communication systems; (f) EDSN: satellite networking demonstration; and (g) iSat: new propulsion and thruster technology. The programme also has a large number of partnership projects with leading universities, which are selected on a 3-year basis.

Probes

NASA’s probes, also referred to as robotic spacecraft, are primarily under the operation of JPL. They are used to explore, collect valuable data, and take photographs. In 1962, its Mariner 2 probe was the first object ever to encounter another planet, Venus.

Since then, JPL has been responsible for the technology behind many of NASA’s most ground-breaking missions, including the Viking probes sent to explore Mars (1975),

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36 "Smallsat Technology Partnership Selections NASA-University Collaborations." NASA. Web. 6 May. 2015
Voyager 1 & 2 probes sent to explore the outer planets and deep interstellar space (1977),
Galileo probe sent to explore Jupiter (1989), Cassini-Huygens probe sent to explore Saturn
(1997) (Fig. 7), and Juno probe sent to further examine Jupiter’s atmosphere (2011).38 In the
early 2020s, NASA plans to launch a probe to explore Jupiter’s moon Europa, looking for
potential signs of life as part of its new focus on astrobiology research.39 This will coincide
with ESA’s Jupiter Icy Moon Explorer (JUICE) mission, which will also explore Europa, as
well as its sister moons Callisto and Ganymede.

Launch capabilities

NASA’s launch capabilities are developed in successive waves of rocket technology,
each one designated as its own programme. They often make use of the Kennedy Space
Center’s ground operations and launch facilities, located in Florida. The Apollo 11 mission’s
launch vehicle was Saturn V, a three-stage liquid-fuelled expendable rocket, which to this
date remains the heaviest payload as well as the only one ever to carry humans outside low
Earth orbit (LEO).40

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38 "All Missions." NASA Jet Propulsion Laboratory. Web. 8 Jan. 2017
40 "What Was the Saturn V?" NASA. Web. 17 Sep. 2010
A notable development was the Space Shuttle programme, the first ever partially-reusable launch system, which started operating in 1981 with a fleet of 5 space shuttles: Columbia, Challenger, Discovery, Atlantis, and Endeavour.\textsuperscript{41} Unfortunately, both Challenger and Columbia were destroyed during spaceflight, leading to a gradual decline in enthusiasm and the programme’s eventual closure in 2011. That same year, NASA announced the Space Launch System (SLS), a new and improved launch vehicle which is being manufactured by Boeing, ULA, Orbital ATK, and Aerojet Rocketdyne, due to start operations in 2017.\textsuperscript{42} Current alternatives include Atlas V (ULA), Delta IV (ULA), Falcon 9 (SpaceX), and Falcon Heavy (SpaceX).

**Manned spaceflight**

NASA’s manned spaceflight technology covers all components related to human survival in space, including: command modules, service modules, lunar modules, space stations, space suits for extravehicular activity (EVA), life support systems, and on-board scientific experiments. NASA’s first ever space station was Skylab, which orbited the Earth from 1973 to 1979, followed by laboratory projects Spacelab and Shuttle-Mir, and eventually the International Space Station (ISS) in 1998. In 2015, NASA officially announced plans for its “Journey to Mars” (Fig. 9), stating that they will be using an SLS launch vehicle and Orion spacecraft to land humans on Mars by the 2030s.\textsuperscript{43} Preliminary steps in the Orion programme will include sending astronauts to explore an asteroid in the 2020s, testing new technologies like solar electric propulsion, and conducting research on human survival in the deep space environment.\textsuperscript{44}

\textsuperscript{41} "Space Shuttle Era." NASA. Web. 8 Jan. 2017
\textsuperscript{43} "NASA’s Journey to Mars." NASA. Web. 1 Dec. 2014
\textsuperscript{44} "NASA’s Orion Flight Test and the Journey to Mars." NASA. Web. 1 Dec. 2014
Fig. 9 – Space technology involved in NASA’s Journey to Mars. Source: NASA

Rovers

NASA’s rovers are partially-autonomous robots which are used to explore celestial bodies. Notable missions include Mars Pathfinder with its Sojourner rover (1996-1997), Mars Exploration Rover with its Spirit rover (2004-2010) and Opportunity rover (2004-present), and Mars Science Laboratory with the famous Curiosity rover (2012-present) (Fig. 10). Just like its probes, NASA’s rovers also recently focused their research on astrobiology, leading to the historic announcement in 2015 that Curiosity had found liquid water below the surface of Mars.45 As per Andrew Coates, head of planetary science at UCL’s Mullard Space Science Laboratory (MSSL): “The evidence so far is that any water would be in the form of permafrost. It’s the first time we’ve had evidence of liquid water there now.”46

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Astrotechnology

NASA’s astrotechnology initiatives include all of its instruments used in astronomy observation and astrophysics research. Its greatest achievement so far is the Hubble telescope, a space telescope launched in 1990 which revolutionised our understanding of the universe by offering an unprecedented level of detail into the cosmos.\textsuperscript{47} In 2016, it was announced that Hubble had discovered the existence of “at least 10 times more galaxies in the observable universe” than had previously been estimated.\textsuperscript{48}

NASA’s next project is the James Webb telescope, in cooperation with ESA and CSA, and due to be launched in 2018. It will be the largest and highest-sensitivity space telescope ever to exist, with a primary mirror almost 3 times as large as Hubble and a field of view which covers more than 15 times as much area.\textsuperscript{49} This will allow us to observe farther

back in time than ever before, reaching into the early universe all the way back to just 200 million years after the Big Bang (Fig. 11).50

![Diagram showing Hubble Probes the Early Universe](image-url)

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IV. SpaceX technology

Launch capabilities

SpaceX, managed by Tesla Motors and Paypal founder Elon Musk, was established in 2002 with the objective of developing space technology to reduce space transportation costs and increase commercial accessibility. In 2008, its Falcon 1 launch vehicle became the first privately-funded liquid-fuel rocket ever to orbit around the Earth. With the aim of fulfilling its vision for reusability, SpaceX then developed its next launch vehicle, Falcon 9, which completed its first flight into low Earth orbit in 2010.

![Fig. 12 - Falcon 9's separation and vertical landing. Source: Popular Mechanics](image)

After many failed attempts to land Falcon 9’s first stage rocket back on Earth, it was finally successful in December 2015, achieving the first ever vertical landing of a launch vehicle with mission Orbcomm OG-2. Then, in April 2016, it achieved the first ever vertical landing on a drop ship at sea with mission SpaceX CRS-8 (Fig. 12). It is currently

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52 "SpaceX Successfully Launches Falcon 1 to Orbit." SpaceX. Web. 28 Sep. 2008
53 "About SpaceX." SpaceX. Web. 8 Jan. 2017
designing Falcon Heavy, a larger variant of Falcon 9, which will be able to support an increased payload as well as conduct manned spaceflight. So far, SpaceX has used its Dragon spacecraft for all missions, many of which have included supply contracts to the ISS and micro-satellite launches. Although Dragon is not yet designed to transport humans, Dragon 2 is due to perform its first manned spaceflight in May 2018.

**Mars colonisation**

On September 27th, 2016, Elon Musk announced the plans for SpaceX’s historic programme to land humans on Mars, the Interplanetary Transport System (ITS).\(^5^4\) It will involve a wide range of space technology, including the ITS launch vehicle, ITS tanker, Interplanetary Spaceship (Fig. 13), infrastructure for rapid launch and re-launch, zero-gravity propellant transfer (re-fuelling in space), and extraterrestrial colonisation technology for the Mars settlement.

![Fig. 13 - Interplanetary Spaceship's arrival to Mars. Source: SpaceX](image)

The ITS launch vehicle will not only have a reusable first stage like Falcon 9, but also a reusable second stage and spacecraft. With the first optimistic Mars landing due to take place in 2025, SpaceX would be the first ever to achieve that objective. Its long-term vision goes even further, aiming to propagate humanity towards Jupiter and Saturn, cementing its place as a multi-planetary species.
V. Discussion

Disruption analysis

Theory of disruption, whilst inapplicable to NASA due to the revolutionary GPT-like nature of its achievements, can be used to analyse SpaceX’s entry into the space technology market. If a methodological approach is to be used, as outlined in this essay’s literature review, the following test must be considered: (1) Is it a disruptive innovation? (2) Does it involve an element of low-end disruption? (3) Did the disruptor innovate further and overtake the incumbents?

With regards to the first condition, it is submitted that SpaceX does indeed offer a different package of attributes from previous mainstream services. This is supported by the fact that it is the only company to have developed a reusable first stage rocket (Falcon 9), as well as one of the few companies in recent times to offer commercial spaceflight. With regards to the second condition, it is submitted that SpaceX’s focus on low-cost travel ($62 million per launch\textsuperscript{55}) is a direct appeal to the lower end of the market, which includes satellite companies, small cargo supplies to the ISS, space tourism, and other private ventures. As per Serra et al. (2014), “micorsatellite performance is rapidly evolving […] despite the increasing demand for light launch opportunities, launch providers are ignoring this trend and putting all their efforts on heavy launchers”.\textsuperscript{56} Unlike military and government, these customers place more importance on cost, and less importance on reliability and performance. This observation is supported by Christensen, Davidian, Kaiser, and Foust (2011), whereby “the space tourism customer segments represent over-shot customers in functionality and reliability […] preferences are for lower launch costs at a lower performance level than provided by the current incumbent”.\textsuperscript{57} With regards to the third condition, it is submitted that

\textsuperscript{55} "Capabilities & Services." SpaceX. Web. 8 Jan. 2017
SpaceX’s continuous innovation with Falcon 9 (and the upcoming Falcon Heavy), as well as its plans to move up the market and overtake NASA’s Journey to Mars with its own Interplanetary Transport System (ITS), indicates that it has reached the theory’s last stage.

To conclude, since all three conditions of the test are fulfilled, SpaceX’s entry into the space technology market can indeed be described as a disruptive innovation as per Christensen’s model. This assertion is supported by Leopold Summerer (2009), which states that “space tourism and some other fully private space activities represent potentially disruptive innovation for the space sector”. 58

Salient analysis

Thomas Hughes’s concept of the reverse salient can be applied to the reusability of rockets by: (1) establishing its existence by observing NASA’s technology, and (2) outlining the way in which SpaceX’s technology is defeating that salient through innovation.

It is submitted that the expendable nature of launch vehicles, tankers, and spacecraft is the most important reverse salient in space technology today. This is backed up by the fact that despite overseeing successive waves of progress in payload weight (Saturn V), distance range (Apollo), and manned spaceflight (Space Shuttle), the cost of space travel under NASA has consistently remained at levels which are too high to be commercially viable for micro-satellites and private initiatives. Thus, the sub-technology of reusable rockets can be accurately characterised as one which has hampered the overall progress of spaceflight as a GPT. Having established that, it is further submitted that SpaceX’s rapid and disruptive innovation is resolving this issue, with specific focus on Falcon 9’s recent achievement in vertical landing. This is supported by Dinardi, Capozzoli, and Shotwell (2008), whereby “the

significantly lower cost of the Falcon family of launch vehicles, as compared to similar-class vehicles, will redefine the satellite launch market".  

To conclude, not only has SpaceX’s focus on lowering costs allowed it enter the space technology market as a disruptive innovator, but it has also started to resolve the most significant reverse salient in the entire industry. Thus, it is likely to have an impact that will go far beyond the firm context, affecting both the market and society context.

R&D analysis

Research and development has interesting implications with regards to the different incentives behind national organisations and commercial firms. This will be used as a framework to make observations about both NASA and SpaceX.

It is submitted that although commercials firms may choose to focus on indirect financial returns and social returns, they are less likely to do so than national organisations. This is backed up by the fact that whilst NASA has engaged in a wide range of different space technologies (satellites, probes, rovers, astrotechnology), SpaceX and other commercial firms have almost exclusively focused on areas which generate revenue for direct financial returns (launch vehicles). Social returns from NASA’s projects often arise from the positive externalities of unpredicted spin-off technologies, such as the James Webb telescope’s derivative applications in medical devices, high speed optical sensors, integrated circuits, and infrared sensors. As NASA receives public funding, and thus does not have the burden of private creditors, it can engage in R&D with long payback periods, with a high risk of no returns, and even with the sole objective of increasing our understanding of the universe, such

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as its recently announced astrophysics mission to study “supermassive black holes, neutron stars and pulsars”.  

This is not a criticism of private companies, but rather a natural result of their need for liquidity and profitability. Furthermore, it is important to acknowledge that SpaceX’s manned spaceflight programme (ITS) will have immense social returns for all of humanity, which highlights the non-absolute nature of this observation.

Public-private relationship

As a counterpoint to the previous section, it must be stated that commercial space firms have a distinct set of advantages over the public sphere. Due to the profit motive, as well as a lack of public interest prioritisation, they are able to innovate with greater flexibility and risk than national organisations. This is backed up by the fact that SpaceX disrupted the space technology through private financing within just a decade of its foundation.

With regards to national innovation, it is submitted that whilst national organisations like NASA were unequivocally essential in leading the space technology revolution, private firms like SpaceX have opened up an entire new paradigm of possibilities for innovation and cooperation. As per Laplane’s “mission-oriented finance for innovation” (2015), it is often much easier to implement vertical policy coordination for national programmes like Apollo 11 than for commercial projects with a multiplicity of private suppliers and operators. Therefore, as observed by Nauwelaers (2008), modern innovation policies have developed from a focus on “optimal allocation of resources” towards ensuring the system’s “overall coherence” and improving its evolution capacity. Thus lies the rationale behind NASA’s “Space Act Agreements”, a modern national innovation policy which acknowledges the complex system of space technology and allows NASA to work together with private entities

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to fulfil its objectives.\textsuperscript{63} This led directly to its Commercial Orbital Transportation Services (COTS)\textsuperscript{64} programme, which was the main mechanism behind SpaceX’s commercial services contracts to resupply the ISS.\textsuperscript{65}

To conclude, although there has been a substantial amount of skepticism over the last decade regarding the commercial viability and technological value of private space firms, I believe that NASA and SpaceX have already benefited significantly from each other, and will continue to do so for the foreseeable future. This is supported by Anderson (2013)\textsuperscript{66}, whereby “the partnership between NASA and private companies through Space Act Agreements show a new level of understanding and cooperation between the public and private sectors”, as well as Lambright (2015), which expresses the same observations about the COTS programme.\textsuperscript{67}

\textsuperscript{63} "NASA Space Act Agreements." NASA. Web. 20 Nov. 2012
\textsuperscript{64} "Commercial Orbital Transportation Services (COTS)." NASA. Web. 8 Jan. 2017
\textsuperscript{65} "NASA Awards Space Station Commercial Resupply Services Contracts." NASA. Web. 23 Dec. 2008
VI. Conclusions

The following observations have been established throughout this essay: (i) SpaceX’s entry into the space technology market can be characterised as disruptive innovation; (ii) NASA’s technology was unable to effectively address the reverse salient of reusable rockets; (iii) SpaceX’s innovation with reusability and vertical landing is solving that issue and thus benefitting the industry as a whole; (iv) national space organisations are more likely to engage in R&D with indirect or social returns; (v) NASA’s leadership was a necessary first step in the era of space exploration in terms of incurring high risks and uncertain returns; (vi) SpaceX now finds itself in a unique position to innovate and lead the space technology market with its Falcon and ITS programmes; (vii) NASA’s Space Act Agreements and COTS are excellent modern innovation policies and effective steps towards utilising its public-private relationship with SpaceX and other commercial space firms – thus taking us from the confinement of our Earth and turning humanity into a multi-planetary species.
Bibliography


"NASA’s Earth Observing System." NASA. Web. 8 Jan. 2017

"Explorer 6." NASA. Web. 8 Jan. 2017

"STMD: Small Spacecraft Technology." NASA. Web. 8 Jan. 2017

"Smallsat Technology Partnership Selections NASA-University Collaborations." NASA. Web. 6 May. 2015


"All Missions." NASA Jet Propulsion Laboratory. Web. 8 Jan. 2017


"What Was the Saturn V?" NASA. Web. 17 Sep. 2010

"Space Shuttle Era." NASA. Web. 8 Jan. 2017


"Nasa's Curiosity rover finds water below surface of Mars." The Guardian. Web. 13 Apr. 2015


"SpaceX Successfully Launches Falcon 1 to Orbit." SpaceX. Web. 28 Sep. 2008

"About SpaceX." SpaceX. Web. 8 Jan. 2017


"Capabilities & Services." SpaceX. Web. 8 Jan. 2017
64 "Commercial Orbital Transportation Services (COTS)." NASA. Web. 8 Jan. 2017