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Is the Lunar Economy Solely for the Space Industry? Opportunities for Non-Space Companies in Lunar Infrastructure Leveraging Technological Synergies

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Abstract

Joint infrastructure ventures between space and non-space companies can create benefits for all stakeholders. This includes initiatives for cis-lunar exploration, where infrastructure is particularly resource intensive. This paper aims to support involvement of terrestrial sectors in cis-lunar infrastructure projects, by providing evidence-based management frameworks. The study between the SDA Bocconi Space Economy Evolution Lab and the Moon Village Association Lunar Commerce and Economics Working Group supports joint work on the Lunar Commerce Portfolio – a study on the lunar economy, whose first edition was published in November 2022. For space industry actors, the potential benefits of joint development with non-space actors are widespread. Space agencies could reduce resources dedicated to technology design and development, which could be redistributed for sustaining purchase agreement contracts. Space companies could reduce market uncertainties, increasing the economic attractiveness of projects, while reducing liabilities through risk allocation. Financially, equity providers could be incentivized by the participation of non-space corporates as risk takers, signalling venture reliability to capital markets. Non-space actors could also benefit considerably from advanced science-based technology innovation with reduced uncertainties. Target applications would be explicitly defined in arrangements with space industry partners, with non-space firms acting as a supplier or investor within the joint venture. This provides opportunities for high technology R&D with identifiable end-uses and reduced risk. Further, the target market is represented by collateral terrestrial customers, for whom the technology could be adapted and traded. Terrestrial spill overs could also contribute towards the UN's 17 Sustainable Development Goals. Embarking on space-for-space activities entails pursuing the industrialization of technologies to serve a concentrated portfolio of customers. These activities are extremely risky and would be priced by a rational investment manager accordingly, unless a diversification strategy is pursued, or returns on investment are exceptional. Lunar infrastructure, and the collaboration of space and non-space players, is exemplary of this, and therefore offers multiple areas of investigation under management perspectives, such as correction of market failures, infrastructure financing, and technology commercialization. This paper therefore brings evidence on how non-space companies can contribute to the realization of lunar infrastructure through exploiting technological synergies. While the paper focuses on the lunar economy as an emerging area of interest, its findings carry broadly applicable lessons to other areas of space technology.

Keywords: Lunar Economy, Lunar Infrastructure, Non-Space Industry, Synergies

Acronyms/Abbreviations

B2B: Business to Business
COTS: Commercial Orbital Transportation System
DARPA*:* Defense Advanced Research Projects Agency
ESA: European Space Agency
IDA: Institute for Defense Analysis
IP: Intellectual Property
JAXA: Japanese Aerospace Exploration Agency
LTE: Long-Term Evolution
NASA: National Aeronautics and Space Administration
PwC: Pricewaterhouse-Coopers
R&D: Research and Development

1. Introduction

Commercial lunar activity holds the promise of generating considerable economic value. In 2022, the Moon Village Association's Lunar Commerce and Economics Working Group (Webber et al., 2022) estimated that revenue from sales of lunar goods and services could range from $4 to upwards of $30 billion in a representative year by approximately 2040. The United Launch Alliance (ULA) (Kornuta et al., 2019) has previously estimated that near-term demand for lunar resource-derived propellant alone, once a lunar market is established, will account for approximately $2.4 billion. PwC (Scatteia and Perrot, 2021) has estimated the potential for revenue from lunar goods and services of up to $170 billion by 2040. While estimates vary, therefore, there is a general expectation that the market for lunar goods and services will be a multi-billion dollar one.

Previous waves of space exploration (and commercialization) have not only expanded the field of human knowledge and generated direct economic return to longstanding aerospace firms. They have also provided economic opportunities for firms not traditionally engaged in the space industry. One need only look at NASA's annual spin-off reports to view a range of technologies unlocking value in sectors not directly related to the space industry.

As interest in commercial lunar activities is increasing, a subtle but growing trend is emerging. Companies previously not engaged in lunar activities, or the space industry at all, are directly pursuing commercial lunar opportunities, often in partnership with more traditional space players. NASCAR has partnered with Leidos to produce a lunar rover; Toyota is developing a pressurized lunar rover in collaboration with JAXA; Nokia is trialing LTE on the lunar surface. Further examples abound, and further cases are being announced regularly, and at an increasing pace.

The significance of these developments is threefold. Firstly, joint financing of lunar projects in collaboration with non-space sectors, many of which have considerable capital at their disposal, may de-risk lunar projects. This, in turn, may make reaching a critical mass of in-space infrastructure for sustained commercial activity more achievable. Secondly, these activities are expected to provide notable economic return to non-space sectors, both directly through successful commercialization of joint projects, and indirectly through various spin-off and spillover channels that have been well documented in literature. Finally, given the notable potential for space technologies, in particular to find applications in support of sustainable development goals, the latter two factors indicate the potential to support the achievement of sustainable development objectives on Earth through these proposed projects.

This model of development is vastly different to the period of lunar exploration of the 60s and 70s. While consortia and joint ventures between space and non-space companies are not new, such a trend has not been widely observed beyond Earth orbit until now. Therefore, while these developments generate considerable benefits as described, further study into optimal arrangements, and recipes for success is warranted. This study examines the drivers, barriers, and configurations of space and non-space collaboration in the lunar domain, and seeks to provide some insight into best practice of industrial arrangements to unlock maximum economic and societal value.

1.1 Research Area

On its own, the lunar venture is already a very complex and multifaceted endeavor, and its current, embryonic phase offers multiple opportunities for research and study. Even more dramatically, the suggestion of a system of collaborations between space and non-space companies in the development of the same venture, as well as on the creation of potential new markets centered on the lunar activities, may be investigated under several and very different viewpoints.

The present work aims to study why and, more importantly, *how* the lunar economy will be beneficial for companies and industries outside the space field, taking as a main focus its economic and managerial side. More precisely, this paper investigates the company-level drivers, trends and opportunities for participating in this endeavor from the viewpoint of the business features that companies may leverage, develop, learn or improve thanks to their participation in the lunar projects. Consequently, no technical or political motivations will be considered as the angle of our analysis.

Primarily, themes of both process and product innovations will be investigated. Connected to these, additional relevant topics will enter the analysis, regarding both more direct benefits like new, near-term commercial opportunities and more indirect ones like returns on reputation, investors' attractiveness and company culture.

The following section specifies the literature area to which this work contributes, in its twofold nature: on one side, the paper represents a first involvement in the discussion around the creation of a lunar economy, from the innovative perspective of the collaboration possibilities for non-space companies; on the other side, it also recalls the wide literature that studies how new ventures impact a company's business from the viewpoint of internal and external innovation.

1.2 Background: literature review and theory

The establishment of joint infrastructure ventures between space and non-space companies for the development of lunar activities carries significant, potential mutual benefits and spurs economic growth. To justify the former sentence, as per the goal of this paper, the literature review aims to explore the current knowledge in support of such collaborative initiatives. In fact, several studies have provided valuable contributions towards, on one hand, analyzing how and through which channels non-space companies can contribute to the development of lunar activities; and on the other hand, in understanding the market trends, challenges, demand drivers, sustainable infrastructure development, and commercial prospects of those same activities.

Regarding the former, the most obvious item is represented by technological synergies. It is already well-known how space is a sector able to transfer its paramount innovations to other industries, hence proving that technological spillovers in and out of the sector are possible and already happening. Automotive and transportation, robotics, civil engineering, but also apparel and eyewear are some of the most famous examples. Aguzzi et al. (2022) expands the concept to industries similar to those under study in the present paper, and point out that most innovation spillovers from one industry to another spring from product innovation channels, or similar (e.g., materials). From a management perspective, the phenomenon has also been widely studied under the umbrella of patents' registrations and usage. Verspagen (1996) explores a variety of approaches to quantify knowledge spillovers between different sectors, then assessing the impact of such spillovers on the growth of productivity within the manufacturing industry. The methods the author tests involve the count of patents in sectors that are technologically close, and demonstrates that innovation in one sector measured by an increase in patents is transferred into other sectors through consequent increases in similar patents. The approach is nevertheless contested by Trajtenberg (1990) who claims that patents differ in importance on the basis of citations. Hence, what the author refers to as "a simple count" cannot be an effective measure of technological spillovers between industries unless it is weighted by the number of citations for each patent. With this paradigm, the author finds a stronger correlation between citation-based patent indices and objective assessments of the societal impact of innovations within particular fields. Still, the validity of studies like Verspagen (1996) is not fully discarded.

Wolff and Nadiri (1993) instead test a different methodology to come to similar conclusions. By employing an input-output analysis on manufacturing and related sectors, the authors prove how the pace of technological advancement within that industry is positively linked to the progress observed in its supplying sectors. Even if this may seem a topic not so close to this work's, one can argue that, in the case of lunar ventures, the space sector may be closely related to supporting non-space industries in a way that can recall the use of the input-output methodology, hence making Wolff and Nadiri (1993) a useful reference for discussion.

In addition to contributions to the management of innovation and technological spillovers between industries, a wide set of literature directly focuses on lunar activities directly, a story of which is of paramount importance to understand what the scope of this work is in terms of target activities. Certain initial contributions arise from research projects that space agencies have conducted to explore the viability of specific endeavors. Zuniga, Modi, Kaluthantrige, and Vertadier (2019) conducted a study under NASA's purview, focusing on how to build economical and sustainable lunar infrastructure to enable human lunar missions. In the first place, their work emphasizes the importance of sustainable practices in infrastructure development and, very importantly, offers valuable strategies for the integration of space and non-space players in achieving long-term lunar goals. As a major example, it retrieves concepts from NASA's COTS program and derives from it a theoretical framework for the formation and management of public-private partnerships. Results focus on the feasibility for constructing a lunar infrastructure system encompassing power, thermal, communication and navigation components; moreover, the system is seen to allow for human missions lasting from a few days to several months, requiring minimal upkeep and part replacements.

A precursor for these kinds of studies on lunar infrastructure building is the work by Schrunk et al. (2007). The authors first provide a comprehensive analysis of lunar resources, development prospects, and the potential for human settlement. Then, they assess the feasibility and challenges associated with resource utilization, technological advancements required for infrastructure development, and the potential for sustainable lunar colonies. By delving into the intricacies of lunar resources, the authors present a compelling case for the importance of lunar infrastructure in enabling future space exploration and settlement. Interestingly, this seminal publication offers a multidisciplinary perspective since it encompasses scientific, technological, economic, and societal aspects. In doing that, it builds the case for the creation of joint infrastructure ventures between space and non-space companies by stating that the interaction between different industries is a necessary condition for the success of such high-risk ventures.

Exploiting this kind of contribution, and aiming to go beyond feasibility studies, a full research stream has focused on why humankind should go back to the Moon, to stay. More explicitly, a number of scholars and experts have tried to assess the potential demand that may arise around lunar commercial activities. Calvin, Crane, Lindbergh, and Lal (2021) from the IDA Science and Technology Policy Institution investigate the demand drivers of the lunar and cislunar economy. In order to incentivize private entities from sectors outside of space exploration and attract investors, the authors emphasize the need for lunar and cislunar goods and services driven by NASA's requirements. It is noteworthy that their focus lies on identifying opportunities for generating non-government revenue. In the findings, authors count up to twelve cislunar goods and services that households and/or businesses may be willing to purchase, but only nine of these are actually sustainable as an economic lunar activity. In terms of drivers, instead, authors highlight two results: first, public expenditures on Moon-related activities directly trigger demand for transportation, capsules and landers; second, transportation costs from Earth to orbits and the Moon are a potential driver since they are perceived as costlier compared to what may be achievable thanks to a stable lunar infrastructure. But importantly, the study leaves behind the question regarding whether a pure-play lunar economy would be sustainable thanks to private-only demand. The contribution from Benaroja (2001) adds to that, exploring the idea that it is not just economic advantages that are possible drivers for the installation of lunar infrastructure, but also social issues and contexts on Earth that relate to education and culture. Still, the question remains somewhat unanswered, and indeed this is the main research route in which contributions are needed. A possible topic for expansion, then, comes from a twofold consideration: on one hand, what non-space businesses may gain by participating in lunar infrastructure ventures; on the other hand, how they could contribute to the same ventures, and thanks to which kind of synergies with space companies and activities. This is also the field in which this paper is collocated.

To start to consider the spillover effects and potential benefits of lunar infrastructure projects, the study by Long Gen Ying (2005) is highly relevant. Although not directly related to lunar ventures, it provides insights into how infrastructure projects can generate positive externalities and contribute to broader socio-economic development. Long Gen Ying's study indeed examines the spillover effects of infrastructure projects in China and highlights how these can generate positive externalities that extend beyond their immediate scope. The research investigates various channels through which spillover effects occur, such as job creation, technology transfer, and regional development. By measuring these spillover effects, the study provides insights into the potential socio-economic benefits that could be realized through collaborative lunar infrastructure projects. The authors believe that understanding the spillover effects and the relative channels is crucial for assessing the broader impact of joint ventures and for informing strategies to maximize positive outcomes, which is also the scope of this work for both space and non-space actors.

Lastly, there are also some non-academic, more practice-oriented contributions that are worth citing. Scatteia and Perrot (2021), for example, present a lunar market assessment report published by PwC, which provides insights into market trends and challenges in the development of a lunar economy. The study offers a comprehensive analysis of the economic landscape and market opportunities that can guide the involvement of non-space companies in lunar infrastructure projects. Different types of activity treated are: lunar transportation, lunar data commercialization and space resource utilization, both in-situ and not. For all these activities, the authors identify the most indicated, non-space collaborative industries, hence clearly extending the scope of lunar ventures to private actors. Most recommended industries appear to be automotive, mining, construction, energy and robotics.

As the scope of this paper is wide, the contributions were found to cover very different topics around the research questions of this paper. The multifaceted nature of this work is indeed one of the features that places it into a clear literature niche: our contribution aims to expand the considerations around potential gains that non-space businesses can obtain through their involvement in lunar infrastructure ventures, as well as around most likely ways through which their contribution may be key. The cited contributions offer an introductory framework as they collectively provide a solid foundation for understanding and supporting joint infrastructure ventures between space and non-space companies in the creation of lunar ventures, offering insights into market assessment, demand drivers, sustainability, commercial activities, and potential spillover effects, which are crucial for evidence-based management frameworks in the pursuit of successful lunar infrastructure projects.

1.3 Purpose and Expected Benefits

Literature regarding high technology partnerships strongly suggests that the active participation of non-space partners in space ventures would have multiple benefits. This includes – and is perhaps particularly true for – lunar infrastructure.

The creation of a lunar ecosystem, where all technologies and infrastructure are available to enable complex market interactions, can in many ways be seen as a coordination problem. The task ahead requires a significant number of technologies to be developed, which span a large expanse of capabilities and fields. Further, all pieces must be in place to make the ecosystem work. Power, communications, resources, transportation, and other services must all be introduced near-concurrently, or markets fail to materialise. Here, therefore, network spillovers become highly important. As described by Jaffe (1998): "*the expected value of any one research project is an increasing function of the number of different projects undertaken.*" To address this coordination problem therefore, one would expect to see multiple diverse partners engaging in joint R&D projects, focused development programmes, and a variety of other partnerships.

Where joint R&D funding is involved, Teirlincka and Khoshnevis (2020), examining regional space clusters clusters, have found that joint funding by space and non-space partners increases R&D output efficiency. Supply chain partnerships – distinguished from traditional buyer-seller relationships by high joint commitment, trust, interdependence, and a strong shared vision – have also been shown by He, Gallear and Ghobadian (2011) to facilitate knowledge transfer, and are recognised to lead to improved time efficiency and quality, and increased innovation.

For non-space partners, engagement in the lunar ecosystem would seem to offer a variety of benefits. Engagement in itself represents horizontal expansion into a new market, and the potential spin-off of existing IP to generate value in a new domain. Moreover, particularly where a joint project may involve significant external funding from a government agency, both space and non-space partners are likely to see the full range of benefits of spinoffs resulting from the collaboration. As described by Cohendet (1997), these can include technological, commercial, organisational, methodological, and work factor effects. Technologies developed and refined in a partnership may themselves find novel markets on Earth, or alternative applications in space, that further increase the benefit to involved parties.

In short, the nature of the emerging commercial lunar ecosystem implies that a wide variety of partnerships, comprising considerable multidisciplinary expertise, is expected. These partnerships would offer various benefits, with some of the primary ones including:

- Ameliorating the coordination problem inherent to building a lunar ecosystem
- Improving R&D output efficiency
- Improving project outcomes, including schedule and quality
- Increasing the innovative capacity of involved partners
- Generating opportunities for spinoffs of the forms described by Cohendet

1.4 Research Questions

The general question that the present paper tries to answer is if non-space companies should and/or could contribute to the development of lunar activities, and if yes, how and why. Such a course of questioning is of course very broad, and any kind of answer may seem deterministic to some degree and would almost certainly miss some of the elements that one could consider.

Consequently, the present work seeks to try and answer the second part of the question only, namely regarding the modalities and the motivations for a non-space company to join a challenging and costly space project. In other words, we assume as a given that the participation of non-space companies in the lunar activities' development is certainly beneficial for the same companies. Thus, we neglect to measure and balance the pros-and-cons for non-space actors to join the lunar venture, and we limit the scope of the paper to the question: *why and how should a non-space company engage in the development of lunar activities*?

This question still has a twofold declination, meaning it has to be further specified. Focusing on the first query, that regards the motivations a company may consider in its go-no-go choice, previous sections have already provided the reader with some hints. First of all, we expressed in Section 1.1 that we want to focus on the business and managerial aspects of the venture. hence, on the reasons why a non-space company may be attracted by the lunar economy. From a management perspective, the economic theory is very clear in suggesting that a company will introduce and develop a new practice or activity only in presence of a tangible benefit for its business development. In general, benefits can have very different forms and magnitudes, and can impact any side of a company's performance, without losing their nature of driving positive elements of development. This is to say that we consider, for example, a rapid and strong increase in revenues on the same level of importance as a more efficient resource allocation system, or also as the creation of a better cultural environment for the company's workers, because all these three items are benefits to business. In the case we examine, of course, benefits that may impact a non-space actor for its involvement in a lunar project are not already certain to the non-space company itself. To shelter our analysis from this possible obstacle, we then decide to show what are the *expected*, more than tangible, benefits that a non-space company foresees as possibilities stemming from the rise of the lunar economy.

Then, the first part of the question takes a more precise form that could be synthetized with: *what business benefits does a non-space company expect from its engagement in the development of the lunar economy?*

Of course, this side has to be coupled with the second part of the original question, regarding the modalities the company will leverage for its involvement in lunar projects. Again, these must be connected to business items, more than others. Generally, a company can manage and utilize several elements of its business model to enter new projects in collaboration with other entities. Given the vastity of approaches that have been developed and that are at full disposal of any business administrator, we believe the best approach to be to leave the question broad, so to possibly collect answers and views that may be unreachable if we opted for alternative perspectives. For the second part of the research question, then, we just limit our analysis to the field of business and management, assuming no further occurrences.

In conclusion, the guiding research question we want to answer in this work is: *what business benefits does a non-space company expect from its engagement in the development of the lunar economy? What characteristics of its business management will most likely be involved, for it to proficiently join the collaboration?*

The next section focuses on the methodological approach we intend to use to answer the question.

2. Material and methods

2.1 Methodology

The methodological approach used in this work is based on multiple case studies.

The advantage of studying a phenomenon is the ability to provide context-specific insights. Many theories in social sciences are based on general principles and may overlook the nuances and complexities of specific situations. The use of case studies, on the other hand, allows researchers to uncover context-specific factors that influence the phenomenon under investigation. This context-rich understanding can enhance the applicability and relevance of the theoretical framework in real-world settings.

Certainly, one of the main other advantages of using case studies to develop theoretical frameworks is also the rich and in-depth understanding they provide. Case studies involve the detailed examination of a specific phenomenon, context, or event, allowing researchers to explore complex social phenomena in their somehow natural setting. Through careful analysis of the case, researchers can identify patterns, processes, and relationships that might have been unforeseeable before. In doing so, such a methodology can therefore contribute to the development of innovative and original theoretical findings. This approach is particularly useful when investigating unique or rare questions that may not be adequately addressed by existing theories, as is the scope of this paper.

Nevertheless, it is fundamental to note that there are also limitations and potential drawbacks to assessing theoretical frameworks from case studies. One of the main criticisms is the limited generalizability of findings, or their external validity. Since case studies focus on specific instances or contexts, it can be challenging to extend the findings to broader populations or situations. The unique characteristics of the case may indeed limit the transferability of the tested theoretical framework to other settings, thus reducing its external validity. In this sense, case studies are also well exposed to a lack of quantitative rigor since it may be hard to derive insightful statistics from case-study desk research.

Moreover, case studies can be susceptible to researcher bias and subjectivity. The whole process of selecting, analysing, and interpreting data in case studies involves researchers' subjective judgments. This subjectivity can introduce potential biases and compromise the objectivity of the derived theoretical framework.

Eisenhardt and Graebner (2010) provide an analysis of the opportunities and challenges associated with the utilization of case studies to develop and/or test theory. While noting the challenges involved, which will be better discussed below, the authors yield novel insights, refine existing theories, illustrate conceptual frameworks, and provide a comprehensive contextual understanding. Similarly, Ridder (2017) delves deeper into the contribution of case study research designs to theory evolvement. He places emphasis on two complementary elements, namely the generation of fresh insights and the testing and refinement of existing theories. Nevertheless, the author stresses the importance of adopting a theoretical lens, collecting comprehensive data from multiple sources, conducting meticulous analysis, and ensuring clear and concise reporting.

It is also true, however, that the converse argument may apply as well. Rule and John (2015) indeed argue that theory plays a crucial role in guiding the process of case study research, enabling the interpretation of data, generating valuable insights, and ensuring the generalizability and utility of research findings for other scholars.

Ylikoski (2019) explores the use of mechanism-based theorizing in case study research and highlights its role in overcoming challenges, making studies rigorous and useful for theory development, and explaining findings, while reasoning that direct empirical generalization from explanatory case studies is challenging in sociology.

His approach consists in using case studies to provide mechanism schemes that can serve as building blocks of causal scenarios. He advocates this approach for its ability to reconstruct how sociologists reason from cases and its focus on middle-range theories and testing mechanistic presuppositions.

George (2019) presents the method of structured, focused comparison, which involves systematic comparison of multiple cases, identifying common patterns and themes, developing and refining theories, explaining findings, and making them generalizable.

2.2 Approach

The initial stage of our research on case study phenomenology involves the careful selection of cases for analysis. In order to accomplish this, we began by identifying prominent large corporations that demonstrate an interest in expanding their business operations to the lunar surface. We specifically focused on categories such as mineral exploration companies, mining companies involved in extracting propellant or precious metals from the lunar surface, base metal manufacturing companies that could utilize lunar resources, and infrastructure construction companies capable of establishing essential transportation systems and industrial plants within the lunar value chain. Within each category, we further pinpointed several specific companies to approach for participation, prioritizing executives who hold decision-making authority.

To gather data and insights, we developed a questionnaire specifically tailored to our research objectives. Initially, the questionnaire was distributed to the selected companies through offline channels. Subsequently, we engaged in semi-structured discussions with the company executives, utilizing the questionnaire as a reference point for our conversations.

3. Analysis

<table>
<tr><th>Partnership in Focus</th><th>Primary Space Related Activity</th><th>Organisational Arrangement</th><th>Cited Benefits</th><th>Cited Challenges</th></tr>
<tr><td>Enel
Thales Alenia Space</td><td>Feasibility study of:
• Lunar power plant
• Lander with charging capabilities
• Space based solar power</td><td>Studies are conducted by Enel Innovation team in collaboration both with operations teams and external partners (e.g. Thales)</td><td>For Enel
• Discover new opportunities and improve current practices
• Exploring energy storage methods in a lunar setting, where space and weight are crucial, could lead to innovative charging solutions for cars on Earth.
• Discover new business models.</td><td>• Difficulty in going beyond feasibility studies due to low maturity of the technology, and of lunar infrastructure.
• Convincing company management that space related activities should be given higher priority
• Communication: “How can I invest in clean energy on the Moon while people are struggling with paying high electricity bills?”</td></tr>
<tr><td>Chiyoda Corporation
Yokogawa Electric
ispace
University of Tokyo
Ibaraki University</td><td>Development and launch of a lunar water analyzer, with a view towards establishing a commercial energy plant on the lunar surface.</td><td>• Project working arrangement between partners to jointly collaborate on the project
• Project hosted in Chiyoda Corporation’s Frontier Business Division, Space Business Department
• Assuming partnership formation will be changed from collaboration to joint venture when commercial business will commence</td><td>For Chiyoda Corporation:
• Utilization of experience in terrestrial hydrogen supply chain and energy plant construction for lunar projects.
• Shared revenue from the joint venture’s sale of lunar data (expected from 2027) and the sale of lunar resources (expected from 2030+).
• Enhancement of terrestrial business by adapting lunar hydrogen and oxygen technology for Earth, especially in harsh environments
For partner organisations:
• Shared revenue from the joint venture’s sale of lunar data (expected from 2027) and the sale of lunar resources (expected from 2030+)
• Academic partners able to advance their research and commercialize it in an industry setting</td><td>• Uncertainty regarding the distribution, concentration, and state of lunar water, making internal business cases uncertain
• Difficulties in financing due to the aforementioned uncertainties
• Uncertainties regarding transportation options
• Need for strong space agency and government support, especially in the early stages
• Requirement for robust international ecosystem of commercial, academic, and government players</td></tr>
<tr><td>Nokia
Lunar Outpost
Intuitive Machines</td><td>Development and surface testing of an LTE network on the lunar surface, with a view towards establishing LTE communications networks to support future lunar missions and industry.</td><td>• Provision of payload services to Nokia by Lunar Outpost and Intuitive Machines, and technical support in payload integration
• Project executed through Nokia Bell Labs (acquired in 2016)</td><td rowspan="2">For partner organisations:
• Longer-term opportunity of lunar markets
• Tangible return on investment as lunar markets mature
• Drivers of innovation within partner organizations through collaboration
• Engagement in lunar projects enhances the innovative culture
• Successful execution of lunar projects signals positively to future investors and potential clients
• Contribution to important future developments for humankind – non-quantifiable benefits to company morale and energy from involvement in such projects
For Lunar Outpost:
• Aiding global expansion through regional partnerships
• Building a commercial ecosystem by involving non-space companies in the lunar infrastructure domain</td><td rowspan="2">Need for reduced delays and more predictable schedules for lunar markets to mature and for new entrants to get involved</td></tr>
<tr><td>EPE
Lunar Outpost
+ Consortium Partners</td><td>Development of a sovereign Australian lunar rover, with a view towards securing Australia’s position in the prospecting, extraction and use of lunar resources.</td><td>• Partnership on proposal and programme funded by Australian Space Agency
• Organisations leading a broader consortium competing in ASA’s Trailblazer Programme</td></tr>
</table>

			• Broader confidence benefits as markets scale and require expanded supply • Mutual benefit from potential partners' considerable resources and know-how	

3.1 Enel

Enel, an Italian prominent player in the energy sector, has ventured into space exploration starting in 2019. Its focus is on energy generation, distribution, and storage on the Moon's surface.

The main projects Enel has worked on are three feasibility studies.

The first, in collaboration with Thales Alenia Space Italy started in 2019 and was concluded in 2021. This study explored the feasibility of a photovoltaic-like power plant to benefit astronauts and a moon base.

The second project is investigating potential new business models associated with a lander that integrates a photovoltaic generator, an energy storage system, and vehicle charging capabilities to supply energy to astronauts during the initial phases of their lunar mission. It is a feasibility study funded by the European Space Agency (ESA) and commenced in 2022, ending in 2023.

The third project studies space-based solar power, involving a satellite in geostationary orbit. It aims to generate photovoltaic energy and transmit it to the Moon. This project, also funded by the ESA, began in early 2023.

The primary motivation to engaging in these studies, is to discover new opportunities and improve Enel's current practices. "For instance, exploring energy storage methods in a lunar setting, where space and weight are crucial, could lead to innovative charging solutions for cars on Earth. So, certainly, embarking on such projects allows [Enel] to explore novel approaches and potentially discover new business models."

These projects also generate internal collaborations between different departments and give participating employees additional visibility and satisfaction.

Embracing the Open Innovation Program, Enel underwent a paradigm shift that involved integrating its expert Innovation Team with its business units to manage space-related projects. This approach allowed the company to leverage the knowledge and expertise of its team members and collaborate with external partners, such as the European Space Agency, Microsoft, and Thales Alenia Space, to cross-fertilize ideas and find solutions for lunar infrastructure.

Enel's involvement in space activities is not a solitary endeavour. The company forms partnerships and collaborations with various organizations in the space industry to support its projects. These agreements take various forms, such as Memoranda of Understanding or framework cooperation agreements, tailored to suit the specific collaboration requirements. Enel's collaborations allow it to tap into the expertise of space industry actors, reducing market uncertainties and increasing the economic attractiveness of their projects. In return, Enel contributes its knowledge in renewable energy and energy distribution, enhancing the overall capabilities of these joint ventures.

While Enel currently operates without a dedicated space team, the company has considered the possibility of creating one in the future as space activities gain momentum. A dedicated unit would enable Enel to better coordinate and focus on space-related projects, potentially leading to more substantial involvement and investments in the space sector. This future-oriented perspective demonstrates Enel's willingness to expand its role in lunar infrastructure and space technology.

Enel's venture into lunar exploration comes with its share of challenges. These include obtaining support from internal stakeholders, securing funding for resource-intensive projects, and addressing communication challenges to justify the allocation of resources. Moreover, as a company with significant state participation, Enel also considers the regulatory and legal aspects associated with space activities. The company takes a cautious step-by-step approach to mitigate risks and ensure sustainable growth and success in the long run.

Enel's involvement in lunar infrastructure projects exemplifies the potential benefits of joint development between space and non-space companies. By leveraging its expertise in renewable energy and innovative energy solutions, Enel actively contributes to space technology while seeking opportunities for terrestrial applications. The company's open approach to collaboration and the exploration of technological synergies demonstrate how non-space actors can play a crucial role in the realization of lunar infrastructure and other areas of space technology. As space exploration progresses, joint ventures between space and non-space companies are expected to drive innovation and technological advancements, creating a new era of collaborative opportunities in the space industry.

3.2 Chiyoda Corporation

Chiyoda Corporation is a Japanese engineering company specialising in oil and gas. Chiyoda first ventured into the space market in the 1990s, producing equipment in support of life sciences experiments in Japan's ISS KIBO module. More recently, Chiyoda has entered the lunar market, specifically in the field of lunar resource extraction.

Chiyoda is leading design and system integration of a lunar water analyser, intended to launch in 2026, which will analyse the prevalence and characteristics of water on the lunar surface. Lunar water is of particular interest, given its potential use for life support and fuel. However, later prospecting missions are also intended to characterise other resources of interest.

The ultimate goal of Chiyoda Corporation is to support a human habitat on the Moon. To do this, Chiyoda Corporation intends to manufacture a lunar plant that generates liquid hydrogen and oxygen. Chiyoda has considerable experience in the terrestrial hydrogen supply chain and energy plant construction, and intends to leverage this to create a lunar plant.

Chiyoda Corporation is pursuing the lunar water analyser project in partnership with several other organisations. Chiyoda is leading the project as system integrator, and is producing the analyser's drill and vaporiser subsystems. Yokogawa Electric, a global provider of industrial automation, test, and measurement solutions, is producing the laser analyser which will be used to assess vapourised regolith. Academics from Tokyo University and Ibaraki University are supporting on the module specification. Finally, ispace, a provider of lunar transportation services, is envisioned to contribute lunar transportation and payload hosting services for the project.

The project is developed by the team of Chiyoda Corporation and the partner organizations, which is focused on identifying and exploiting business opportunities beyond the terrestrial energy market. To date, the project is financed entirely through internal funding by the team. Further, the partner organisations have entered the partnership willingly without exchange of funds.

For the organisations involved, such a programme offers several benefits. The industry partners involved will be able to sell the prospecting data produced by the module, as well as potentially the module itself. The academic partners involved are able to advance their research, and commercialise it in an industry setting. The team expects to benefit directly from the revenue produced from the sale of lunar data, which expects to be generated from 2027, and from the sale of lunar resources, which it expects from 2030+. Further, the programme offers potential benefits for Chiyoda's terrestrial business. Chiyoda Corporation has been working on commercialization and demonstration plant for hydrogen for energy on Earth. Through developing a lunar plant for utilising hydrogen and oxygen, the company can bring the technology back to Earth, and can use the experience gained from lunar exploration to expand on this market on Earth, in particular in harsh environments.

Programmes such as this are not without challenges. Until the distribution, concentration, and state of lunar water is better understood, it is difficult to produce an internal business case with much certainty, which in turn makes financing projects such as this more difficult. Further, transportation options to build up the infrastructure required for extraction and processing are also still uncertain, despite emerging options on the market. The high uncertainty in projects such as these means that strong space agency and government support is envisioned to be required for the early stages of the programme. This, however, is viewed as a necessary but not sufficient condition for commercialisation. Beyond the involvement of governments in reducing economic uncertainty, Chiyoda Corporation anticipates that programmes such as these require a strong *international ecosystem* of commercial, academic, and government players. This is seen as necessary in order to deconflict commercial activities, efficiently develop core technologies and infrastructure, and build safe sustaining markets. Japan has already seen some initial developments in this direction, with the establishment of the Lunar Industry Vision Council. However, the grouping is national, and further, formal, international engagement is seen as necessary going forward.

As part of this ecosystem, a growing and necessary role is seen by Chiyoda Corporation for companies not traditionally engaged in lunar exploration, or the space industry. Firstly, on the component and assembly level of the supply chain, many companies not currently engaged in the space industry produce robust parts of clear application in space. Greater participation by these companies in the lunar market is hoped to reduce the cost for critical components required to expand lunar markets. Secondly, a considerable role is envisioned for companies building technologies for harsh environments on the Earth. These, again, have clear applications in lunar environments, and the entry of these companies into the lunar market is seen as mutually beneficial. Finally, if humans are expected to inhabit the Moon for extended periods, the ecosystem of companies engaged in lunar exploration must include those with the expertise to develop Earth-like amenities. For example, if it is envisioned that the lunar environment will at some point host hotels for tourists, it is seen as necessary that terrestrial hospitality companies are engaged in the lunar ecosystem to shape its progression.

3.3 Lunar Outpost

Lunar Outpost is a lunar infrastructure and transportation company founded in 2017 with the goal of creating a permanent and sustainable human presence off

Earth. This space company was interviewed given its strong involvement in lunar projects with traditionally non-space companies. The company produces robotic systems and vehicles to provide lunar payload services to its customers, with the first intended operational system being its MAPP lunar rover, set to launch in 2023. The company is notable for its leadership in off-world mobility and extensive partnerships. Two are particularly notable.

The first is partnership with Australian company EPE. EPE provides force protection, counter IED and CBRN solutions to security bodies. As such, the company has also developed expertise in robotics, autonomous systems, artificial intelligence and machine learning, and their deployment in hazardous environments. Lunar Outpost has partnered with EPE to lead a broader consortium – including BHP, Northrop Grumman Australia, RMIT University's Space Industry Hub, and University of Melbourne's Space Laboratory – to bid on the Australian Space Agency's Trailblazer Moon to Mars initiative. The team has successfully won phase 1 of the program, and is now one of two teams competing for phase 2. The programme ultimately aims to see an Australian lunar rover delivered to the Moon's surface.

The second partnership is with Nokia Bell Labs. While Bell Labs, acquired by Nokia in 2016, has a longstanding space heritage, pioneering the development of Telstar 1 in the 1960s, Nokia itself has not seen as significant forays into the space industry to date. Together with Intuitive Machines, Lunar Outpost will support Nokia Bell Labs in testing the deployment of a lunar 4G LTE network, with the IM lander, Lunar Outpost MAPP rover and IM hopper all carrying LTE payloads to establish a communications network on the lunar surface. The viability of this network could lead to the broader adoption of the technology for lunar surface communications.

These partnerships highlight further avenues of engagement for organisations that are venturing into the domain of lunar infrastructure for the first time. In the case of Lunar Outpost's partnership with Nokia, the provision of payload space – as well as accompanying supporting services on systems integration, such as communications, environmental controls, etc. – is a promising avenue of collaboration. The organisational arrangement is fairly clear cut, and allows Lunar Outpost to provide the full depth of its space expertise, while also allowing Nokia to fully leverage its capabilities and resources. Meanwhile, Lunar Outpost's partnership with EPE highlights partnership on proposals as a very good opportunity. Jointly leveraging organisational capability to pursue a government contractual opportunity such as Australia's Trailblazer programme presents a comparatively low risk manner for companies to enter into the space and lunar infrastructure domain, that presents clear objectives and joint development opportunities.

Both Lunar Outpost and its partners derive mutual benefits from these collaborations.

For partner corporations, like Nokia, the longer-term opportunity of lunar markets is a driving force. These companies have obligations to their shareholders, with returns on investment that need to be met. Now, as lunar markets mature, this return on investment for lunar infrastructure is seen as becoming tangible at reasonable timescales. Collaboration on projects such as Nokia's lunar LTE network or Lunar Outpost and EPE's Australian lunar rover project, are also seen as important drivers of innovation within partner organisations. Applying a company's IP and practices in challenging novel contexts is a powerful driver of innovation, and engagement in these projects is seen as a booster to building an innovative culture. Outwardly, engagement in, and successful execution of, lunar infrastructure projects is also a beneficial signal to future investors and potential clients. Lastly, through engaging in partnerships such as those conducted by Lunar Outpost, traditionally non-space companies can contribute to developments that are fundamentally important to the future of humankind. While this is not a quantifiable benefit on a company's balance sheet, it is nevertheless an important potential benefit, not to mention can serve as a powerful source of morale and energy for a company's employees.

For Lunar Outpost, partnership with companies not traditionally engaged in lunar infrastructure also offers benefits. The establishment of strong regional partnerships has, and continues to, aid the company's global expansion. Further, bringing non-space companies into the lunar infrastructure domain as partners is critical to building out a commercial ecosystem. At this stage, it is important for Lunar Outpost to support building out a larger ecosystem, in which the players involved gain increasing confidence in their ventures. For companies like Lunar Outpost and others, creating this broader confidence will pay off manyfold once markets move to scaled operations, that require expanded supply. Many of the potential partners for lunar resources hold considerable resources and know-how. If this confidence in employing these assets can be built now, this sets a foundation for considerable mutual benefit in the future.

Of course, for the industry, establishing and building out these partnerships will not be without challenges. A key identified challenge within the industry more broadly is schedule delays. The space industry routinely sees mission and launch delays. However, in order for lunar markets to mature, and, critically, for new entrants to become increasingly involved, a reduction in delays and more predictable schedules is seen as a necessary condition.

4. Results and Discussion

Reflecting on the research questions of the paper, several identifiable patterns emerge from the case studies examined.

Regarding the form and arrangements of managerial practice, it is clear that collaborations may take a host of different forms. These span everything from one-off collaboration agreements to ongoing facilities sharing, payload exchange and joint use. In some cases, a two-sided B2B agreement is sufficient for the projects to be developed. In other situations, coordinated action between a large number of entities is crucial.

While this variety in the forms of collaboration may partially be a function of the relative early stages of commercial lunar activity, and companies trialling multiple forms of collaboration, the diversity in collaborative arrangements is expected to persist. One interviewee, when asked about future forms of arrangement suggested future collaborations would be dictated by individual circumstances and priorities. Larger (originally non-space) companies may establish their own branches or organisations that are focused on space, as has already been observed in some of the organisations studied. Additionally, one phenomenon not observed in the case studies may be expected to emerge, namely mergers and acquisitions, as smaller companies that prove their capabilities are increasingly seen as a good investment by larger companies. These companies, observing a maturing market, rather than trying to spin out a new division, may simply acquire a company that has developed desired capabilities. The role of capital markets matter. There are in emerging space markets some smaller companies that have reached the end of the runway and would benefit from being consolidated into larger entities including being merged with a relevant non-space company. Beyond startups and early stage, there are later stage space companies whose stakeholders would benefit from merging with a larger entity, including a non-space actor, as an alternative to venture capital investment, while providing a neat exit to current stakeholders.

The mix of the points above seems to suggest that the ways in which the collaborations are structured and managed may not drive primary impact on the project itself. Space and non-space companies appear to freely coordinate on the most efficient way to work together and there does not appear to be a form of "best practice" in this regard.

Considering the benefits of space and non-space collaboration on lunar infrastructure, those for non-space companies appear to fall into two categories: product innovation and expected strong positioning in future markets. Product innovation allows for a more immediate, near-term benefit on the transfer of innovation from Moon to Earth, resulting in an enhancement of the standard business. Considerations around future markets comprise: an expected long-term financial benefit in the form of future (new) revenue streams and consequent returns on investments; and other general benefits such as reputation, attractiveness to investors, cost reductions etc.

In general, the majority of expected benefits noted in *Section 1.3 Purpose*, seem to be borne out. Multiple organisations cited the importance of establishing an ecosystem of suppliers and collaborators, given the diversity in capabilities required. This links to the coordination problem inherent to building a lunar ecosystem. Recently, organisations such as DARPA have also sought to address this issue, forming fora to establish a lunar economy. Expected improvements to innovative capacity and R&D output efficiency were also observed within case studies, as were expected benefits arising from spinoffs.

5. Conclusions

This paper has provided an insight into a novel emerging area, namely the collaboration of space and non-space companies in the domain of lunar infrastructure. Studying the already existing contributions both in the business management and in the space fields, we opted for a methodological approach based on interviews to non-space actors, except for Lunar Outpost, and on the relative, emerging multiple case studies' analysis. This approach has provided us with results that confirmed only in part the expectations we formulated based on theory and literature reviews. Interviews highlighted a wide array of benefits and managerial arrangements that the companies are employing in the development of the lunar venture, but also a set of challenges that are diversified and touch several aspects of a business' organization. In any case, both the methodology employed has been successful in finding the elements to respond to our research questions, with satisfying levels of detail both on the motivation and on the modalities side.

Space and non-space collaboration has been studied in the literature in other areas, however, the sphere of lunar infrastructure remains comparatively unexplored. If this might be connected to the slower development that features the lunar economy, relative to other space markets, it is still relevant to point out how space and non-space partnerships may be a great engine not only in the field of lunar activities. The methodology presented in this paper may be used for several other studies involving new investigations on the benefits of space and non-space collaborations. The authors find this feature crucial as they believe the space sector to be a possible flywheel for the World's economies and societies. For instance, beneficial effects stemming from this research field may impact developing countries, aiding them to possibly grow in new, futuristic markets – like space ones – even in the absence of an adequate national space ecosystem in support. The authors believe these to be great fields for future expansion of the present research.

Several other areas of potential future research can be foreseen. Firstly, there is a clear need to expand the pool of collaborations examined and include even more stakeholders in the data collection process, in order to capture more viewpoints. Additionally, the early stage of many projects currently makes the examination of financial performance difficult to assess. This matter is complicated further by the reliance of many companies on venture funding and inherent future uncertainty regarding capital markets. However, as the ecosystem matures, and further data becomes available regarding organisational arrangements and financial performance, a further area of interest would be larger scale examinations of organisational arrangements and the ultimate performance of joint projects, both from a direct perspective (return on investment), and indirect (spinoff, spillover, societal and intangible effects). Continuing to build understanding in these areas, and translating findings into business practice, would help to accelerate and optimise this new horizon of industrial activity in space. This, in turn, will reap considerable benefits, not only for industry, but humanity as a whole.

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