Recent Lunar Activities and Takeaways from the GLXP Competition

Backgrounder & Case Study

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Overview

This paper serves as a background summary of recent lunar exploration activity in the context of relevant stakeholder interests, and as a case study of the Google Lunar X Prize (GLXP) competition, to supplement the Open Lunar Foundation (OLF) study on Stakeholder Interests in Lunar Governance. The Analytic Hierarchy Process is introduced as a method to examine the interests of these stakeholder groups, establish a rank and prioritization of those interests to form a hierarchy, and then compare different scenarios against interests. This informs future work towards understanding the lunar futures each stakeholder group will support, based on their suitability in addressing those interests and motivations.

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Background

Recent lunar activities by major space actors have ignited a renewed global interest in Lunar exploration. With international lunar policy development stalled for many decades, incongruous positions are bound to form on the way to treat the Moon and its resources. In the media, we often see news pieces about governments and billionaires funding their own way to our closest neighbour and drawing lines in the regolith as to how it shall be treated on our behalf. But has anyone ever asked whether these activities align with the interests of all the relevant stakeholders that benefit from lunar exploration?

A good starting point for building a lunar governance framework is to understand who benefits from lunar exploration. Government agencies and industry immediately come to mind, but any progress in lunar exploration cannot be achieved without the scientific community exploring the unknown; without educators transferring knowledge to the next generations to keep advancing knowhow; and without the public supporting the actions of policy makers to push our capabilities further. Variations of those five stakeholder communities (i.e. political; industrial; scientific; educators; and the general public) can often be found in assessments to engage society as they form a type of value loop in exploration.[1] While this is a very broad classification of stakeholders and each community can easily be divided into smaller subcategories, this grouping allows us to begin to consider the full landscape of interests at stake in future exploration initiatives. And while the interests of these stakeholders can differ, some can also align and be interdependent.

Historical Context

A Lunar Renaissance: Increased Activity Since the Millennium

In the last decade, just a handful of space agencies have conducted lunar exploration missions. The most notable include NASA's Lunar Reconnaissance Orbiter (also the LCROSS impactor, and Grail-A and -B, and LADEE orbiters which also impacted the Moon at the end of their missions); China's Lunar Exploration Program (including the Chang'e 2 orbiter, Chang'e-3 and -4 landers carrying the Yutu and Yutu-2 rovers, the Chang'e 5-T1 sample-return technology demonstrator, the Longjiang-2 impactor, and the Chang'e 5 sample return mission), ISRO's Chandrayaan-2 orbiter, carrying the Vikram lander and Pragyan rover, both of which were lost during a failed landing attempt. Other privately funded missions included: LuxSpace's Manfred Memorial Moon Mission (4M mission), which launched with the Chang'e 5-T1, and flew by the Moon in honour of the passing of Manfred Fuchs (the founder of LuxSpace's parent company OHB Systems); and SpaceIL's Beresheet lander, the first Israeli lunar lander mission which failed after it encountered a main engine failure while descending from lunar orbit.

In the 2000s, the Japanese space agency (JAXA) launched its Selene orbiter and other payloads which impacted the Moon in 2009, and the European Space Agency (ESA) launched a single lunar mission SMART-1, an orbiter which also impacted the Moon at the end of its mission in 2006. Absent from this list is Russia's space agency missions, which abruptly ended in 1976 following the end of the space race between the former Soviet Union and the United States. Whereas political interests to achieve technological leadership fuelled the push and rapid growth of the roughly 100 lunar missions in the first space race, the scientific interests of the past two decades added another 30 missions while also increasing the diversity of actors and our understanding of the lunar environment.

[1] P. Ehrenfreund, N. Peter, Toward a paradigm shift in managing future global space exploration endeavors, Space Policy, Volume 25, Issue 4, 2009, Pages 244-256. http://www.sciencedirect.com/science/article/pii/S0265964609000976. Accessed 4 June 2020.

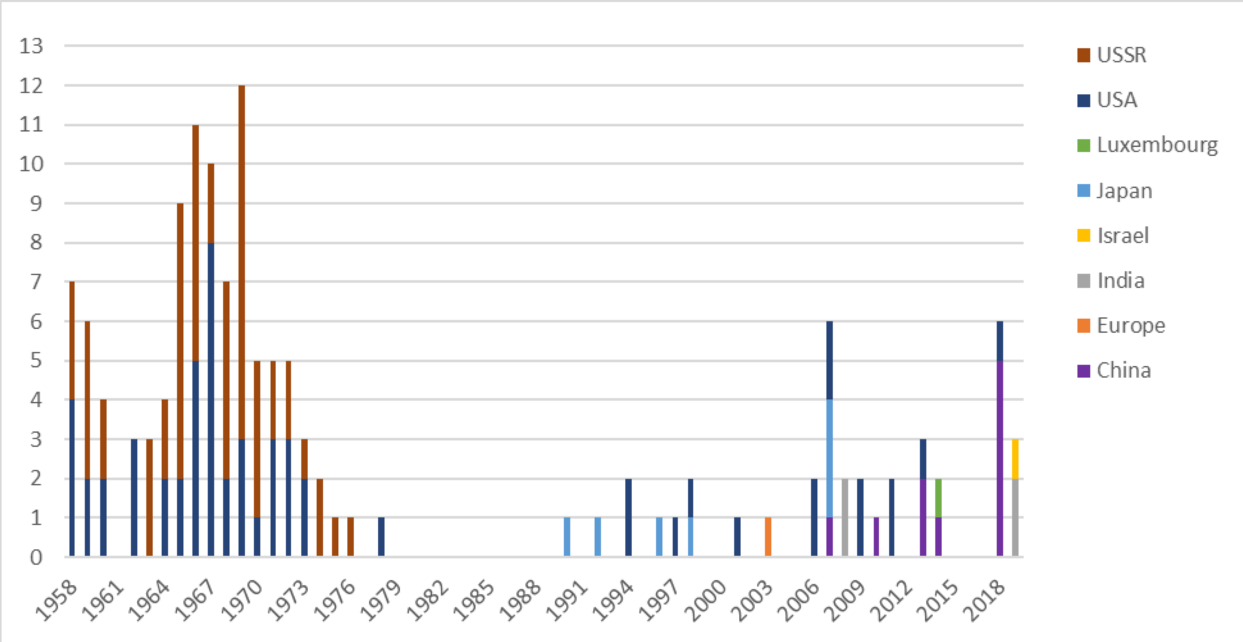

Fig I. Timeline of Lunar Missions by Country (Source: Wikipedia). This figure shows the intensity of lunar activity over time. Note the great emphasis on politically motivated missions prior to 1970, and then the period of very few missions between 1970 and 2006.

National Lunar Activities

Government space agencies will likely continue to be the main drivers of lunar exploration. China, India, Russia, and the United States have developed their own ambitions to reach the Moon, but that ambition comes at a higher cost when pursued without an ecosystem of government, commercial, and international partners.

China

Since its rapid economic rise beginning in the 1980s, China's government has made innovation a top economic priority.[2] While still seen as a developing country, its space program (in existence at the time of the Cold War) has similarly seen rapid growth with China becoming the third country to independently place humans in orbit in 2003, and the third country to conduct a soft landing on the Moon and release a rover in the following decade. China's space agency (CNSA) began its lunar exploration programme in 2007, transitioning from orbiters, to soft landers and rovers, to sample return, to the establishment of a robotic research station at the Moon's south pole, and to ultimately having boots on the ground in the 2030s. Recently, China landed its Chang'e 5 mission on the lunar surface, which will return lunar samples to Earth by mid-December 2020. Yet, China's space sector lacks a robust innovation ecosystem due to the isolation of state-controlled enterprises and the general lack of mutually beneficial interplay among diverse stakeholders groups; on top of this, intellectual property concerns and export controls also limit China's access to U.S. restricted technologies, requiring much of its technologies to be developed indigenously.[3]

India

India is another developing country with a rapidly growing economy; behind only the United States and China.[4] India's space agency, ISRO (in existence at the time of the Space Race), has mainly focused on developing launch and application capabilities intended to reach Earth orbits. ISRO is developing indigenous human space flight capabilities and aims to be the fourth country to independently place humans in orbit in 2021; to be followed by the development of a space station program and a crewed lunar landing.[5] Yet, ISRO's exploration ambitions have yielded only one

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[2] *China's Economic Rise: History, Trends, Challenges, and Implications for the United States*. Congressional Research Service, 25 June 2019, https://fas.org/sgp/crs/row/RL33534.pdf. Accessed 15 June 2020.
[3] De Selding, Peter B. "U.S. ITAR satellite export regime's effects still strong in Europe." *SpaceNews* 14 Apr. 2015, https://spacenews.com/u-s-itar-satellite-export-regimes-effects-still-strong-in-europe/. Accessed 4 June 2020.
[4] Wikipedia Contributors. India as an emerging superpower. *Wikipedia, Wikimedia Foundation*, 27 May 2020, https://en.wikipedia.org/wiki/India_as_an_emerging_superpower. Accessed 4 June 2020.
[5] Sharma, Dinesh C." ISRO Looks Beyond Manned Mission; Gaganyaan Aims to Include Women." The Quint, 16 June 2019, https://www.thequint.com/amp/story/voices%2Fopinion%2Fgaganyaan-isro-human-space-flight-men-women-gender-inclusive. Accessed 4 June 2020.

interplanetary mission to Mars (Mars Orbiter Mission, 2013), and two lunar missions (Chandrayaan-1, 2008; Chandrayaan-2, 2019). While ISRO's Chandrayaan-2 mission to the Moon ended in failure last year, the agency intends to become the fourth country to make a soft landing on the Moon with the launch of Chandrayaan-3 mission in 2021.[6] India's market has been somewhat restrictive for foreign private actors looking to do business in the country[7], and while FDI restrictions have been loosened as part of a push to position India as a manufacturing hub they remain subject to the sectoral guidelines of the Department of Space/ISRO.[8] And unlike China, India is not subject to restrictive export controls, opening the path for cooperation, e.g. 6 of the 11 instruments on the Chandrayaan-1 lunar orbiter were carried for NASA, ESA, and other European and North American institutes/companies free of cost.[9]

Russia

Russia's space sector has substantial lunar exploration experience from the Soviet Era, but with a four-decade gap in lunar missions the focus of political actors no longer appears to be on technological leadership in exploration. Following the Soviet Union's collapse in the 1990s, Russia's space industry was privatized, with its successor space agency Roscosmos maintaining funding for core space programs through commercial space launches (astronauts and satellites), space tourism, and scientific missions funded by Russian and international stakeholders. Russia plans to revive its lunar program with the launch of a series of Luna missions in the 2020 decade, with the potential involvement of ESA and NASA on some of its missions.[10] However, its progress might hinge on those partnerships as Russia's space sector is beset with challenges in the form of reliability challenges, technology obsolescence, and an aging workforce without replacement by new generations due to unattractive labour wages.

United States

In the United States, NASA amalgamated components of its cost intensive Constellation program (Orion, SLS) and its Asteroid Redirect Mission (power and propulsion system) into its Artemis program, which will involve international partners (i.e. ESA and several of its member agencies (Europe), JAXA (Japan), CSA (Canada), and the ASA (Australia)) and private sector partners for a human return to the Moon.[11] Whereas the program cost for the Constellation program (2005-2010) developed only by NASA was $230 billion (2004 est.), the cost for Artemis (2020-2024), developed by NASA and partners will be $35 billion. Under its Space Policy Directive 1, NASA will aim to organize more effectively government, commercial and international efforts to develop a permanent presence off Earth that generates new scientific and economic markets and opportunities.[12] And Government participation in the Artemis program will involve executing bilateral Artemis Accords agreements, which describe a shared vision for principles, grounded in the Outer Space Treaty of 1967, to create a safe and transparent environment which facilitates exploration, science, and commercial activities for all of humanity to enjoy.[13]

Upcoming Missions

While the space sector will likely contract due to the COVID-19 pandemic, a number of lunar missions are anticipated in the near future. In the United States, NASA plans to launch the Artemis 1 in November 2021, an uncrewed flight-test that will place the Orion MPCV and the European Service Module in Lunar orbit using NASA's SLS launcher; a successful demonstration will clear the way for a crewed flight-test of the Artemis 2 mission in 2022/23.[14] Several CLPS missions are also expected in 2021, including a cubesat orbiter being developed by Advanced Space in partnership with Tyvak Nano-

[6] Staff Writers. "Chandrayaan 3: ISRO Starts Work On Second Lander Mission To The Moon, Launch Planned In Early 2021." *Tech2* 27 Jan. 2020, https://www.firstpost.com/tech/science/chandrayaan-3-isro-starts-work-on-second-lander-mission-to-the-moon-launch-planned-in-early-2021-7959961.html. Accessed 4 June 2020.
[7] Sood, Rakesh. "Expanding India's share in global space economy." *The Hindu*, 5 July 2019, https://www.thehindu.com/opinion/lead/expanding-indias-share-in-global-space-economy/article28286469.ece. Accessed 4 June 2020.
[8] Make in India, https://www.makeinindia.com/sector/space. Accessed 4 June 2020.
[9] Wikipedia Contributors. Indian Space Research Organisation. *Wikipedia, Wikimedia Foundation*, 3 June 2020, https://en.wikipedia.org/wiki/Indian_Space_Research_Organisation. Accessed 4 June 2020.
[10] Foust, Jeff. "NASA studying potential cooperation on Russian lunar science missions." SpaceNews 13 Oct. 2017, https://spacenews.com/nasa-studying-potential-cooperation-on-russian-lunar-science-missions/. Accessed 4 June 2020.
[11] Potter, Sean. "NASA Gains Broad International Support for Artemis Program at IAC." *NASA*, 8 Nov. 2019, https://www.nasa.gov/feature/nasa-gains-broad-international-support-for-artemis-program-at-iac. Accessed 4 June 2020.
[12] "Explore Moon to Mars." NASA, https://www.nasa.gov/specials/moontomars/index.html. Accessed 4 June 2020.
[13] "Principles for a Safe, Peaceful, and Prosperous Future." NASA, https://www.nasa.gov/specials/artemis-accords/index.html. Accessed 4 June 2020.
[14] Clark, Stephen. "Hopeful for launch next year, NASA aims to resume SLS operations within weeks." *SpaceFlight Now* 1 May 2020, https://spaceflightnow.com/2020/05/01/hopeful-for-launch-next-year-nasa-aims-to-resume-sls-operations-within-weeks/. Accessed 4 June 2020.

Satellite Systems to test the intended elliptical polar orbit around the Moon that NASA plans to use for Lunar Gateway missions.[15] Another mission being developed by Intuitive Machines, now free from a legal dispute with Moon Express during the GLXP[16], will test a precision automated landing system of its lander, along with delivering up to 5 instruments to the Moon for NASA and will include some commercial payloads.[17] And Astrobotic Technology will continue developing its Peregrine lander to deliver a suite of 14 NASA and commercial payloads to the lunar surface.[18] China is in phase III of its Lunar Exploration Program, with its Chang'e 5 lander and sample-return vehicle currently in operation on the Moon; phase IV will take place in mid-2020s and will consist of a series of missions to establish a lunar research station on the Moon. India will launch its single Chandrayaan-3 mission in 2021. Russia is also planning a series of Luna missions to the moon in the next decade, with international collaboration being discussed with the United States, Europe, and China on various Lunar missions. And Israel just announced plans to launch its Beresheet 2 mission in 2024, which will send an orbiter and two landers that will land in difference regions on the Moon.[19] Similarly, New Zealand's launch company Rocket Lab plans to send a spacecraft to lunar orbit in 2021.[20] Australia has begun consultation on a Moon to Mars initiative worth $150 million.[21] And the United Arab Emirates plans to send a rover to the lunar surface in 2024.[22]

[15] Foust, Jeff. "NASA cubesat to test lunar Gateway orbit." *SpaceNews*, 16 Sept. 2019, https://spacenews.com/nasa-cubesat-to-test-lunar-gateway-orbit/. Accessed 4 June 2020.
[16] Foust, Jeff. "Intuitive Machines secures launch contract, wins lawsuit." *SpaceNews*, 3 Oct. 2019, https://spacenews.com/intuitive-machines-secures-launch-contract-wins-lawsuit/. Accessed 15 June 2020.
[17] Etherington, Darrell. "Intuitive Machines picks a launch date and landing site for 2021 Moon cargo delivery mission." *TechCrunch* 13 Apr. 2020, https://techcrunch.com/2020/04/13/intuitive-machines-picks-a-launch-date-and-landing-site-for-2021-moon-cargo-delivery-mission/. Accessed 15 June 2020.
[18] Foust, Jeff. "NASA awards contracts to three companies to land payloads on the moon." *SpaceNews*, 31 May 2019. https://spacenews.com/nasa-awards-contracts-to-three-companies-to-land-payloads-on-the-moon/. Accessed 15 June 2020.
[19] Ovadia, Yafit. "'Israel is going back to the Moon,' announces SpaceIL co-founder." *Calcalist*, 12 Sept. 2020. https://www.calcalistech.com/ctech/articles/0,7340,L-3880380,00.html. Accessed 20 Oct. 2020.
[20] Grush, Loren. "How small launcher Rocket Lab plans to pull off its first mission to the Moon next year." *The Verge*, 17 June 2020. https://www.theverge.com/21292753/rocket-lab-nasa-capstone-moon-mission-photon-hypercurie-engine. Accessed 24 Nov. 2020.
[21] "Australia to support NASA's plan to return to the Moon and on to Mars." Australian Government, *Department of Industry, Science, Energy and Resources*, 22 Sept. 2019. https://www.industry.gov.au/news/australia-to-support-nasas-plan-to-return-to-the-moon-and-on-to-mars. Accessed 24 Nov. 2020.
[22] Gibney, Elizabeth. "UAE ramps up space ambitions with Arab world's first Moon mission." *Nature*, 12 Nov. 2020. https://www.nature.com/articles/d41586-020-03054-1. Accessed 24 Nov. 2020.

Enabling Private Actor Leadership

Government Catalysing the Private Space Sector in the U.S.

In the decades that followed the space race, government interests in the US space program focused on cost and risk-minimization. With its proposals for large follow-on missions to the Moon and Mars consistently rejected by the US Congress, NASA shifted priorities to focus on market interests as the main driver. NASA's strategy in the new century focused on serving its primary stakeholders and customers in science, education, commerce, public policy, and in other Government agencies, with the public as the ultimate resource provider and the ultimate beneficiaries of investments.[23]

Since the beginning of NASA's Commercial Orbital Transportation Services (COTS) program (2006-present), the role of NASA has changed from being a driver in the funding and development of a capability (including defining its requirements, along with incurring the total cost in a cost-plus arrangement) to having a more commercial-oriented approach that enables greater industry leadership. NASA now acts more as a facilitator, defining its goal but allowing industry to define the method, and providing investment via milestone payments and sharing more extensively costs and risks of development with industry. NASA has continued this approach with its Lunar CATALYST initiative (2013-present) to encourage the development of U.S. private-sector robotic lunar landers capable of successfully delivering payloads to the lunar surface using U.S. commercial launch capabilities[24]; and with its CLPS initiative (2018-present) to enable the rapid acquisition of lunar delivery services from a growing number of American companies for payloads that advance capabilities for science, exploration or commercial development of the Moon[25]. A similar industry-led approach was applied by European counterparts in the development of the Ariane-6 launcher, which was led by industry as industry also bore more risk.

Private Support of New Lunar Actors Globally

In parallel to space agency activities in the past two decades, interests in lunar exploration has also emerged among non-government stakeholders. The Google Lunar X Prize (GLXP) is a prime example to show how different stakeholders helped to catalyse private teams to succeed in lunar exploration. Building on the success of the X-Prize Foundation's Ansari XPRIZE for Suborbital Spaceflight (1996–2004), which incentivized companies to compete for a $10 million award to break the 100-kilometer (62.5 mi) boundary of space, new challenges were opened across a range of exploratory domains. The GLXP (2007-2018) soon followed with a $30 million award to inspire a new generation of private investment in space exploration and technology with prizes for the first two privately funded teams to safely land on the Moon, travel 500 meters, and send HD video, images, and data of the journey. After several extensions, the competition ended in 2018 without a winner; but several of the competitors which advanced in the contest expressed an intent to continue their work and independently launch in the future. Some participants began working with NASA on its Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative, after winning NASA awards in 2014 to spur commercial cargo transportation capabilities to the surface of the Moon. And following NASA's cancellation of its Resource Prospector mission to land a rover on the Moon, a new competition emerged to win indefinite delivery, indefinite quantity contracts with a combined maximum contract value of $2.6 billion during the next 10 years under NASA's Commercial Lunar Payload Services (CLPS) program.

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[23] *Strategic Plan 2000*. National Aeronautics and Space Administration, Sept. 2000, page 61. https://www.hq.nasa.gov/office/codez/plans/pl2000.pdf. Accessed 27 May 2020.
[24] "Lunar CATALYST." *NASA* 31 Oct. 2017. https://www.nasa.gov/lunarcatalyst. Accessed 27 May 2020.
[25] "Commercial Lunar Payload Services Overview." *NASA* 20 Oct. 2020. https://www.nasa.gov/content/commercial-lunar-payload-services-overview. Accessed 24 Nov. 2020.

CASE STUDY – Google Lunar X Prize Competition: The Evolution & Maturation of the Private Lunar Actor Ecosystem

Gaining Backers & Customers Beyond Google Lunar XPRIZE

Under the GLXP rules, only 10% of team funding could come from public financing (i.e. space agencies and governments), so the most successful competitors from the GLXP went on to evolve their focus towards business development and other market interests. While most teams took a commercial approach to attract VC investment, other compelling science, education, and society interests drew non-commercial stakeholders to finance teams as well.

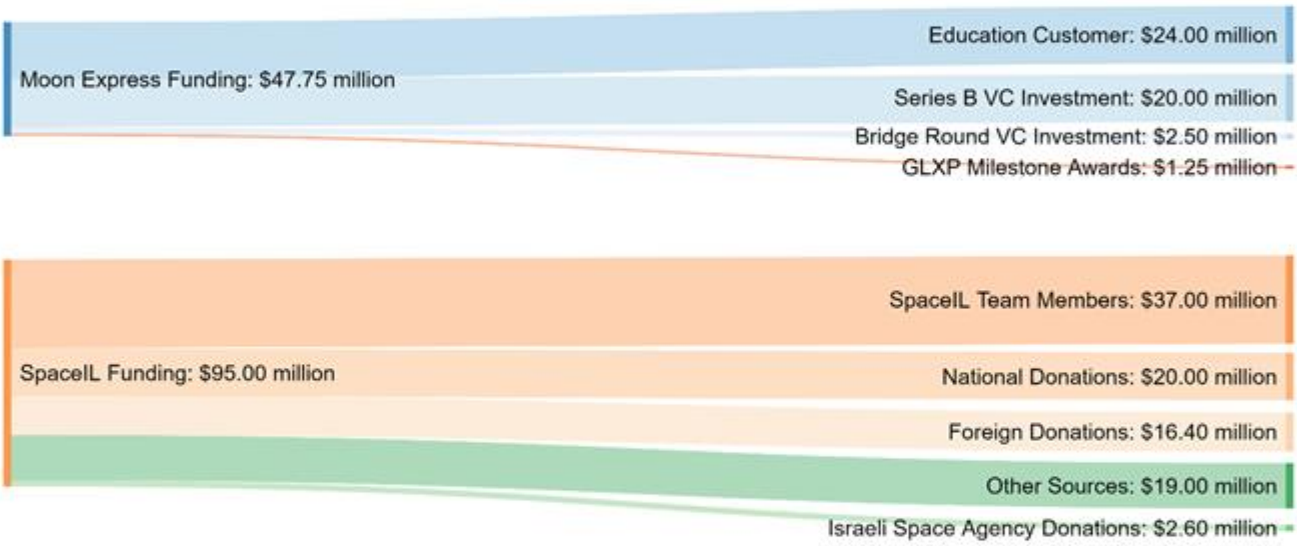

Fig 2. Contrasting Sources of Funding (Source: compiled from web sources). This figure shows different types of investments. Note that commercial VC investments are more likely to be cost sensitive. Also, SpaceIL, a non-profit funded nearly entirely through donations, has been the only competitor to make an attempt to land a spacecraft on the Moon following the ending of the GLXP competition.

The following section provides summaries of the way many of the privately funded competitors activated support from interested stakeholders and evolved their business model through different financial incentives and partnership opportunities. While a commercial approach was the norm for many competitors in raising funding, some competitors received substantial intangible support through partnerships with universities and different forms of donations from general public stakeholders in support of their missions (see Figure 2).

- Astrobotic Technology, a spin-off company from Carnegie Mellon University, began winning research funding and contracts from smaller NASA initiatives meant to scale-up small businesses, and also became one of three companies eligible to bid on NASA's Lunar CATALYST Initiative contracts. While Astrobotic Technology was the first competitor to announce a launch services contract with SpaceX and had achieved every milestone award for the GLXP, it withdrew from the competition after its launch window with SpaceX slipped past the 2017 launch requirement to focus on the institutional and industry stakeholder and customer-base it had formed.[26]

- Moon Express, formed by Silicon Valley and space entrepreneurs for the purpose of competing in the GLXP, had based itself at NASA Ames early on and secured a data purchase contract with NASA worth potentially $10 million. Moon Express also became eligible to bid on NASA's Lunar CATALYST Initiative contracts, but it remained in the GLXP and finished as one of the 5 teams to secure a launch contract.

- Hakuto (originally "White Label Space" [27]), created by space professionals in Europe and later transitioned to Japan under a parent company **"iSpace"** in 2013, initially focused on targeting advertising budgets of large

[26] Thornton, John. "Graduating from the Google Lunar X Prize." *SpaceNews Magazine*, 19 Dec. 2016. http://www.spacenewsmag.com/commentary/graduating-from-the-google-lunar-x-prize/. Accessed 27 May 2020.
[27] About. *WhiteLabelSpace*, 1 Jan. 2008. http://www.whitelabelspace.com/2008/01/vision.html. Accessed 27 May 2020,

brands to finance the development of its rover. Early in the GLXP, it chose to forego developing its own lander, to have its rover flown instead on a lander operated by another GLXP team (first Astrobotic Technology[28] and then Team Indus[29]) for delivery to the lunar surface; the team also finished as one of the 5 teams to secure a launch contract.

- Part-Time Scientists, created by a group of German aerospace engineers and scientists for the GXLP, formed partnerships with automobile manufacturer Audi as its technology partner and other well-known German brands, and planned to deliver payloads for institutional and industry stakeholders and customers. While Part-Time Scientists had announced it had secured a launch contract weeks before the deadline, the contract was not verified as it took place outside of the GLXP timeline, cutting short Part-Time Scientists' spot as a finalist in the competition.[30]

- Team Indus, created by science, technology, finance, and media professionals to compete in the GLXP, transitioned its operations to be in close contact with ISRO and the nearby aerospace cluster which provided technical and scientific expertise, facilities, and access to large venture capital from local sponsors and investors.[31] The team was one of the 5 teams to secure a launch contract, having reserved a launch on ISRO's PSLV launcher.

- SpaceIL, created by engineers and entrepreneurs as a non-profit organization to advance discourse on science and engineering in Israel, likewise received technical and scientific support from the IAI and the Israel's space cluster, universities, and access to large venture capital from local sponsors and investors, and became the first team to have a verified launch contract.[32] Its Beresheet lander was launched to the Moon after the GLXP ended, and was the first GLXP contestant to make a landing attempt.

- Synergy Moon, created by social entrepreneurs, educators, artists, scientists, technologists, and engineers for the GLXP, aimed to develop space exploration technologies for institutional and industry customers. Before the deadline to secure a valid launch contract expired Synergy Moon formed a network partnership with four other contestants to facilitate their continued participation in the GLXP.[33]

Common Elements For Success Among The Competitors

The strongest performing competitors shared a common configuration for success by taking a market-oriented approach to generate sustainable business, and cultivating partnerships and customers from the political and agency, industry, science, education, and the public stakeholder spectrum. At the top of the pyramid were teams that secured institutional contracts with NASA as an anchor customer, partnered with top-tier system integrators from industry, received substantial venture capital investments, sold scientific payload delivery services to space agencies and universities, partnered with university networks to crowd-source innovative solutions to the challenges of the competition, secured substantial private funding from philanthropic donations and angel investors whose interests extended beyond pure monetary return, and received wide-spread public support in the form of outreach, donations and volunteer work from the community. It is interesting to note that the only team to launch a mission since the cancellation of the GLXP competition wasn't a commercially focused team backed by cost-sensitive investors, but a non-profit organisation funded almost entirely by public donations.

Non-U.S. teams often did not have to share the spotlight with domestic rivals, and so inherently received undiluted national support during the competition. SpaceIL received strong backing from investors in Israel, a state known internationally as an innovation hub. Similarly, Team Indus was able to rely on ISRO's expertise, the agency to launch the

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[28] Foust, Jeff. "Astrobotic Adds Another Google Lunar X Prize Team to Its Lander." *SpaceNews* 27 Oct. 2015. https://spacenews.com/astrobotic-adds-another-google-lunar-x-prize-team-to-its-lander/. Accessed 27 May 2020.
[29] Foust, Jeff. "Japanese Google Lunar X Prize team finds new ride to the moon." *SpaceNews* 20 Dec.2016. https://spacenews.com/japanese-google-lunar-x-prize-team-finds-new-ride-to-the-Moon/. Accessed 27 May 2020.
[30] Foust, Jeff. "Google Lunar X Prize field narrowed to five." *SpaceNews*, 25 Jan. 2017. https://spacenews.com/google-lunar-x-prize-field-narrowed-to-five/. Accessed 27 May 2020.
[31] Madhumathi, D.S. "Bullish investors back Team Indus moon shot." *The Hindu*, 26 Nov. 2016. https://www.thehindu.com/news/national/Bullish-investors-back-Team-Indus-Moon-shot/article16705021.ece. Accessed 27 May 2020.
[32] Foust, Jeff. "Israeli X Prize Team Announces Launch Contract for Lunar Mission." *SpaceNews*, 7 Oct. 2015. https://spacenews.com/israeli-x-prize-team-announces-launch-contract-for-lunar-mission/. Accessed 27 May 2020.
[33] Myrick, Kevin. "SYNERGY SPACE EXPLORERS." *XPrize*, 24 Dec. 2016. *Wayback Machine*, https://web.archive.org/web/20170113133603/http://lunar.xprize.org/teams/synergy-Moon/blog/synergy-space-explorers. Accessed 27 May 2020.

Mars Orbiter Mission for just $63 million, to develop their lander and rover. Likewise for Hakuto which managed to raise a large amount of venture capital funding through corporate partnerships. The competitors entered into the GLXP for different purposes. In terms of national prestige, it was simply a bigger deal if an underdog succeeded, whereas some competitors entered the GLXP with a commercial interest, focusing on quickly generating revenue and acquiring institutional and industry customers. From a public interest perspective, the public's response to the teams likely followed along the lines of Hofstede's cultural dimensions theory[34] where favourable cultural aspects galvanize some competitors. For countries with emerging space capabilities an individual team could be seen as representative of national identity to be supported as one would cheer on a football team. In contrast, in countries with well-developed space capabilities, the excitement generated by competitiveness among local rivals might touch on another aspect of national identity, but would split support by some measure for the different teams.

Common Enabling Factors	Common Inhibiting Factors
• In the United States, NASA provides a deep well of institutional funding that can be accessed/bid on by U.S. companies. • U.S. competitors which participated and collaborated with NASA initiatives (through gaining research funding and winning smaller contracts with the agency) eventually could access greater institutional funding opportunities. (C.f. Astrobotic Technology and Moon Express). • Outside of the United States, the biggest source of funding for non-U.S. competitors came from philanthropic and venture capital investments. (C.f. Team Indus and SpaceIL). • Competitors located near space agencies and domestic space clusters had more access to expertise and technology. • Competitors which pivoted quickly and collaboratively in organisation and business models remained in the GLXP. • The existence of an ecosystem of government, commercial, and international partners helps to lower the cost of space missions.	• Loss of public interest / support leading to paucity of funding (Cf. Team Indus later cancellation of its PSLV launch due to lack of funding, and PT Scientists entry into bankruptcy protection). • Isolation - Close contacts didn't understand the nature of the activity/ hard to find the motivation to continue development. • As the competition was out-of-pocket, participation came at personal expense • Lack of institutional funding available for companies outside of the U.S. • Non-U.S. competitors are unable to directly bid for large NASA contracts, and can only do so as a partner to a U.S. company. • National space ecosystems which lack a mutually beneficial interplay among stakeholder groups provided little support.

Table 1. Factors Impacting the Small Actor Ecosystem

Stakeholder Involvement in Private Lunar Missions

While the small private actors brought ingenuity and grit in the GLXP, the support from stakeholders enabled competitors in reaching their goals. Understanding the interests of those stakeholder groups and aligning lunar exploration plans to include those interests can help to ensure optimal support in further lunar development.

- POLICY: Government agencies with substantial funding for emerging technologies helped to incubate the development of start-ups and new technologies with additional contracts. Providing start-ups access to funding and technical expertise to scale up businesses.

[34] Hofstede, G. (2011). Dimensionalizing Cultures: The Hofstede Model in Context. *Online Readings in Psychology and Culture*, 2(1). https://doi.org/10.9707/2307-0919.1014. Accessed 27 May 2020.

- SCIENCE: Close collaboration with a space agency provided access to facilities and technical expertise. Science and exploration stakeholders provided the impetus to reach the Moon and develop knowledge.

- INDUSTRY: The local industry near space agencies, and other parallel technology industries, that partnered with the respective teams provided additional access to facilities and technical expertise. Industry collaboration and partnerships provided a network to develop technology with commercial interests. And VC investors also added financial liquidity to the teams.

- EDUCATION: Academic institutions also provided facilities and technical expertise, and benefited significantly by the GXLP outreach. Education stakeholders sought to create a knowledge transfer feedback loop; collaborating with teams to inspire more students to enter STEM studies.

- PUBLIC: In addition to institutional and commercial funding, companies also relied on the positive public outreach and philanthropic donations by private individuals which believed in the importance of the mission. Members of the public identify with teams, providing social, cultural, philanthropic and venture capital support.

Using the Analytic Hierarchy Process (AHP) to Assess Stakeholder Interests

The Open Lunar Foundation (OLF) aims to further understand stakeholder interests in the lunar environment. Some guidance on this topic comes from a 2012 pilot study performed by the European Space Policy Institute (ESPI) for the European Space Agency (ESA) to aid in future programmatic decision-making.[35] Part of that study identified the interests of relevant stakeholder groups (referred to as 'needs') which benefit from space exploration and have the potential to impact the manner in which space powers develop their space exploration programs (Policy, Industry, Science, Education, and Public) and applied the Analytic Hierarchy Process (AHP) to put those interests at the centre when assessing different planning scenarios.[36] With the broad interests of those stakeholder groups predefined, and the assessment methodology validated, OLF intends to apply this methodology to assess stakeholder interests in different governance/management scenarios that could be formed in the lunar environment.

The AHP helps decision makers to make informed choices on the optimal path forward by structuring a decision problem, defining and quantifying its elements, relating those elements to overall goals, and evaluating alternative solutions. Participants express judgements on the relative importance of a set of interests through pair-wise comparisons on a questionnaire using a 9-1-9 scale. Their answers are converted to numerical values that can be ranked and measured to determine the preference intensities of the respective stakeholder groups and form a hierarchy of those interests. The process can then be stratified to consider how different development framework scenarios meet the respective interests of each stakeholder group.

[35] Gerhard Thiele, Bernhard Hufenbach, and Fabian Eilingsfeld, Incorporating benefit assessment in programmatic decision-making, IAC 2015 Congress Proceedings, 66th International Astronautical Congress (IAC), 12–16 October 2015, Jerusalem, Israel. Available at: https://dl.iafastro.directory/event/IAC-2015/paper/30955/

[36] Al-Ekabi C. (2014) The Benefits of Human Space Flight; the Discourse at a Time of Financial Crisis. In: Al-Ekabi C., Baranes B., Hulsroj P., Lahcen A. (eds) Yearbook on Space Policy 2011/2012. Yearbook on Space Policy. Springer, Vienna. Available at: http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-7091-1649-4_8

Stakeholder Group Interests

Policy Stakeholders

Generally, Policy Stakeholders (i.e. national governments) are representative of society at different levels of subsidiarity and therefore safeguard the sometimes-conflicting interests of other stakeholders within a society. They set the mandate for space agencies, and have broad interests that focus on both internal and external levels. As policy stakeholders seek to ensure the well-being of the population, enabling the subsistence of the society, the development of infrastructure, and the ability to respond effectively to internal threats caused by natural and human influenced events (i.e. COVID-19, etc.) are part of its interests. Policy stakeholders also have an interest in maintaining peace and sustainability, through protecting the population from external threats, and enhancing diplomacy and government relations through involvement in international undertakings.

The interests based on the above description can be listed as follows:

- Subsistence (Internal)
- Development (Internal)
- Domestic Security and Safety (Internal)
- International Security and Stability (External)
- Diplomacy and Governmental Relations (External)

Industry Stakeholders

Industry stakeholders generally seek to drive sustainable success, by having strong leadership and clear strategic direction, and by developing and improving their people; partnerships and resources; and processes to deliver value adding products and services to their customers. These enablers (i.e. Leadership; People; Policy and Strategies; Partnerships and Resources; Process, Products and Services) are found in the Excellence Model of the EFQM, used by 30,000+ organisations in Europe as a comprehensive management framework, and they outline what an organization, regardless of sector, size, structure or maturity, does to achieve successful results.

The interests based on the above description can be listed as follows:

- Leadership
- Policy & Strategies
- People
- Partnerships & Resources
- Processes, Products, and Services

Science Stakeholders

Science stakeholders share a common goal to better understand the world in an objective and rational way through employing accepted and verified methodologies. While scientific community covers many different domains in the natural and social sciences, common needs to all scientists include: stability in funding and planning; visibility to the global community; infrastructure to carry out the science; an ability to stimulate effective communication with peers to ensure knowledge exchange; educating the next generation of students to perpetuate scientific research; knowledge creation; science policy; and an evaluation process.

The interests of this stakeholder group can be listed as follows:

- Funding Stability
- Research Visibility
- Infrastructure & Equipment
- Communication Network
- Education
- Knowledge Creation
- Science Policy
- Evaluation Process

Education Stakeholders

With the vast increase in data creation and information dissemination resulting from the growth of Information and Communication Technologies (ICT), Educators have an increasing role to create awareness, meaning and understanding for the next generations of students and transform them into life-long learners. Education stakeholder interests can be summarised as follows: orientation; motivation and inspiration; access to knowledge; transdisciplinary learning; learning partnerships; and internship opportunities and networking, to increase the number of STEM students.

These interests can be listed as follows:

- Orientation
- Motivation & Inspiration
- Access to Knowledge
- Transdisciplinary Learning
- Learning Partnerships
- Internships & Networking

Public Stakeholders

In contrast to Political Stakeholders whose interests are focused on the broader society, Public Stakeholder interests are in the context of individual human beings. As the interests of members of the Public can differ by education, economic standing, culture, and geography, the 'Human Scale Development' by Max Neef can be used to represent a common set of fundamental needs (interests).

These interests are listed as follows:

- Subsistence
- Protection
- Affection
- Understanding
- Participation
- Leisure
- Creation
- Identity
- Freedom

The Different Stakeholder Interests

A note about stakeholder interests. As political, industry, science, education, or public stakeholders all coexist in society a certain overlap in interests is unavoidable; those interests might align, conflict or be interdependent. Moreover, individuals can be part of more than one stakeholder group, and in some cases stakeholder groups are overarching (i.e. public and policy).

For additional detail on how these stakeholder interests were translated into the questionnaire for study participants, please contact the Open Lunar Fellowship research team.

References

[1] P. Ehrenfreund, N. Peter, Toward a paradigm shift in managing future global space exploration endeavors, Space Policy, Volume 25, Issue 4, 2009, Pages 244-256. http://www.sciencedirect.com/science/article/pii/S0265964609000976. Accessed 4 June 2020.
[2] *China's Economic Rise: History, Trends, Challenges, and Implications for the United States*. Congressional Research Service, 25 June 2019, https://fas.org/sgp/crs/row/RL33534.pdf. Accessed 15 June 2020.
[3] De Selding, Peter B. "U.S. ITAR satellite export regime's effects still strong in Europe." *SpaceNews* 14 Apr. 2015, https://spacenews.com/u-s-itar-satellite-export-regimes-effects-still-strong-in-europe/. Accessed 4 June 2020.
[4] Wikipedia Contributors. India as an emerging superpower. *Wikipedia, Wikimedia Foundation*, 27 May 2020, https://en.wikipedia.org/wiki/India_as_an_emerging_superpower. Accessed 4 June 2020.
[5] Sharma, Dinesh C." ISRO Looks Beyond Manned Mission; Gaganyaan Aims to Include Women." The Quint, 16 June 2019, https://www.thequint.com/amp/story/voices%2Fopinion%2Fgaganyaan-isro-human-space-flight-men-women-gender-inclusive. Accessed 4 June 2020.
[6] Staff Writers. "Chandrayaan 3: ISRO Starts Work On Second Lander Mission To The Moon, Launch Planned In Early 2021." *Tech2* 27 Jan. 2020, https://www.firstpost.com/tech/science/chandrayaan-3-isro-starts-work-on-second-lander-mission-to-the-moon-launch-planned-in-early-2021-7959961.html. Accessed 4 June 2020.
[7] Sood, Rakesh. "Expanding India's share in global space economy." *The Hindu*, 5 July 2019, https://www.thehindu.com/opinion/lead/expanding-indias-share-in-global-space-economy/article28286469.ece. Accessed 4 June 2020.
[8] Make in India, https://www.makeinindia.com/sector/space. Accessed 4 June 2020.
[9] Wikipedia Contributors. Indian Space Research Organisation. *Wikipedia, Wikimedia Foundation*, 3 June 2020, https://en.wikipedia.org/wiki/Indian_Space_Research_Organisation. Accessed 4 June 2020.
[10] Foust, Jeff. "NASA studying potential cooperation on Russian lunar science missions." SpaceNews 13 Oct. 2017, https://spacenews.com/nasa-studying-potential-cooperation-on-russian-lunar-science-missions/. Accessed 4 June 2020.
[11] Potter, Sean. "NASA Gains Broad International Support for Artemis Program at IAC." *NASA*, 8 Nov. 2019, https://www.nasa.gov/feature/nasa-gains-broad-international-support-for-artemis-program-at-iac. Accessed 4 June 2020.
[12] "Explore Moon to Mars." NASA, https://www.nasa.gov/specials/moontomars/index.html. Accessed 4 June 2020.
[13] "Principles for a Safe, Peaceful, and Prosperous Future." NASA, https://www.nasa.gov/specials/artemis-accords/index.html. Accessed 4 June 2020.
[14] Clark, Stephen. "Hopeful for launch next year, NASA aims to resume SLS operations within weeks." *SpaceFlight Now* 1 May 2020, https://spaceflightnow.com/2020/05/01/hopeful-for-launch-next-year-nasa-aims-to-resume-sls-operations-within-weeks/. Accessed 4 June 2020.
[15] Foust, Jeff. "NASA cubesat to test lunar Gateway orbit." *SpaceNews*, 16 Sept. 2019, https://spacenews.com/nasa-cubesat-to-test-lunar-gateway-orbit/. Accessed 4 June 2020.
[16] Foust, Jeff. "Intuitive Machines secures launch contract, wins lawsuit." *SpaceNews*, 3 Oct. 2019, https://spacenews.com/intuitive-machines-secures-launch-contract-wins-lawsuit/. Accessed 15 June 2020.
[17] Etherington, Darrell. "Intuitive Machines picks a launch date and landing site for 2021 Moon cargo delivery mission." *TechCrunch* 13 Apr. 2020, https://techcrunch.com/2020/04/13/intuitive-machines-picks-a-launch-date-and-landing-site-for-2021-moon-cargo-delivery-mission/. Accessed 15 June 2020.
[18] Foust, Jeff. "NASA awards contracts to three companies to land payloads on the moon." *SpaceNews*, 31 May 2019. https://spacenews.com/nasa-awards-contracts-to-three-companies-to-land-payloads-on-the-moon/. Accessed 15 June 2020.
[19] Ovadia, Yafit. "'Israel is going back to the Moon,' announces SpaceIL co-founder." *Calcalist*, 12 Sept. 2020. https://www.calcalistech.com/ctech/articles/0,7340,L-3880380,00.html. Accessed 20 Oct. 2020.
[20] Grush, Loren. "How small launcher Rocket Lab plans to pull off its first mission to the Moon next year." *The Verge*, 17 June 2020. https://www.theverge.com/21292753/rocket-lab-nasa-capstone-moon-mission-photon-hypercurie-engine. Accessed 24 Nov. 2020.
[21] "Australia to support NASA's plan to return to the Moon and on to Mars." Australian Government, *Department of Industry, Science, Energy and Resources*, 22 Sept. 2019. https://www.industry.gov.au/news/australia-to-support-nasas-plan-to-return-to-the-moon-and-on-to-mars. Accessed 24 Nov. 2020.
[22] Gibney, Elizabeth. "UAE ramps up space ambitions with Arab world's first Moon mission." *Nature*, 12 Nov. 2020. https://www.nature.com/articles/d41586-020-03054-1. Accessed 24 Nov. 2020.
[23] *Strategic Plan 2000*. National Aeronautics and Space Administration, Sept. 2000, page 61. https://www.hq.nasa.gov/office/codez/plans/pl2000.pdf. Accessed 27 May 2020.
[24] "Lunar CATALYST." *NASA* 31 Oct. 2017. https://www.nasa.gov/lunarcatalyst. Accessed 27 May 2020.
[25] "Commercial Lunar Payload Services Overview." *NASA* 20 Oct. 2020. https://www.nasa.gov/content/commercial-lunar-payload-services-overview. Accessed 24 Nov. 2020.
[26] Thornton, John. "Graduating from the Google Lunar X Prize." *SpaceNews Magazine*, 19 Dec. 2016. http://www.spacenewsmag.com/commentary/graduating-from-the-google-lunar-x-prize/. Accessed 27 May 2020.
[27] About. *WhiteLabelSpace*, 1 Jan. 2008. http://www.whitelabelspace.com/2008/01/vision.html. Accessed 27 May 2020,
[28] Foust, Jeff. "Astrobotic Adds Another Google Lunar X Prize Team to Its Lander." *SpaceNews* 27 Oct. 2015. https://spacenews.com/astrobotic-adds-another-google-lunar-x-prize-team-to-its-lander/. Accessed 27 May 2020.
[29] Foust, Jeff. "Japanese Google Lunar X Prize team finds new ride to the moon." *SpaceNews* 20 Dec.2016. https://spacenews.com/japanese-google-lunar-x-prize-team-finds-new-ride-to-the-Moon/. Accessed 27 May 2020.
[30] Foust, Jeff. "Google Lunar X Prize field narrowed to five." *SpaceNews*, 25 Jan. 2017. https://spacenews.com/google-lunar-x-prize-field-narrowed-to-five/. Accessed 27 May 2020.
[31] Madhumathi, D.S. "Bullish investors back Team Indus moon shot." *The Hindu*, 26 Nov. 2016. https://www.thehindu.com/news/national/Bullish-investors-back-Team-Indus-Moon-shot/article16705021.ece. Accessed 27 May 2020.
[32] Foust, Jeff. "Israeli X Prize Team Announces Launch Contract for Lunar Mission." *SpaceNews*, 7 Oct. 2015. https://spacenews.com/israeli-x-prize-team-announces-launch-contract-for-lunar-mission/. Accessed 27 May 2020.
[33] Myrick, Kevin. "SYNERGY SPACE EXPLORERS." *XPrize*, 24 Dec. 2016. *Wayback Machine*, https://web.archive.org/web/20170113133603/http://lunar.xprize.org/teams/synergy-Moon/blog/synergy-space-explorers. Accessed 27 May 2020.

[34] Hofstede, G. (2011). Dimensionalizing Cultures: The Hofstede Model in Context. *Online Readings in Psychology and Culture*, 2(1). https://doi.org/10.9707/2307-0919.1014. Accessed 27 May 2020.
[35] Gerhard Thiele, Bernhard Hufenbach, and Fabian Eilingsfeld, Incorporating benefit assessment in programmatic decision-making, IAC 2015 Congress Proceedings, 66th International Astronautical Congress (IAC), 12–16 October 2015, Jerusalem, Israel. Available at: https://dl.iafastro.directory/event/IAC-2015/paper/30955/
[36] Al-Ekabi C. (2014) The Benefits of Human Space Flight; the Discourse at a Time of Financial Crisis. In: Al-Ekabi C., Baranes B., Hulsroj P., Lahcen A. (eds) Yearbook on Space Policy 2011/2012. Yearbook on Space Policy. Springer, Vienna. Available at: http://doi-org-443.webvpn.fjmu.edu.cn/10.1007/978-3-7091-1649-4_8