INNOVATION IN SPACE

POWERING A NEW ERA

Final Report

INTERNATIONAL SPACE UNIVERSITY

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OPEN INNOVATION IN SPACE

Team Project Final Report

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The Space Studies Program 2014 of the International Space University (ISU) was held at the École des Hautes Études Commerciales de Montréal (HEC Montréal) and École de Technologie Supérieure (ÉTS) in Montréal, Canada.

Cover photo: The Open Innovation cover art shows a metaphoric sun rise, symbolizing the potential beginning of a new era in the space sector. The logo shows the word Open with negative space lettering. The O is filled in blue and overlaid with the letter i, to look like an orbiting satellite, making it immediately clear that space is the topic.

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ABSTRACT

The global space sector is rapidly changing in how the development and operation of space activities is undertaken. Commercial entities are gaining abilities once held only by super powers and governments around the world continue to create new space agencies. Introduction of new space actors requires a new approach to space innovation. Open Innovation is a potential way of addressing the current challenges in the space sector that makes use of existing frameworks while taking advantage of increased accessibility to space and the public interest it generates.

In this report we define Open Innovation as the process of strategically managing the sharing of ideas and resources among entities to co-create value. We explore existing methods of innovation and how our definition can be applied to the space sector. We also analyze the successes and failures of entities that have implemented an open framework and how the lessons learned can be applied to the new industry of asteroid mining.

FACULTY PREFACE

The Space Studies Program participants who chose Open Innovation (OI) as their Team Project faced a rather unusual challenge. OI is not an entirely new concept, nor is it an all-purpose solution to the challenges we face in the space sector. Furthermore, there is no universal definition of this concept or any standardized way to implement it. Compared to most other Team Project topics, the scope of the work was very broad. They were asked to derive an operational definition of OI, and make a critical assessment of its potential in the space sector.

The way they tackled this challenge was a true testament to the power of ISU's "3I" approach in space education. They used the international nature of their team to the greatest extent possible by researching cutting-edge OI examples from around the world. Their interdisciplinary approach enabled them to explore the intricate linkages among the business, legal, technical, and societal dimensions. Finally, their intercultural team structure helped form a professional and positive work environment where diverse opinions were valued and shared.

The most tangible result of this creative, and at times, chaotic process is this document. They strived to bring clarity to the meaning of OI for the space sector. They performed a critical analysis of the literature to identify the benefits and limitations of existing OI applications. Then, they selected and developed a case study to illustrate the promise and perils of OI for an emerging space market: asteroid mining.

However, we believe that an equally important intangible result was produced: they proved that the space sector is capable of change by reaching out and bringing in the best of what non-space has to offer. The old habits of closed innovation, secrecy, rigid cooperation structures, and an acute case of "not invented here" syndrome are not going to disappear from the space sector overnight. But this team has taken the initial steps on a long intellectual journey that has the potential of transforming the way we do business in space. We are proud to have witnessed those steps and now encourage them to push this project further by bringing their knowledge back home where they shall positively influence and lead the change.

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AUTHOR PREFACE

The team project Open Innovation in Space - Powering a New Era is a product of 33 professionals spanning 15 nationalities over nine intensive weeks of the 27th of International Space University Space Studies Summer Program in Montréal, Canada.

The old ways of conducting research, development, and innovation are changing. They are being steadily challenged, reshaped, and replaced with new frameworks such as Open Innovation. This shift relies on the recognition that organizations and companies are facing a new era of thinking and applying frameworks for innovation.

These changes are progressively entering the space sector, but government space agencies and private space companies are still testing Open Innovation methods to achieve their goals due to their lack of experience. This team project has investigated the potential of applying Open Innovation models in space by exploring the theoretical backdrop, identifying the most promising applications, capturing the limitations, and providing recommendations. We then describe a business case for a prime Open Innovation candidate, namely asteroid mining. Finally the value of Open Innovation in space mission design was compared and contrasted with todays closed innovation practices.

Our Open Innovation in Space team has addressed this challenge through:

- Using this rare opportunity to produce a report that compiles a unique mix of intercultural, international, and interdisciplinary competencies and reflections
- Reaching out to the space community through survey, conversation, and communication to harness the valuable input from experts, professionals, influencers, and organizations in the space sector
- Working diligently to manage, motivate, and integrate the skills of a large project team of strong-minded professionals with backgrounds from science, human performance, applications and humanities to management and business, politics, economics, and law.
- Creating and sustaining a positive working environment throughout the phases of the team project, doing our best to ensure the empowerment and contribution of every individual in our group

We hope you enjoy reading our report as much as we enjoy creating it.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

3D	Three-Dimensional
3I	Intercultural, International and Interdisciplinary
AI	Artificial Intelligence
ASC-CSA	Agence Spatiale Canadienne / Canadian Space Agency
BMVSS	Bhagwan Mahavir Viklang Sahayta Samithi
CARIC	Consortium for Aerospace Research and Innovation in Canada
CEDIC	Center For Development of Scientific Investigation
CEO	Chief Executive Officer
CHM	Common Heritage of Mankind
CoIN	Collaborative Open Innovation Network
COPUOS	United Nations Committee on Peaceful Uses of Outer Space
COTS	Commercial of the Shelf
CRIAQ	Consortium for Research and Innovation in Aerospace in Québec
DIY	Do-it-Yourself
DSI	Deep Space Industries
DoS	Department of State
DoC	Department of Commerce
ESA	European Space Agency
ÉTS	École de Technologie Supérieure
EU	European Union
GNSS	Global Navigation Satellite System
HEC	Hautes Études Commerciales
HR	Human Resources
IBM	International Business Machines Corporation
ICBM	Intercontinental Ballistic Missile
IP	Intellectual Property
ISRO	Indian Space Research Organization
ISS	International Space Station
ISU	International Space University
ITAR	International Traffic in Arms Regulations
LC	Liability Convention
LCD	Liquid Crystal Device

LEO	Low Earth Orbit
LIDAR	Light Detection And Ranging
MDA	MacDonald, Dettwiler and Associates
MIT	Massachusetts Institute of Technology
MOU	Memorandum of Understanding
MRI	Magnetic Resonance Imaging
NASA	National Aeronautics and Space Administration
NDA	Non-disclosure Agreement
NEO	Near Earth Object
NGO	Non-governmental Organization
NIH	Not Invented Here
NPV	Net Present Value
OI	Open Innovation
OST	Outer Space Treaty
P&ID	Piping and Instrumentation Diagram
R&D	Research and Development
RAP	Robotic Asteroid Prospector
ROI	Return on Investment
SME	Small and Medium Enterprise
SOFIA	Stratospheric Observatory for Infrared Astronomy
SSP	Space Studies Program
STEM	Science, Technology, Engineering, and Mathematics
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
U.S.C	United States Code
USML	United States Munitions List
VC	Venture Capitalist
WIPO	World Intellectual Property Organization

1 INTRODUCTION

Human expansion into space is increasing through the continued growth of global space activities, but the traditional challenges of schedule, quality, and cost remain. These challenges are partly a consequence of closed innovation models that have been prevalent among actors in the space sector. States have promoted international cooperation to address these challenges and to leverage financial and technical resources to enable more collaborative opportunities.

Open Innovation (OI) is a strategic approach to fostering cooperation. The space sector has just begun to explore OI methods with the goals to reduce costs, diversify risk, reduce development time, and tap new ideas and resources to spur innovation. Government and industry have used OI methods to harness the contributions of external communities and developing markets in pursuit of these goals.

We explored the impact and potential of OI from an interdisciplinary viewpoint addressing engineering, policy, economics, and law; space sciences; humanities; management and business; space applications; and human performance in space. Our ultimate goal is to identify whether space sector entities can adopt OI models to sustainably reduce development time and project cost. In this report we: (i) define specific OI methods and models, (ii) use asteroid mining as a case study to illustrate the benefits and limitations of OI, and (iii) make recommendations for how to apply OI to space activities.

1.1 Space Sector Overview

The global space sector encompasses government agencies, commercial industries and non-governmental organizations (NGO). In 2013 the global space economy was valued at US$313.17 billion, with a growth rate of 4.0%, dominated by commercial space satellite products and services and commercial space infrastructure and support industries (Space Foundation, 2014). The space infrastructure network continued to grow as a result of an increase in the development of new launch vehicles, new spaceports that are closer to becoming operational, and the launch of new satellites. Increases in Science, Technology, Engineering, and Mathematics (STEM) education enrollment at primary and secondary levels indicate that the space sector will have access to an increasing talent pool of qualified professionals. As overall access to higher education increases and the number of non-STEM students goes up, the space sector will also benefit from qualified resources in key areas such as management, humanities and law (CUNY, 2013).

The space economy is changing as a result of increasing contributions from universities, industrial actors, and Small and Medium Enterprises (SME) that now supplement the space activities of established national space programs (Organization for Economic and Commercial Development, 2011). New metrics have been developed to capture space activities of developing countries (Wood and Annalise, 2012). NGOs are impacting the space sector, specifically by influencing policymakers through citizen diplomacy and the public through capacity building activities that increase expertise and awareness of space-related issues (Lukaszczyk and Williamson, 2010).

This shift of the space landscape is placing a growing pressure on these new actors as they seek inclusion in the policy making process (Handberg, 2010). Even as interest in large scale civil space programs decreases, space activities are growing and the sector is benefiting from a broadening community contributing new ideas and routes to market (Space Foundation, 2014).

1.2 Mission Statement and Definition of Open Innovation

Our mission is to explore and identify the benefits and limitations of Open Innovation concepts and to develop a case study that makes recommendations regarding the suitability of specific Open Innovation models to the space sector.

Our team defines Open Innovation as the process of strategically managing the sharing of ideas and resources among entities to co-create value.

1.3 Methodology

The approach to the Open Innovation in Space project began with a literature review. We used terrestrial successes and failures to understand the applicability of OI. Different models of OI are analyzed and their potential investigated. A core element of the project approach is a survey, conducted with members of the space sector to understand the extent to which OI is present to understand the perception of OI within space agencies, industries, and NGOs. The gathered knowledge about theory, terrestrial background and survey results were used as inputs in the development of a case study that illustrates the applicability and feasibility of OI aspects in space project development phases.

2 INTRODUCTION TO INNOVATION THEORIES

The term innovation can have many meanings. Open, closed, distributed, linear, collaborative, radical: many adjectives have been used to define innovation processes. Organizations strive to innovate, but many find it difficult to actually do so or even to understand exactly what innovation means. Innovation is both a complex and necessary process; a nebulous concept with real life ramifications for organizations that try to use it.

This chapter offers a broad overview of the innovation ecosystem. First, we discuss the history of innovation and the evolving rationale behind organizations' collective drive for novelty. Then, we describe the dominant closed innovation models of the 20th century, the forces that led to their erosion, and the transition to democratization of innovation activities. This chapter touches on the significant body of literature on OI, offering both a theoretical and working definition of the concept on which this report is built.

This literature review is not exhaustive and is not intended to debate which model is superior. The literature on innovation is too broad and rich to be summarized in a few pages. The decision to adopt a given model depends on many external and internal factors, not just the intrinsic value of the model itself. The goal is to provide readers with a theoretical outlook within the scope of this report, enabling them to make balanced and informed decisions leading to a course of action that best applies to their organizational innovation strategy.

2.1 Historical Definition of Innovation

Historically, commercial activities have fallen under two types of regimes: exploitation and exploration (March, 1991). This implies that firms are either trying to extract value from existing activities and grow current assets, or to generate novelty and identify future opportunities. While the former falls into the realm of day-to-day operational management, the latter is precisely the objective of innovation efforts. As theorized by March (1991), organizations must balance their efforts between getting better at what they do and learning ways to do things differently. Many firms have failed to re-invent themselves over time, focusing rather on the products and services that had created value in the past. Others experiment with different forms of simultaneous or sequential pursuit of exploitation and exploration activities in order to become an ambidextrous organization (Andriopoulos and Lewis, 2009). Most closed models, discussed in later sections of this report, often follow a form of structural ambidexterity (Tushman and O'Reilly, 1996), that is, having a separate department (R&D) dedicated to exploration activities. OI follows what has been described as a form of network ambidexterity, distributing exploration activities to external partners across the value chain. Refer to Figure 2-1 for the evolution of innovation models.

Economists, managers, and entrepreneurs would all provide a different definition of innovation and its application. Sawhney et al. (2011) define innovation as "the creation of substantial new value for customers and the firm by creatively changing one or more dimensions of the business system." In other words, innovation is not just a technological feat; it can also refer to how organizations manage their operations, engage with outsiders, or deliver their services. It requires a collective action and an organized environment (Hatchuel et al., 2009). Moreover, the need and pace at which organizations must now create new value has increased to a point where it is now viewed as an "all the time, everywhere" imperative (Birkinshaw et al.,2012). Innovation has gone from being a tool for growth to a survival condition (Hatchuel et al., 2009).

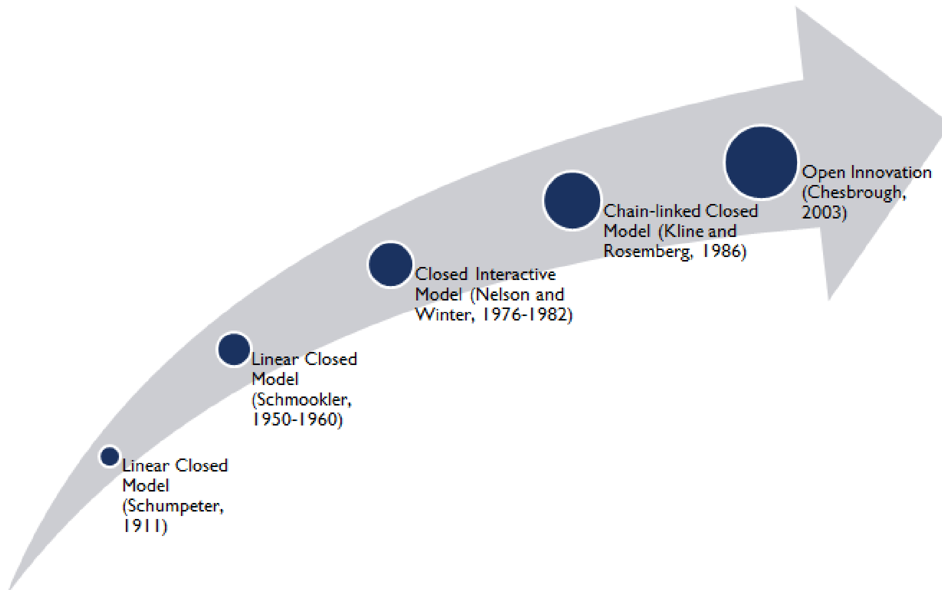

Figure 2-1: Evolution of Innovation Models

2.2 The Evolving Rationale for Innovation

Historically, innovation has been considered a craft rather than an industrial activity. Successful inventions were seen as the work of a few geniuses and learning was accomplished through unstructured approaches such as trial-and-error (Hatchuel et al., 2009). It was only during the second industrial revolution in the early 20th century and in the years after World War II, that innovation became a formal, rationalized, and rather closed process. During the golden age of corporate research, firms rarely outsourced idea development and preferred to innovate internally (Cohendet, 2014). Hune-Brown (2012) detailed this when describing how Bardeen and Brattain at Bell Labs created the transistor by placing two gold points onto a germanium surface to create a power surge. Instead of bringing external innovations into the company to create this technology, they built on years of incremental innovations from within the company. Their work at Bell Labs contrasts with the free flow of information among firms and other actors in the 19th century iron industry, who innovated together to optimize blast furnaces. This shift took place in the mid-20th century in which firms had the monetary and intellectual capital to choose closed innovation over a more collaborative framework (Hune-Brown, 2012).

While innovation has always been a concern for organizations, increasing the effectiveness of the process is a defining trait of current development activities. As related in a 2010 report, technology giant IBM interviewed more than 1,500 CEOs, noting that creativity – a key driver of innovation – is the single most influential quality leaders can possess (Berman and Korsten, 2010). A recent MIT Sloan Management Review reinforces this notion by stating that “companies with a restricted view of innovation can miss opportunities” (Sawhney et al., 2011). Recently, innovation has been made more difficult by the necessity of having to do more with less. The economic crisis of 2008 created an environment of scarcity compared to previous decades. A report released by the Organisation for Economic Co-operation and Development (2012) revealed that global business spending on R&D fell by 4.5% in 2009. It is not forecast to grow steadily again for some time. Even venture capital groups are not investing at the same level as prior to the crisis. In this innovation intensive era, the resources to generate new ideas, products and services are not keeping pace with the demand for innovation (Hatchuel et al., 2009). For instance, space agencies such as the National Aeronautics and Space Administration (NASA) are grappling with shrinking budgets and declining resources for key projects like the Stratospheric Observatory for Infrared Astronomy (SOFIA) (Foust, 2014). Frugal times call for the exploration of new innovation methods and the revisiting of old techniques.

There is no scarcity of creative talents worldwide. The United Nations Conference on Trade and Development (UNCTAD) describes the creative economy as the new driver of value creation through the emergence of organizations embracing economic, cultural, and social aspects interacting with technology, intellectual property, and tourism objectives (United Nations Conference on Trade and Development, 2010). This report points to value creation through increased interaction between humanities organizations and science and technology industries. Interestingly, despite international trade dropping by 12% after the 2008 economic crisis, the creative economy continued to grow (UNCTAD, 2010). Creative industries, a sector comprised of knowledge and intensely creativity activities such as publishing, advertising, software, entertainment and gaming, have shown a level of economic stability while other traditional economic segments have underperformed (Howkins, 2001).

To accomplish closer integration of art, science, technology and business is difficult. Executing this successfully requires a more sophisticated framework for innovation than closed innovation models provide. Additionally, collaborating with entities outside a firm require mechanisms of sharing risk and reward for product development along with managing intellectual property use and ownership. Innovating through the creative economy holds great promise, but must be managed appropriately to deliver benefits.

OI has received renewed attention since 2003; however there are many historical examples that show it was once prevalent. As outlined by Allen (1983), R&D firms and lone actors have rarely contributed to technological advancement. More often, employees learned from routine operations and used their insights to create inventions. One example involves changes to the design of 19th century blast furnaces. Initially, inventors tried enlarging furnaces to increase production. Consequently, this modification caused a notable decrease in furnace fuel consumption. People could easily access information from others on existing furnace design to make incremental improvements. Inventors did not treat this as a trade secret but instead shared it freely both informally and in journal publications. This early adoption of OI principles delivered a societal benefit and encouraged further collaboration. Had the iron industry firms kept their information closed, this low cost, iterative innovation would not have taken place. Without large R&D budgets, a closed model instituted by a few companies could not have sustained the many small innovations required to advance the industry. Scarce resources forced them to innovate collectively. This case exemplifies why open models have been the norm through most of history (Allen, 1983).

2.3 Closed Models

Economic theory and managerial models created in the 20th century ranked firms by the capital they possessed and the strength of their intellectual property (IP). Firms were encouraged to find competitive advantage, increase physical assets, beat competitors to market, and protect ideas through intellectual property mechanisms. (Barney, 1991; Porter, 1987; Huff and Robinson, 1994)

Not surprisingly, the process by which firms bring valuable ideas to market has been portrayed as a tight, highly guarded, closed system. Historically shedding light on such a highly sensitive process was considered ill-advised (Chesbrough, 2003).

2.3.1 Closed Linear Models

Among the first scholars to break away from the so-called black box representations of innovation and attempt to describe the dynamics between science, technology, and the market was Schumpeter, who coined the “technology-push” model of innovation. His work describes the process by which basic research produces knowledge and ideas that a firm can turn into products and bring to market (Schumpeter, 1934). While the model dates back more than a century, most science-intensive fields and R&D centered organizations follow this model today (Marinova and Phillimore, 2003). For example, any market use of nuclear material stems from intensive fundamental research, mostly conducted internally within a limited group of organizations. Schumpeter’s model does not account for external sources of knowledge or pressures from the firm’s ecosystem, and suggests that innovations are the result of isolated work. Such technology emergence, in spite of outside input or feedback, falls under what Dosi (1982) calls “deterministic models” of innovation. The linear sequence of activities comprising the technology-push model is summed up in Figure 2-2.

Figure 2-2: Technology-Push Innovation Model (Based on Schumpeter, 1939)

This linear research-to-market sequence did not account for every innovation. One of Schumpeter’s students came out with a completely different model in which market demand drives the development of new products or services. According to Schmookler’s “demand-pull” model (see Figure 2-3), innovative solutions are meant to solve existing or emerging needs as expressed by end users, not the other way around (Schmookler, 1962). Consumer needs are translated into actual products by firms and later become of interest to researchers. One example put forth by ISU lecturer Prof. Patrick Cohendet is that of horseshoes which were among the most patented inventions of the 19th century created in response to the rapid development of roads and new surfaces. This is an example of relying on customers to identify their own needs, but this approach comes with limitations. The customers did not realize that the burgeoning automobile industry would cause the horseshoes to become obsolete. Customers are known for having a limited ability to express their needs, foresee changes, and envision breakthrough innovation (Christensen, 1997).

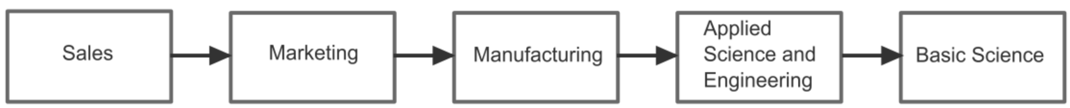

Figure 2-3: Demand-pull Innovation Model (Based on Schmookler, 1962)

The demand-push and demand-pulls models are not conflicting. The demand-push model is more likely to produce disruptive innovations while demand-pull is ideal for incremental innovation. They both depict linear processes with activities that fall under the sole control of a single organization. As Chesbrough (2003) puts it, firms have historically believed they could profit from an innovation only if it was discovered, developed, and manufactured within its walls. It is only the driver of the innovation and the direction of the linear sequence that changes. Despite their flaws, these models of innovation have influenced policy-makers for the past century as they call for different forms of stimuli and public spending. Typically, proponents of the Schumpeterian model will support heavy public investments in basic research, whereas those who believe in the demand-pull model will turn to customer research and development of better metrics or proxies to detect weak market signals as a way to trigger innovation.

2.3.2 Closed Interactive Models

Building on the work of these two scholars, fellow economists (Nelson and Winter, 1982) suggested that while the idea could come from either, research or the market, the linear process by which ideas become actual innovations was not as straightforward. Hence, the evolutionary model of innovation depicts more iterative and complex interactions that lead to new products or services. Departments within a firm build on each other’s work in an iterative fashion until an innovation is deemed robust enough to commercialize. For the first time, formal economic models account for the chaotic nature of innovation, casting doubt on the linear model. These interactive models offer a more complex understanding of the feedback loops and interconnections present in the process. Proponents of these models argue that technological developments do not follow clear pre-determined patterns, and that several innovation paths must be pursued simultaneously to ensure success (Nelson, 2004). Interdepartmental communication within a firm allows innovation drivers to come from anywhere in the development sequence (Beiji, 1998). Despite this evolution, Nelson and Winter continue to describe a process that operates in a closed environment and where interactions with outside actors are limited (Nelson and Winter, 1982). The chain-linked closed model of Kline and Rosenberg, (1986) breaks away from that persistent tradition by modeling a process in which innovation is the result of the interplay between intra-firm and inter-firm activities. While the bulk of the process remains under the control of the firm, knowledge can be purposefully developed and acquired from outside actors within the value chain.

All closed models suggest that innovation should be controlled and results aggressively protected through robust intellectual property mechanisms (Chesbrough, 2011). The 20th century became the golden era of patents, used to protect inventions. Employ the brightest people, own the best production means and the intellectual property, and, the conventional wisdom went, you will win the battle for the market and profits. By leveraging external actors, you can increase access to all of these elements. Any single firm suffers from one truth: “not all smart people work for [you]” (Chesbrough and Teece, 1996).

2.3.3 Erosion of Closed Models

Management scholars were among the first to challenge the closed models of innovation. For instance, von Hippel, (1978) identified the rise of innovations derived from outside the boundaries of the firm. At the time however, most models fell into a manufacturer-active paradigm in which only firms have the knowledge and production means to engage in innovation activities. Although firms interaction with external actors is discussed at length in Chapter 3, it is important to note here that von Hippel’s customer-active theory has challenged the validity of the closed model vision of innovation. His later work on lead-users went further to demonstrate the commercial potential and quality of outsider insights (von Hippel, 1986). Customers are considered more than passive recipients or even innovation drivers as in the demand-pull mode, and are now a commercial force to be reckoned with. As Stewart and Hyysalo, (2008) explain, ever since the “producer company lost its position as the privileged source of innovation, it [has] become urgent to understand how the knowledge from a range of actors flows into the innovation process.”

Erosion of the closed model can be partially traced back to the digital revolution that started in the 1990s, increasing access to information (Brynjolfsson and McAfee, 2012). This shift has revolutionized the culture and structure of firms across all industries and challenged established interactions with actors external to the firm. Previously limited means to learn, communicate, and organize across internal/external borders was replaced with access to nearly unlimited sources of information and a variety of platforms with which to interact. This new technological era disrupted many established processes and methods for doing traditional business, especially those that pertain to innovation (Poetz and Schreier, 2012). Users can create for themselves in the digital age and benefit from individual innovations rather than relying on manufacturers to act as providers (von Hippel 1978; 1986; 2005). The ability of users to develop ideas is increasing because of improving access to technological resources and knowledge, including programming software and 3D printers (Anderson, 2012). As the cost to innovate keeps on shrinking and tools become more accessible, emergence of collaborative creation approaches is likely accompanied by the rise of small, agile competitors. Traditional barriers to innovation are falling one after the other.

A related emerging trend, known as the “do-it-yourself” (DIY) movement is affecting both the development process of innovation and production facilities (Chesbrough, 2006). For example, open source software projects can create, produce, diffuse, and provide user support for complex products without requiring central manufacturers. Users and manufacturers are driven by different interests and values; Anderson, (2012) points to the rise of DIY experts, known as makers, to illustrate how production means have become accessible to users enabling them to literally build new businesses. Whereas aspiring entrepreneurs once needed significant financial investment to create manufacturing capabilities, it now seems that anybody can turn a smart idea into a business, thanks to better access to knowledge, distribution channels, and production means.

In summary, closed models of innovation have been the dominant economic building blocks of the 20th century. While they remain widely used in R&D-intensive sectors and for public policy purposes, they have often failed to describe the complex series of interactions that lead to innovation, in other words, “although very clear and easy to understand, the linear models have always been too much of a deviation from reality” (Marinova and Phillimore, 2003). Despite its success, the closed innovation model waned in utility at the end of the 20th century as circumstances changed. Increased levels of venture capital along with an increase in mobile knowledge workers made it difficult for companies to control their IP, allowing enterprising skilled workers to take ideas discarded by their employers and obtain capital on their own (Chesbrough, 2003). The literature depicts a process that is increasingly decentralized and distributed among a growing number of actors. It points to innovation cycles becoming faster and more complex, which in turn call for more fluid knowledge-sharing practices across boundaries. Renewed understanding of value creation sources and the emergence of new form of organizing innovation has characterized recent work (Amin and Cohendet, 2004). Closed innovation models are however not dead, only eroded (Chesbrough, 2003). They have given way to something new: the open innovation era.

2.4 Open Models

2.4.1 The Rise of Open Innovation

The modern concept of OI has gained popularity in the past decade, in large part due to the work of Chesbrough (2003;2006). As Chesbrough (2011) explains, the division of labor has created new interdependencies between a firm and external actors, as well as opportunities to draw input from qualified people who are not part of an organization. Looking back and theorizing on the development of new technologies between firms and outside actors, Chesbrough (2006) refers to OI as being:

> *"... purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively. [This paradigm] assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology."*

OI is a term used to describe the collaboration trend in idea generation and new products and services development. It points to a shift in the innovation ideal from working inside the firm's boundaries to reaching outside them. While the theory is recent, OI in practice is not new. Rather, it refers to a series of collaborative innovation practices that have always existed (Huizingh, 2011). Loilier and Tellier (2011) demonstrate that a historical review does not uphold Chesbrough's claim that OI is a new development. Many successful firms have become leaders in technological fields without having developed their technology in-house.

OI elements can be found in other forms of technology development such as joint ventures (Peck, 1986), R&D alliances (Lambe and Speckman, 1997), and exploration partnerships (Segrestin, 2005). While the form, breadth, and intensity of the interactions vary among collaborative models, the rationale for open processes remains constant: more efficiency, less risk, newer ideas, and improved sales.

2.4.2 Degrees of Openness and Different Innovation Practices

While OI has been used to describe a wide array of initiatives that incorporate external collaborators, it should not be seen as an all-encompassing term. Scholars have studied the degree of openness firms exhibit when they engage with outside actors. Transparency, accessibility, and replicability describe increasing degrees of access a firm can grant to its external collaborators (West and O'Mahony, 2008; Balka and Herstatt, 2010). Transparency refers to giving outsiders visibility to the innovation process to gather feedback. Accessibility implies that outsiders can interact with the process. Replicability means empowering these outsiders with the tools and knowledge to build technologies the same way the firm does. Firms can select the degree to which they wish to provide collaborators with the relevant knowledge, the production means, and the possibility to influence the design as it goes from idea to actual product. Another tactic firms have used to control the extent of openness is selecting the actors it wishes to work with. Relying on a limited number of partners is an OI form that would qualify as closed collaboration, whereas letting anybody contribute is said to be an open collaboration OI form (Pisano and Verganti, 2008).

Innovation covers a wide spectrum of activities, ranging from idea generation to commercializing of the resulting products or services. The nature of interactions between the firm and outsiders may vary just as much as the degree of openness. External actors can i) provide input and knowledge early to steer the process; ii) integrate into the design, development, and production phases; or iii) help commercialize in the downstream phases of innovation (West and Bogers, 2014). Firms use outsiders in the idea generation phase to better identify opportunities or understand their needs. They engage outsiders in the later phases by allowing them to customize the design of their products or the experience of their services (Franke and Piller, 2004). This means that OI can take various forms and that no single definition can encompass all the potential firm-outsider interactions. Figure 2-4 displays a number of practices along the open and innovation scales.

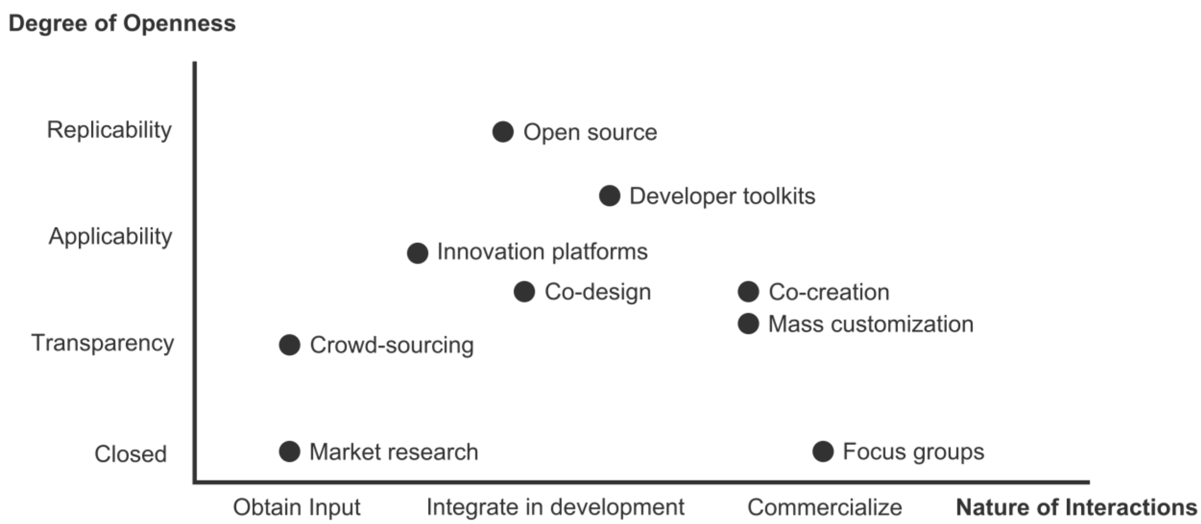

Figure 2-4: Different Open and Collaborative Innovation Practices

2.4.3 Working Definition and Key Concepts

Due in part to Chesbrough's work, OI has become a mainstream term to define a wide array of distributed and democratized innovation activities. At the time this report is being written, Chesbrough's 2003 book has more than 8,000 citations on Google Scholar, indicating the pervasive discussion of his theories in this field of study. Yet there remains a need for better understanding of issues such as metrics and how to assess the value of OI at different levels (West et al., 2014).

Definitions of OI in the literature focus on new product and technology development to the exclusion of other applications. We found these definitions either too complex or too narrow to be useful and therefore adopted the following working definition:

> *"Open innovation is the process of strategically managing the sharing of ideas and resources among entities to co-create value."*

The European innovation research organization EIDON Lab, creators of the Collaborative Open Innovation Network (CoIN) methodology, provide a straight-forward and intuitive model for OI with the closed and open funnel models (Figure 2-5 and Figure 2-7). Each funnel represents the operational boundaries of a business. In the closed model, ideas and concepts originate strictly within internal company R&D. However, many original ideas may not make it to market and end up shelved or thrown away, as indicated by the red lines in the diagram. Only a few ideas (light bulbs), represented by blue lines, make it through the entire innovation cycle, from R&D through to market delivery (target).

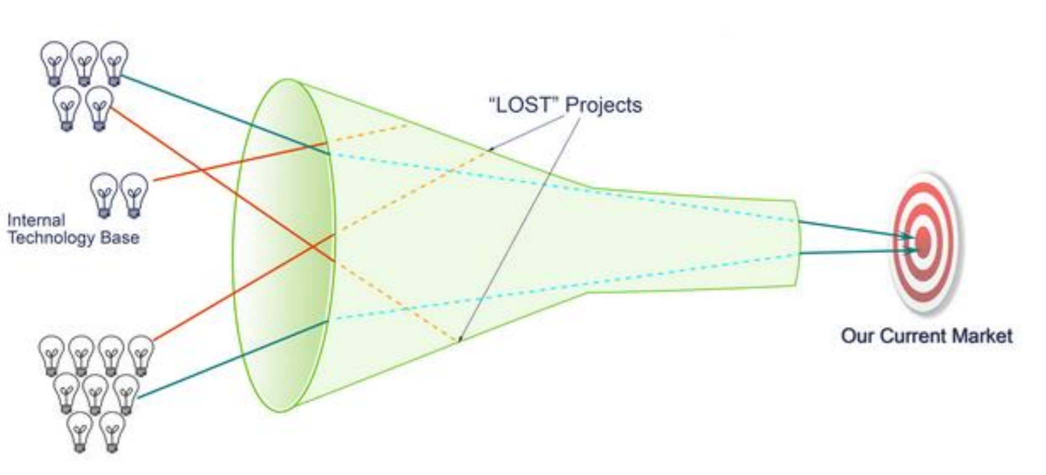

Figure 2-5: Closed Innovation Funnel (Chesbrough, 2003)

In contrast, the OI funnel (Figure 2-7) can be seen as a porous one, with holes at each stage along the innovation process allowing for collaboration with external entities to share ideas and resources (Chesbrough, 2003). The funnel identifies a successful idea as one that reaches market as opposed to one that prioritizes patenting. Internal ideas that were previously side-lined can now be strategically provided to other entities to use for their efforts in a form of inside-out OI. Chesbrough (2012) tells us this approach to innovation is used predominantly by universities, individuals, and start-ups looking to share their ideas with other entities in hopes of gaining exposure and breaking into their desired industries. This is a generalized observation and there are many exceptions of successful firms practicing inside-out OI. Firms should continue internal R&D to build internal capabilities, detect business opportunities, and create knowledge that can be used in future innovation projects (Cohen and Levinthal, 1990).

In contrast to inside-out OI, outside-in OI uses external resources applied internally to create value-added products and services and penetrate new markets. Outside-in OI is more widely used by today's businesses, much more so than inside-out (Chesbrough, 2012). The reasons for this are simple: businesses are more willing and eager to leverage external ideas and resources for their own benefit, but reluctant to share their own with external entities. Limiting the two-way flow of ideas constrains the potential benefits of OI. To strike a balance of outside-in and inside-out OI, businesses must embrace two concepts:

1. Recognition of outside-in OI benefits: There is an abundant amount of information and resources outside of company walls that can and should be taken advantage of.

2. Recognition of inside-out OI benefits: It is possible to protect company IP while sharing it with outside entities for the benefit of the firm. It also allows them to sell or license IP and have outsiders develop new markets and applications. Ideally, the flow of ideas and resources will occur in both directions to benefit all parties.

This process of collaborative creation among entities to achieve mutual benefit best defines OI, and often takes the form of a coupled process (Enkel, 2009). By doing so, firms combine the benefits from outside-in and inside-out approaches, drawing from external knowledge to push innovations and create value. Many successful organizations have been able to conduct joint exploration and exploitation activities with external actors by strategically identifying the activities that could be best pursued in a collaborative manner (Gassman and Enkel, 2004). Coupled processes of co-creating value among entities, discussed in Chapter 2 and 3, are complex and use multiple methods of collaboration. Important steps in adopting OI methods include finding the right partners, identifying interesting and creative collaborations, knowing when to team up (couple), and when to work alone (de-couple). As they transition from closed to open, firms commonly traverse the steps in Figure 2-6.

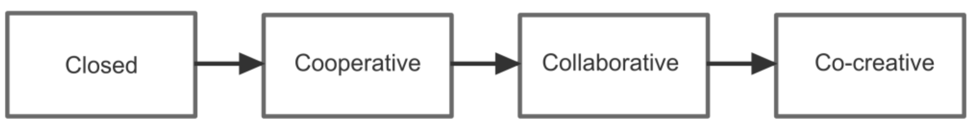

Figure 2-6: Stages Involved from Closed to Open Innovation

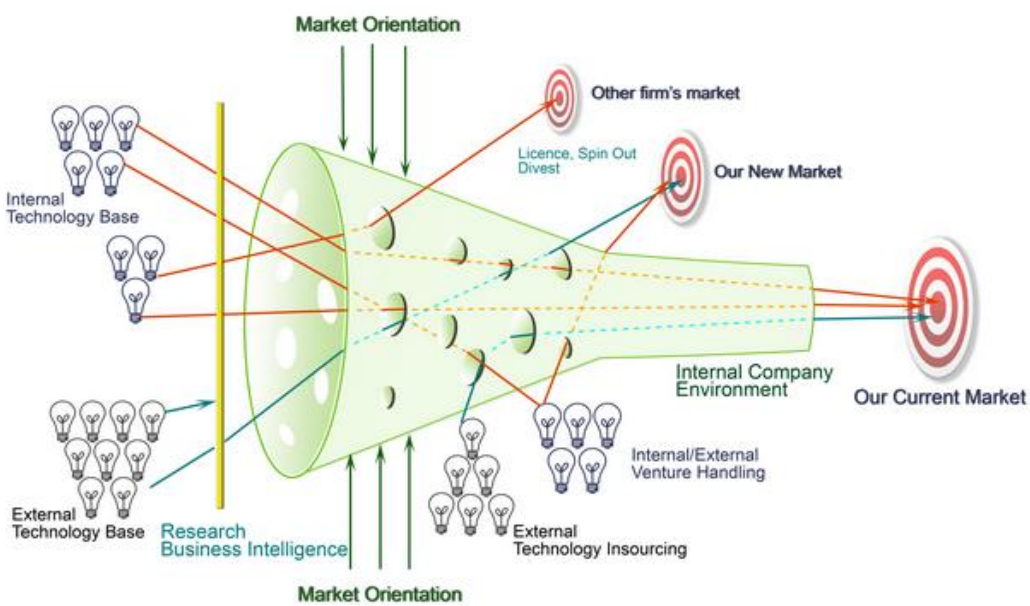

Figure 2-7: Open Innovation Funnel (Chesbrough, 2003)

As innovation practices evolve and open up, it is becoming clear that OI does not jeopardize traditional measures of innovation like patents. In the ten years since Chesbrough released his book, the annual number of patent applications has nearly doubled (United States Patent and Trademark Office, 2014)

This chapter has explored the genealogy of innovation models and addressed the rationale for the recent surge in innovation practices that are pushing the traditional boundaries of firms. We have referred to the historical need for innovation, the eroding factors of closed models and the different ways by which firms are engaging today in OI with external actors. Readers should refer to Appendix 8.1 for a summary of key concepts to ensure a proper understanding of the reminder of the report. As we move to tangible manifestations of OI in Chapter 3, it will become apparent that open practices are not only gaining ground in industry, but also take many forms and shapes. Furthermore, Chapter 3 will provide examples of OI as a strategic management tool, where closed, open and coupled processes co-exist.

3 OPEN INNOVATION

3.1 OPEN INNOVATION AS A GLOBAL CONCEPT

The practice of Open Innovation has local roots in cultures around the world; likewise, the modern resurgence of OI has become a global phenomenon. Across the western world, policies have been implemented that foster OI. The public sectors in the USA, Canada, the UK, and Australia have begun using OI principles to increase citizen engagement in government as demonstrated by competitions to spur research and expert networking like Peer-to-Patent (Lee et al., 2012). In parallel, the eastern world is developing new OI techniques, such as the Jugaad design approach in India that seeks to provide a cost efficient alternative to traditional R&D departments (Radjou et al., 2012). China also began research into the theory of OI almost at the same time as the western world, and the application of that theory can now be seen in the Chinese high technology sector (Ping and Zu, 2011). OI is a truly global concept that is beginning to take hold in a diverse set of cultures and sectors.

3.2 OPEN INNOVATION IN USE

This chapter presents techniques for stakeholders to manage openness within the innovation process. We introduce examples of the most common implementations of OI: inside-out and outside-in, coupled collaborative methods, crowdsourcing and crowdfunding.

3.2.1 INSIDE-OUT AND OUTSIDE-IN

As discussed in Section 2.4, inside-out and outside-in are two aspects of knowledge exchange. Recent examples shown in this section demonstrate the value of these two innovation concepts.

TESLA MOTORS

Elon Musk, the CEO of the electric automobile manufacturer Tesla Motors Inc., announced in 2014 that the company “will not initiate patent lawsuits against anyone who, in good faith, wants to use our technology.” This announcement was a surprise to the automotive industry and Musk justified it by stating, “We believe that Tesla, other companies making electric cars, and the world would all benefit from a common, rapidly-evolving technology platform” (Tesla Motors, 2014). He notes that Tesla’s biggest competitor is the behemoth gasoline car industry, and not the few other electric car companies. The goal of this inside out strategy is to provide free patents to stimulate the creation of electric car companies, grow the market, and spur the industry to develop the infrastructure that will answer to these new needs.

Procter and Gamble

Procter and Gamble (P&G) is one example of a successful implementation of the outside-in method. To apply it, a large number of technology entrepreneurs were assembled to search for promising new technologies and products. The goal was to develop 50% of their products based on this method and to double their revenue between 1990 and 2000. The SpinBrush electric toothbrush, introduced by P&G generated US$200 million in the first year on market (Huston and Sakkab, 2006). This strategy called Connect and Develop involved seeking out external actors such as suppliers, competitors, research centers, universities, and government entities to bring innovation to the company. The collaboration catches external ideas with the aim to increase innovation and reduce R&D expenses. At 2000, P&G however did not reach their intended goals but gained increased revenue, cost reduction, and experience from the outside-in method et (Huston and Sakkab, 2006).

3.2.2 Crowdsourcing

Howe and Robinson (2006) defined crowdsourcing as:

> *"The act of a company or institution taking a function once performed by employees and outsourcing to an undefined network of people in the form of an open call is the technique of crowdsourcing."*

This platform is effective for complex work that can be subdivided into discrete tasks and for work that benefits from diversity of perspective. The organization owns the solutions, and the contributor can be rewarded with some form of recognition. The examples below showcase some of the advantages of this approach.

Fabbrica Italiana Automobili Torino

Due to the closed nature of the regular development process, Fiat Cars were not fulfilling the needs of their customers. To regain them, the marketing department of the company was assigned to design and promote a concept car called Fiat Mio with inputs from users on the Internet. Following the wiki-model of collaborative information gathering, they developed an idea for an open platform to directly engage customers. No selection criteria was applied, instead Fiat encouraged the open public to propose ideas about their envisioned car designs. A vote was conducted through the online platform asking contributors their preferred design. From the results, designers at Fiat Style Center proposed two separate concepts and started constructing the prototypes when enough supplementary information became available. At Sao Paulo Auto Show in 2010, the Fiat Mio was first presented to the public and promoted through social media with the contributors invited to see the result of their work.

Fiat continued to run their platform to gain more customer feedback. Information collected on the platform is used to incorporate new elements to their cars and win market shares from their competitors. The crowdsourcing strategy was a very precious marketing tool which contributed to improve Fiat's visibility and brand image in Brazil and internationally. This strategy allowed the participation of more than 17,000 contributors from 160 countries, generating more than 11,000 ideas (Saldanha et al., to be published).

XiaoMi

The cellphone company XiaoMi, founded in April 2010 pioneered the use of crowdsourcing for developing mobile operating systems in China (Xiong et al., 2013). The success of XiaoMi is linked to their innovation management strategy which involves the customer in an iterative design process (XiaoMi, 2012). XiaoMi's management strategy includes 600,000 enthusiastic volunteers who participated in the development of their mobile phone system (Xiong et al., 2013). Customers are not passive, but also functions as a valuable source of R&D and frequently give feedback to continuously improve the user experience. Thanks to the participation of theirs customers, XiaoMi is able to continuously improve mobile phone software and applications through weekly updates (Ding, 2012). Their crowdsourcing strategy allows them to provide customers tailored-made applications, responding directly to customer needs.

3.2.3 Coupled Activities

As explained in Chapter 2, organizations often combine knowledge generated outside the company (outside-in) to fuel their innovation process, and using knowledge generated inside the company to make profits from products they usually won't sell (inside-out). Engaging with external actors can be done throughout the entire process of innovation, and is not be limited to the fuzzy-front-end of innovation or to the final commercialization phase. Historically, “coupled" implementations of OI have taken form of industrial alliances, partnerships and joint ventures (Enkel et al. 2009). Today, these collaborative processes have evolved into the concepts of co-design and co-creation.

Co-design is a collaborative approach of OI where a product or service is developed using interactive methods. Usually this is achieved through workshops, also referred to as collaborative design activities, where people with relevant knowledge and skills take part and contribute to the design process (Sanders and Stappers, 2008). Design of new products is accomplished by involving suppliers, buyers, users, and other stakeholders (Dubois et al., 2014). Beyond resulting in new objects that are more suited to needs, co-design also fosters connections between participants, which can be put to use in future innovation projects (ibid).

On the other hand, firms who actively interact with external actors to gather feedback, allow users to customize the products to their needs and suggest new design or improvements are said to be engaging in co-creation activities. Often done through online platforms, co-creation implies that problem definition and problem solving be carried out jointly. Through this method, customers, suppliers and the general public are actively involved in generating ideas and concepts towards the development of products or services (Prahalad and Ramaswamy, 2004).

While co-creation can take place within the co-design process, its focus is on tapping into the collective creativity of the stakeholders for new ideas, rather than actually building or designing new objects. Every co-design or co-creation effort is also unique because it involves different people, experiences and problems, and yields outcomes that apply to a specific set of needs. However, these two approaches share a same underlying recognition of the power and the wisdom of the crowd when it comes to innovation (Mahr, Lievens and Blazevic, 2014).

CRIAQ: Consortium for Research and Innovation in Aerospace in Québec

The Consortium for Research in Aerospace in Quebec (CRIAQ) is an example of a successful organization facilitating connections between businesses, universities, and research centers in the aerospace sector. This non-profit organization is a physical co-creation platform which aims to bring together the local R&D forces of the aerospace industry and researchers to stimulate competitiveness of local industries within a global framework (CRIAQ, 2014). Through the organization of workshops, companies present their needs and their challenges to other industrialists and researchers from universities and public research centers. After the workshops, interested actors can start R&D projects together if they gather two companies and two universities or research centers and follow the general agreement of CRIAQ. This general agreement sets a framework for IP collaboration before any work starts. CRIAQ reduces perceived risks to encourage collaboration and allows uninhibited sharing of ideas between partners.

The financial contributions of CRIAQ and the government is an incentive to collaborate in a sector where risks and costs related to R&D are barriers to innovation. CRIAQ brings a multitude of benefits to the aerospace cluster of Montréal. The scope of a CRIAQ project remains in the early stages of R&D, with TRL lower than three. To encourage R&D in the later stages of TRL, four and five, a new initiative was launched in April 2014 to create the Consortium for Aerospace Research and Innovation in Canada (CARIC). CARIC will aim to be an extension of CRIAQ, bringing together aerospace actors across Canada (Dutil-Brutenau et al.,2014).

Go Corporation

Go Corporation was a software startup company that developed an operating system for pen-based personal computer product called PenPoint. The company faced a common startup dilemma between protecting ideas and knowledge from other corporations and sharing information to raise capital and attract customers and employees. Go needed to attract and involve external actors to reduce their schedule for their technology. The firm chose to develop an operating system in collaboration with Microsoft, encouraging them to develop applications for the PenPoint. Knowledge and information was exchanged during numerous meetings between engineers and designers of the two organizations to develop applications.

The two companies signed a nondisclosure agreement (NDA) regarding the co-created applications but never signed anything about other aspects regarding the pen. Afterwards, Microsoft internally developed an operating system for the pen, owning all the IP related to this technology. Go Corporation went into bankruptcy because they shared the confidential information required to develop the pen applications and Microsoft took advantage of this situation using their core competence in operating systems (Chesbrough, 2006).

Collabra

Collabra, founded in 1993 developed a software product to allow multiple users to collaborate jointly on the creation and editing of documents. Collabra was already familiar with the failure of the Go Corporation and they decided to be more secretive and closed in their approach. Signing 195 NDAs with their employees, customers, suppliers, associates, members of the press, and third party companies, they created a strategy based on collaboration with all their customers and their competitors to co-create. The problem for Collabra was that their investors did not sign an NDA. They claimed that to develop investment opportunities with other venture capitalist (VC), it was occasionally desirable to share some information about promising new technologies. The VC's then shared ideas among themselves regarding Collabra to reduce investment risks, because the NDAs imposed by Collabra were costing too much money. In response to the costs imposed by the NDAs, VCs stopped investing in Collabra resulting in the firm being bought by Netscape in October of 1995 (Chesbrough, 2006).

LivingLab in Paraguay: CEDIC (Center for Development of Scientific Investigation, in Spanish)

Another example of collaborative methods is Living Lab which brings together co-creation and co-design methods. The particular example of Paraguay shows a success story of collaborative methods through a non for profit example with societal implications. Paraguay have numerous social problems that government and communities try to fix. One of the major issue is related to support and improve the situation of indigenous families who are living in really poor conditions. In 2014, a LivingLab was implemented to bring together government, researchers, civil society, citizens and local communities. The methodology used was simple. First step was a brainstorming between interdisciplinary stakeholders to present their opinion and their perception of the problem. Second step was the organization of several participatory workshops with different ethnies in local indigenous communities to better understand their needs and their problems. Third step was to put together universities/researchers, local communities, citizens, companies and government/municipality through a non-for-profit organization, the CEDIC, acting as LivingLab to treat and give solutions to citizens problems (Center for Development of Scientific Investigations, 2014). The last step was to train men and women from indigenous villages to solve their issues. All this process results in the development of creative solutions in three different domains: collection of water and organic vegetable gardens for production of basic food, housing model and health education (De Arias et al., 2014).

This example has shown that OI can be implemented in a broader scope than for profit activities bringing creative solutions to solve societal issues using interdisciplinary knowledge and ideas.

3.2.4 Crowdfunding

Crowdfunding is an initiative undertaken to raise money for new projects, collecting small to medium-size investments from multiple individuals or organizations (Ordanini, 2009). When a project initiator has a requirement to raise money, they have the option to propose ideas or projects and use a crowdfunding model to get direct access to gather funding from the market. The crowd, or supporters, may then decide to financially support these projects, bearing a risk and expecting a certain payoff. The crowd co-produces the output, selecting, and sometimes developing the offers they deem to be most promising or interesting.

A moderating organization is needed to maintain a platform that enables all parties to work together and launch the initiative. As described by the author (Ordanini, 2001), crowdfunding has been boosted by recent technological developments, Web 2.0 in particular, that offer new opportunities and scenarios where consumers can use, create and modify content and interact with other users through social networks. Example can be observed where crowdsourcing is used in parallel with crowdfunding.

APPSTORI

AppStori is a relevant example of OI, both as a crowdsourcing and crowdfunding platform. The platform tries to implement a dialogue between developers and users in order to best design applications that respond directly to consumer needs (Appstori, 2014). The principal goal of the platform is to provide crowdfunding activities to help developers raising funds to bring their ideas to market.

AppStori incorporated user friendly interface allowing future entrepreneurs to explain their projects and set funding goals. Members of the community can join a project as beta testers to contribute to the development or provide a financial contribution to the project. If a project meets its funding goal in the proposed timeline, the developer will receive the money and AppStori will charge 7% of the total amount. If the funding goal is not met, there is no exchange of money. The platform stimulates entrepreneurship and development of new mobile applications based on enthusiasts and experts thanks to the financial support provided by contributors (Tsai, et al., 2014).

3.3 LESSONS LEARNED

Section 3.2 contains examples of OI and how it can bring benefits for organizations interested in investing in innovation, as well as its limitations. Section 3.3 describes the implications of OI through various vantage points: Economical and financial, managerial, IP, technical, and social and ethical. Figure 3-1 displays a number of benefits and challenges in implementing OI.

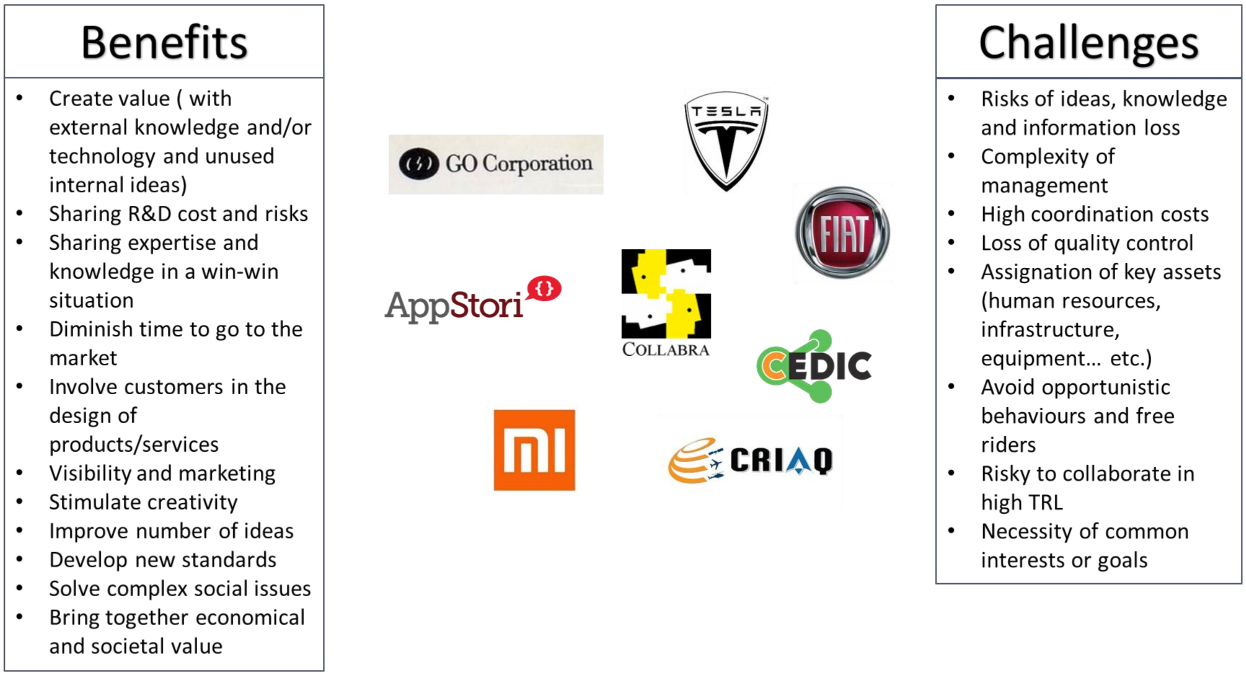

Figure 3-1: Open Innovation Examples

3.3.1 Economical and Financial Implications

OI enables co-creation which increases economic value from available internal and external resources. A major benefit of applying an OI framework is the potential to create monetary value that otherwise would have been lost in a closed innovation model. OI allows firms to leverage external sources of innovation capabilities to improve the firm's products or services. External innovation efforts can lead to new products, services, processes or create new markets for the organization. The application of the OI framework includes identification and scanning of unexploited internal ideas and patents, for potential use outside of the firm. A firm can decide to sell patent or license patents to receive royalties which can result in a passive income stream.

To create financial value, the application of OI models demands greater involvement from users and customers in the design or development of a product. OI strategies such as crowdsourcing are a good example of leveraging the public to directly assess the demand of a product or service. The same type of strategy is used as marketing tool to improve a company's visibility that has resulted in an increase in market share, like in the case of Fiat Mio as described in Section 3.2.2. One radical idea is to freely offer outside entities the ability to make use of patents to spur the development of a new industry such in the case of Tesla as described in Section 3.2.1.

OI allows firms to reduce the time-to-market for new products or services, its processes can help organizations reduce R&D costs by dividing the expenses related to innovation with external partners. Continuous heavy investment in R&D by a single firm can be a risk and OI processes allow firms to share that risk. A lowered risk stimulates and encourages greater investment in R&D efforts; external innovation should contribute to reduce internal R&D cost (Williamson,1985).

One of the major economic concerns of the implementation of OI is the high coordination cost related to the use and interaction of different external actors with the firm's internal resources. The multiplication of flows of information, knowledge, and ideas between entities needs to be managed efficiently and coherently. Another important concern is the redistribution of profit between the actors in a collaborative environment. Special consideration should be given to the definition and ownership of IP between the partners as seen with the Go Corporation example in Section 3.2.3. There are challenges in crowdsourcing strategies, for example, dealing with how to evaluate the contribution of actors and the allocation of profit. Some conflicts may appear if firms begin to make profit with crowdsourced ideas.

3.3.2 Managerial Implications

As David and Fahey (2000:13) explain: "…technology is only 20% of the picture. The remaining 80% is people. You have to get the culture right". This implies that OI should be regarded as a managerial state-of-mind, which calls for renewed leadership styles and a proper culture. Setting up processes so that the identification, use of internal and external ideas from different areas can fuel the firms' innovation process is only one part of the equation. Yet, however good external ideas may be, a common problem in OI is the "Not Invented Here" (NIH) syndrome, that is, when the belief that only internal idea are valuable (Katz and Allen, 1982). Firms' set of values, norms and practices can inhibit the flow of knowledge and the way collaborators are perceived, which in turn impact the success of OI practices. Knowing that organizational culture influences the creation of new knowledge, fosters social interactions and shapes assumptions about which knowledge is deemed important, it is vital that firms identify internal barriers and question their behaviors as they engage in OI (David and Fahey, 2000).

Efficient OI processes are closely linked to the absorptive capacity of the firm (Cohen and Levinthal, 1990). Absorptive capacity is the ability for a firm to integrate external knowledge or technologies. Organizations should develop a creative slack of ideas (Cohendet and Simon, 2007) to keep in memory the creative outputs it develops through any innovation processes. This retention of ideas is beneficial because unused ideas could be relevant and useful in future projects inside the organization, or outside as a potential future spin-off.

Another challenge in the application of OI frameworks is to deal with opportunistic behavior. Collaborating with external organizations of different sizes can lead to power disproportions. OI brings risks when large firms try to use their size as an advantage to perform disproportional competition for resources, buying strategic assets or trying to hire the best employees from smaller companies after collaborations. Because of limited resources and assets, entities should strive to find the right balance between assets assignment to external and open activities, and assists to those activities that remain closed.

3.3.3 Intellectual Property Implications

The definition and use of IP is a fundamental part of understanding the implication of OI. The use of IP should be clarified and agreed upon before initiating collaboration with external partners of a company. In terms of output of the collaboration, important aspects are the ownership and scope of usage for patents (co-patents, scope of application), licensing of patents (license exclusivity, royalties, agreements about innovation on the content of the license), copyrights and publications as well as collaborations with universities and academia. The CRIAQ example in Section 3.2.3 describes an IP framework between actors.

Opening up the innovation process implies sharing valuable knowledge and abandoning control over what external actors can do with it. It also raises questions about the appropriation of new knowledge created in open settings.

Another challenge that might spur legal actions is the loss of control over key assets that belong to the organization as a competitive advantage. An aggressive approach to the sharing of IP and patent pools can inhibit collaboration because it becomes too complex to manage the information flow. A firm may not want to interact and collaborate with external entities if it is required to sign complex NDAs each time representatives speak with external people, as shown with the Collabra example in Section 3.2.3.

It is important for firms to find balance between managing the company's internal IP base and implementing an open sharing approach while protecting core IP assets. A successful collaboration relies on a firm's ability to develop relations based on trust, ensuring equal stakes in the collaboration effort.

3.3.4 Technical Implications

OI brings together actors from different industry segments, markets, and different backgrounds which allows an interdisciplinary approach to improve important inter-organizational processes such as innovation, production or commercialization.

OI can be useful in the effort to develop common standards in industries and enable the use of complementarity products from various companies. Widely adopted standards enable collaboration between industries allowing for the development of the production of goods, quality control mechanisms, and improving the consumer experience.

The complexity of technology could be an important issue when looking at the implications of OI collaboration. In high-tech environments, quality control is an important concern because it is more difficult for a single organization to have visibility of the overall project. Due to this, a firm may have to rely on external actors for its quality control. If one or more partners have a lower quality standard than expected, all actors in the value chain will be affected. Thoroughness in screening and selecting external partners for technology development is fundamental when high quality control is required.

3.3.5 Social Implications

OI results in many societal benefits which allow different entities or communities to share knowledge and information. This sharing provides communities with knowledge that they would not otherwise possess. This spillover enables the fertilization of society through dissemination of knowledge and information to industries, agencies, communities or users. This element is important to solve complex societal and environmental issues. Information sharing may lead to solutions to unresolved issues.

3.3.6 Schedule Implications

OI can be useful in the early stage of an R&D project. Going outside the boundaries of a firm improves the number of ideas received by an organization using OI strategies. Openness stimulates creativity, improves quantity, quality, and diversity of ideas. Firms should be cautious at this stage about sharing information about their core competencies to avoid losing their competitive advantages.

As a project matures and TRL increases, implementing new ideas becomes increasingly difficult. Organizations tend to converge on a single implementable solution that requires disciplined development. Introducing new ideas and multiple players at later stages can introduce rework of earlier decisions.

During commercialization, OI can be valuable to reduce the time-to-market when IP is already defined and protected. OI can be valuable for the company to better respond to customer needs or to develop new applications for an existing product or service. These new applications have the potential to create new markets and stimulate potential spin-off and spin-in.

4 OPEN INNOVATION IN SPACE

4.1 WHY USE OPEN INNOVATION IN SPACE

This section discusses the rationale of OI in space. In Chapter 3, the benefits and limitations of OI were discussed; examples of OI in the terrestrial sector were given, covering both successes and failures. In this chapter, the unique features of the space sector will be examined. The rationales for using OI in space applications to address challenges in the space sector will be discussed. Different frameworks will be proposed to show which OI concepts can be applied in areas such as space research, development, and commercialization phases, and lessons learned from examples of OI within the space sector will be covered.

4.1.1 BUSINESS AND MANAGEMENT INCENTIVES

According to our definition, the motivation for applying OI is to co-create value. Achieving co-creation results in smaller investments and higher returns for an organization. This section examines challenges specific to the space sector and how OI frameworks can provide solutions. Based on the theoretical analysis of OI concepts as discussed in Chapter 2, four key reasons have been identified for applying OI in the space sector: cost-sharing, risk-sharing, decreased time-to-market, and introducing new ideas and resources into the organization.

COST SHARING

There are various reasons why R&D and commercialization of space components and systems is an expensive endeavor. The highly technical aspect of space technology requires a well-educated and trained workforce. Durable and high quality equipment is needed to survive the harsh space environment. Lengthy qualification tests are conducted before hardware can be used in space. Extensive tests also increase the cost of a space mission.

In 2005, the cost of launching payloads to space ranges from US$15,000 to over US$25,000 per kilogram-to-orbit (Hertzfeld et al., 2005). The number and variety of satellites launched per year do not allow space components to be mass-produced, thereby increasing the cost per unit. As a result, innovation in this sector required a large investment, which could only be undertaken by large companies or governments. This has limited the number of small and medium sized companies involved in the space sector.

One of the key concepts of OI is sharing the costs by dividing the investment over multiple partners, reducing the capital required to be put forth by each individual company. This cost reduction can occur in any stage of research, development, launch, or operations.

RISK SHARING

The space environment is more hostile than on Earth. Challenges, such as space weather phenomena, micrometeoroids, microgravity, and the vacuum of space pose constraints on the spacecraft and its mission. The facilities used in qualification tests on Earth have limited abilities to replicate the exact space environment. This increases the risk of failure on the hardware because every situation cannot be tested. Once in space, the system cannot easily be repaired and any damage may remain during the spacecraft's life cycle. The reduction of a spacecraft's lifespan will reduce the profits of a satellite operator.

Launch failure is a threat to any space program. Such events results in launch delays, damage to payloads, or even the total loss of the spacecraft. This would negatively affect a launch provider's future as suppliers may turn elsewhere for more reliable and less risky services.

DECREASING TIME-TO-MARKET

The main reason for a lengthy product development time is that typically, only flight-proven equipment will be flown on commercial or publicly funded missions. For a product to be flight-ready, a technology readiness program must be followed to bring hardware from a low to high TRL. The complexity of the testing and the process required to achieve high TRL increases a product's time-to-market. Many SMEs are unable to enter the space industry due to these challenges. This lowers the number of firms able to interact in collaborative environments such as OI where diversity is an important factor.

INTRODUCING NEW IDEAS AND RESOURCES

Due to high risk, high cost, and a low number of entities combined with the space industry's relatively small size compared to other industries, space companies often are highly specialized in one domain. Sourcing all the expertise needed for an entire program requires a large investment in capital and time, which only a few companies or space agencies have the resources to acquire.

This process can be simplified by being open to new ideas and resources from external sources and rejecting the NIH syndrome as discussed in Sector 3.3.2.

An example of introducing new ideas was the adaptation of solar panels for space applications. Solar panels were invented at Bell Laboratories in the early 1950s, but they had no terrestrial applications due to their poor efficiency. In space, the advantage of solar panels over batteries was that they were lighter and lasted longer. The Sun's energy was not diminished by the Earth's atmosphere and the panels could be positioned to constantly receive this energy (Perlin, 2014).

4.1.2 ADVANTAGES OF OPEN INNOVATION IN SPACE

A summary of the possible information flow within the space sector is shown in Figure 4-1. Each node represents an entity and each connecting line represents their potential interactions. The advantages of OI in the space sector can be categorized into benefits for private industries and benefits for agencies.

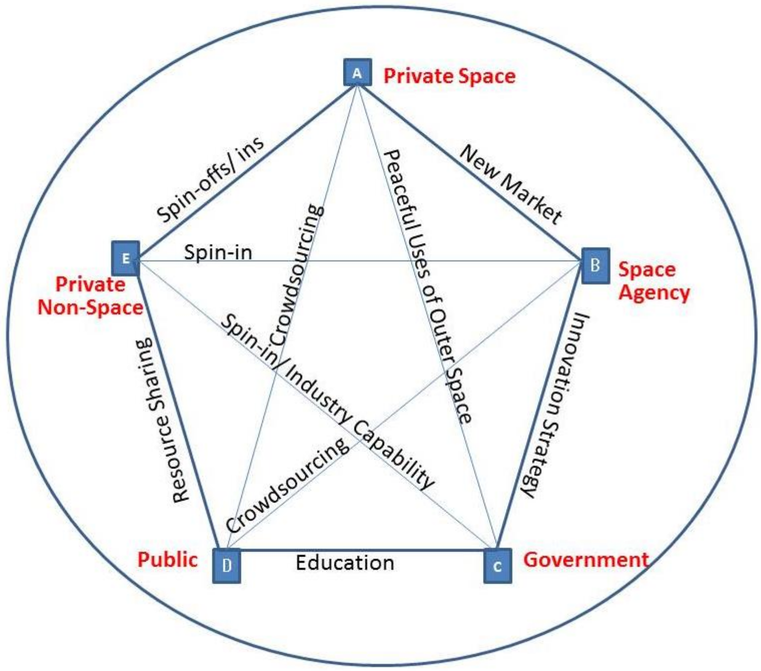

Figure 4-1: Advantages of Open Innovation in Space and Non-Space

Benefits for Private Sector

There are multiple paths of success using OI as a framework for the private sector. Development costs in a project such as the creation of tools or development of IP can be shared among entities. Having firms bear costs together also implies that wealth and infrastructure created during a project should be distributed among them. If applied correctly, OI can reduce the timeline of a project by maximizing the efficiency of resource allocation in terms of manpower, materials, money, and machines. Firms are allocated these resources in terms of their performance in relation of other entities within a given OI framework.

A benefit for SME's is access to resources and knowledge from larger firms and agencies that would be too expensive to develop on their own. Examples of where OI have been applied in the private sector include companies such as NanoRacks, PlanetLabs, and NanoSatisfi.

Benefits for Agencies and Public Sector

The space sector requires global collaboration due to its increasing complexity and decreasing budget. OI helps agencies in building a strong collaborative environment to overcome the future challenges. It helps to remove the tremendous inertia existing in national agencies when it comes to sharing ideas and resources with outside entities. OI also assists in developing a new business model and bringing in cultural change across the agency itself and its customers. (Svenja, 2013). OI creates an opportunity to develop an innovative culture from the "outside in", through continued exposure to and relationships with external innovators. (Martins and Terblanche, 2003).

 Open Innovation in Space

The benefits of OI between space and non-space sector are shown in Table 4-1.

Table 4-1: Benefits of Open Innovation for Different Sectors

Benefits of OI	Private Space	Private Non-Space	Space Agency	Public	Government
Commercial Exploitation	✷	✷			
Supply Chain	✷		✷		
Enhance Industry Capability	✷	✷			✷
New Market		✷			
Public Participation			✷	✷	
Promotes Education				✷	✷
Promote Peaceful Uses of Space					✷
Widespread Collaboration	✷	✷	✷		
Cultural Benefit			✷		✷
Attract Funding	✷	✷	✷		
Optimization of Resources	✷	✷	✷		
Simultaneous Problem Solving	✷		✷		✷
Access to Resources and Knowledge	✷			✷	
Reduced Product Development Time	✷		✷		
Improved Program Timeline			✷		
New Source of Income	✷	✷			
Explore Hidden Innovation Potential	✷	✷			
Make Alliances	✷	✷	✷		
Participation through Crowdsourcing			✷	✷	
Win-win Partnership	✷	✷	✷		
Strategic IP rights Management	✷	✷	✷		
Cross-Border Networking	✷		✷		✷

4.1.3 Risks of Open Innovation in Space

Chapter 3 provided information on how OI has gained renewed attention as a management strategy. There are risks involved in applying OI in the space sector. The following subsections focus on the business risks of OI in space.

Commercialization Risk

The very elements that make OI attractive also carry risks. Inherent in sharing comes the loss of control over many aspects of the business, including knowledge transfer, cost, and schedule. This is more prevalent in the space sector due to the complexity of projects and technology and lengthy time-to-market.

Strategic Partner Selection Risk

Choosing the right partners is a matter of concern for commercial actors in space. A partner's poor performance in a collaboration can permanently impact a firm's reputation in the space industry. Because of the low number of actors in the space industry, a negative image could potentially limit future business.

Management Risk

Firms interested in transitioning from closed to open innovation are at risk to experience organizational behavior challenges. Managing a dramatic change within an organization can lead to disruption in work, temporary loss of efficiency, and morale issues. OI introduces a large number of interface points which can introduce risk in technical projects creating deviations from standards. These are further amplified by a deeply rooted risk-averse culture that is inherent to the space industry.

Risk involving Intellectual Property

The strategic use of IP is a strong concern for firms participating in the space industry. The lack of precedence of IP sharing creates potential for conflict and administrative burden. The IP risks involved in OI are:

- Loss of patenting opportunities
- Loss of trade secrets/confidential information
- Design/copyright risks
- New competitors can be created based on the sharing of information
- Loss of freedom to operate

More information about the legal considerations of IP can be found in Section 3.3.3

Profit-Sharing Risk

Financial motivations are a key driver for adopting OI in the space industry. It can be challenging to measure participant contributions to the final output. Uncertain distribution of benefits can make participants hesitant to invest in OI. The risk of opportunistic behavior and free rider mentality within the collaboration can result in negative Return on Investment (ROI).

Financial Risk

The space industry is often characterized by a long development cycle and high capital investment, potentially straining less financially stable partners. Firms could suffer from partners who are unable to maintain their investment over the long term. Cross border partnerships are particularly at risk due to their exposure to changing policy, geopolitical, and economic factors.

4.1.4 Frameworks for Open Innovation in Space

In this section, different frameworks for using OI methods and mechanisms are explored. Examples of organizations using OI concepts within the space sector help link the theory to successful implementations.

Framework Based on the Benefits of OI

Based on the key benefits of OI discussed in Section 4.1.2, the framework in Table 4-2 has been created. The framework shows a matrix containing potential OI methods that could be used during each mission phase activity. Space activities are divided into three phases of activities for which these benefits can apply. The mission phases used by space agencies and the case study in Chapter 5 are provided between parentheses.

- Research (Phase A/B)
- Development (Phase C/D)
- Operations (Phase E/F)

Table 4-2: Open Innovation Mechanisms Based on the Project Phase and Desired Benefit

	Research (Phase A/B)	Development (Phase C/D)	Operation (Phase E/F)
Sharing Cost	Co-research (universities and research institutes), Sharing laboratories (Agencies, research institutes), Open-source	Co-development, Open-source, Public-Private Partnership, Crowdfunding (e.g. Planetary resources, Nanosatisfi)	Crowdfunding Sharing of resources Open-source data mining (e.g. Space Apps)
Sharing Risk	Co-research, Public-Private Partnership	Co-development, Public-Private Partnership	Sharing resources (e.g. Nanoracks), Sharing data
Decrease Development Time	Spin-in	Spin-in, Use of Commercial Off the Shelf (COTS) components (e.g. PhoneSat)	Open-source data mining (e.g. Space Apps), Technology demonstration programs (e.g. Proba)
New Ideas / Resources	Prize-based challenges (e.g. Innocentive, Centennial Challenges), Spin-in	Prize-based challenges (e.g. X-Prize, Innocentive), Spin-in	Spin-in (e.g. KickSat), Prize-based challenges (e.g. X-Prize), Open-source data mining (e.g. Space Apps)

Framework Based on The Complexity and the Scope of the Project

Figure 4-2 demonstrates another framework to evaluate effectiveness and benefits of using OI (Szajnfarber et al., 2014). The figure discusses the various OI methods and mechanisms currently in use by NASA as a function of the system complexity.

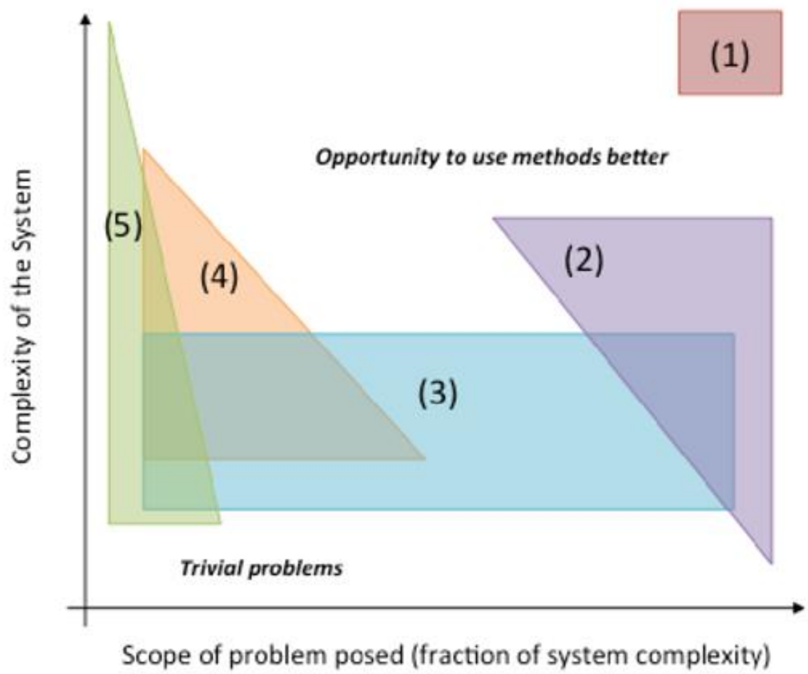

Figure 4-2: OI Mechanisms as a Function of the System Complexity Space (Szajnfarber et al., 2014)

Problems with a wide scope and high level system complexity can be found at the top right of the system complexity spectrum (Figure 4-2). They require fully implemented solutions, which require a significant amount of time and resources. Market stimulating challenges (1), like the Ansari X-Prize, offer an OI mechanism to involve external parties. The participants are motivated by the prestige as well as the potential for future returns.

Lead entrepreneurs (2) innovate by modifying existing systems to exploit opportunities in the space sector. These needs range from a low complexity to high complexities at a medium to wide scope. They are generally motivated by creating a new product in advance of the rest of the market. For problems with a lower complexity, but with scopes ranging from small to wide, the help of software development communities (3) can be used. These solvers are believed to be mainly motivated by the challenge of the problem.

If the scope of the problem is limited, broadcast searches (4) can be used to find answers in new industries where the seeker was previously not looking. A mechanism that can be used is a prize-based challenge. Problems with a lower scope, but with a wide range of complexities, prize based procurements (5) can be found. They require in general a minimal effort, but also result in a prize which is usually small.

As can be seen in Figure 4-2, there is a gap at mid-to-high-level complexity over a broad range of problem scopes. This is the area where most of the problems faced by space agencies are located, and has been the domain of contractors and subcontractors. In the current framework of OI, no mechanism has yet been identified which can be applied in this region. However, the way that the traditional (sub)-contractors operate in this region can be enhanced by using OI, as discussed in the next section (Szajnfarber et al., 2014).

Framework Based on the Technological Readiness Level of the Project

To provide a framework in which the traditional (sub)-contractors can use OI methods in their work; we examined the possibilities as a function of the TRL. The suitability of using OI for each TRL level was discussed in Chapter 3. The research and development phase can be subdivided in three phases:

- Prove feasibility (TRL 1 to 3): In this phase, the basic principle is observed, formulated and a proof-of-concept is performed. This is the research phase.
- Technology demonstration (TRL 4 to 6): In this phase, the proof of concept is validated in environments which are increasingly more relevant to the actual space environment. This is the development phase.
- Technology validation (TRL 7 to 9): in this phase, the concept is validated for its use in space. This is the final phase of the development.

Table 4-3 shows the general characteristics of the different TRLs and lists the possible OI concepts and key partners which can be used to improve the way the traditional (sub)-contractors can do business.

Table 4-3: General Characteristics with Respect to TRL, Possible OI Concepts and Key Partners

TRL	Key characteristics	OI concepts	OI Key partners
1 2 3	Uncertain applicability High investment Difficult to make profit	Spin-in of basic research outcomes Reduce costs: Research partnerships, sharing of research resources (laboratories)	Universities, research centers, agencies (funding)
4 5 6	No certain outcomes High investment No finished product, but already product which could be used	Spin-in of TRL-3 concepts from external sources Joint development Crowdsourcing Prize as development model Licensing (spin-out) of basic concepts	Research centers, industries, public agencies (funding and research facilities)
7 8 9	Joint development Crowdsourcing Prize as development model Licensing (spin-out) of basic concepts	Joint development Spin-out /licensing	Agencies (funding and research facilities), industries

4.2 Legal and Policy Implications

Space law refers to a set of international and national regulations that govern human activity in and related to outer space (Kopal, 2008). Space policy can be defined as a political decision making process for the application of national public policy regarding its space activities. A space policy not only dictates national policy with regards to a civilian space program, but also a nation's policy on the use of outer space for military and commercial purposes (Goldman, 1992). At an international level, national space policy acts as a guidance document that lays emphasis on an actor intended long term approach to space activity. It provides internal entities a clear framework that promotes transparency and compliance under both national and international law. National space policies define long term national goals and set out specific objectives that enable space agencies to shape the roadmap of their programs. Some examples of national space policies include the National Space Policy of the United States (Obama, 2010), the Canadian Space Policy (Minister of Industry, 2014), and the Brazilian Space Policy (Brazilian Space Agency, 2005). Both national space law and policy are used as instruments to define and regulate civilian and military activities in outer space.

4.2.1 Rationales Behind National Space Programs

Over the last two decades there has been a steady rise in the number of actors participating in space activities, and an even larger dependence by actors on space-based information and resource utilization. Therefore an argument can be made that practically every nation can be classified as a spacefaring, where spacefaring refers to a nation that uses space-based information for internal purposes (Sharma, 2012). While a nation may be spacefaring, it may not have a dedicated policy or legislative structure that governs its space activity. Outer Space Treaty (OST) Art VI states that nations are responsible for developing and implementing their national space laws. Regardless of whether they have a space policy, States must ensure their space programs are compliant under international law.

Emerging and established actors have different objectives with regards to the development of their national space programs. Emerging actors focus on a policy and legal framework that can be used to develop a roadmap that would enable the country to exploit space-based information for internal socio-economic development; established actors review their policy and legal frameworks not only for internal socio-economic benefits but for leveraging their position in the global marketplace (Sharma et al, 2013). If we consider existing national space programs, we find that they were all initiated due to a successful combination of national political will, technical capability and available financial capital to sustain program development (Sharma, 2012).

Currently the majority of research and development related to the space sector is conducted by ESA, China, Japan, India, Israel, Russia and the United States, with the United States, ESA and Russia accounting for 90% of the global civilian budget allocated to space activity. The success of these nations comes in part due to the influence of a clearly defined, implemented, and supported national space policy along with long standing traditions of international cooperation and collaboration on commercial projects. In their current form, national space policies do not necessarily hinder the application of OI to the space sector however they don't specifically mandate governmental entities to adopt OI either (Sharma, 2012).

Although national space policies are designed to serve the strategic and socio-economic interests of the actors, a vast majority of actors have the following objectives in common (Sharma, 2012):

- Develop and exploitation of space applications to serve the States' public policy objectives;
- Ensure that the States national security and defense needs are met with regards to space,
- Secure unrestricted access to critical technologies allowing states to pursue independent applications, and
- Expand international collaboration between like-minded nations through improved coordination of international activities and by setting in place a better mechanism for sharing of resources.

When defining national space policy, actors look at the principles defined under 1967 Outer Space Treaty (OST) to provide a framework for new legislation. Some of the principles discussed in the OST can be found in Table 4-4 (United Nations Office of Outer Space Affairs, 1967).

Table 4-4: Principles of the Outer Space Treaty

Article	Principle
1	Exploration of outer space, including the Moon & other celestial bodies is the province of all mankind.
2	Outer Space, including the Moon and other celestial bodies is not subject to appropriation.
3	State parties shall carry out activities in accordance with international law, including the charter of the United Nations.
6	States are internationally responsible for their national space activities, including the national space activities of non-governmental actors, and States are tasked with ensuring their compliance with international law through authorization and continuing supervision.
7	States shall be internationally liable for damages to other States party to the OST for their launched space objects.
8	States retain jurisdiction and control over their launched space objects, and any personnel aboard, which are placed on their national registry of space objects.

The OST provides an overarching framework that governs the activity of States and intergovernmental organizations in outer space, which was subsequently expanded upon by further treaties by the United Nations Committee on Peaceful Uses of Outer Space (UN

COPUOS) to better define the obligations imposed on national actors. Treaties that define these obligations can be found in Table 4-5.

While majority of national actors agree in principles contained in the OST they also consider space a vital resource for ensuring national security. One argument for the development and application of critical technologies is to support a States national defense capability. The focus on national security and the cross-disciplinary nature of research and development programs in the space sector has, over time, led to an integrated industrial base, where a clear separation between civilian and military programs is open to challenge.

This lack of clarity between different sectors poses legal challenges when considering the application of OI methodologies to the space sector as a whole. The following section elaborates on the dual use of space-technology and some of the challenges in implementing OI. Dual use refers to technology that can be used in both civilian and military applications, such as launch technology, where rocket designs developed during the cold war for peaceful purposes also saw applications in missile systems like the Intercontinental Ballistic Missile (ICBM).

Table 4-5: List of Space Treaties

Treaty Name	Abridged Name	Year of Enforcement
Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space	Rescue Agreement	Adopted by the General Assembly in resolution 2345 (XXII). Entered force: December 1968
Convention on International Liability for Damage Caused by Space Objects	Liability Convention	Adopted by the General Assembly in resolution 2777 (XXVI). Entered force: September 1972
Convention on Registration of Objects Launched into Outer Space	Registration Convention	Adopted by the General Assembly in resolution 3235 (XXIX). Entered force: September 1976
Agreement Governing the Activities of States on the Moon and Other Celestial Bodies	Moon Agreement	Adopted by the General Assembly in resolution 34/68. Entered force: July 1984

4.2.2 Legal Implications for Open Innovation in the Space Sector

To better understand the legal implications related to the application of OI, for the purpose of this report we define space industry and space sector as in Table 4-6. Legislation applied to the sector as a whole has direct impact on all space industries. However legislation and policy recommendations enacted for a specific industry do not necessarily impact the entire space sector.

Table 4-6: Definition of Space Sector and Space Industry

	Definition
Space Sector	Encompasses all global space activities and includes space products and services, the space industry; space infrastructure; and workforce and education
Space Industry	Is a specific subset of the space sector that can include both governmental and non-governmental actors (launch industry, commercial satellite industry)

With this in mind the application of OI to the sector as a whole, in its present form, is restricted by three key obstacles discussed below.

Export Control

The inherent dual use of space technology currently limits technology transfer in commercial applications, not only due to export control restrictions but also due to concerns with regards to intellectual property and commercial copyright. A key example of this would be the International Traffic in Arms Regulations (ITAR) and the United States Munitions List (USML), as imposed by the United States Department of State (DoS) and the Department of Commerce (DoC). Under US national law ITAR predominantly dictates how companies involved with the space sector should interact with third parties including non-US entities and individuals.

Enacted during the cold war, ITAR was designed to protect US interest and restrict transfer of US technology beyond its shores. ITAR not only has a huge impact on US space activities, but also significantly restricts international trade of space technologies and commodities (Minerio, 2011; Kaufman et al., 2008; Air Force Research Laboratory, 2007; Chao, 2008; Platzer, 2009).

The duality of space technology coupled with restrictions imposed on technology transfer by national and international regulations such as ITAR and the Wassenaar Agreement (Wassenaar Agreement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies) will continue to act as a hindrance for commercial entities who wish to adopt an OI approach. While ITAR may change in the near future to better represent the interests of the commercial space sector in the US, it is currently stifling the 2nd and 3rd tier of the US industrial base (Chao, 2008).

Intellectual Property Rights

IP refers to creations of the mind such as inventions, creative, literary and artistic works, and images or symbols that might be used in commerce. IP usually falls into one of two camps:

- Industrial Property - covers trademarks, patents and industrial design.
- Copyright - covers literary, artistic and creative works.

Therefore, IP rights can be defined as property rights as protected by national and international law that enable the inventor or creator to benefit from their own work or from their investment in the creation of a product.

The World Intellectual Property Organization (WIPO), that administers the Paris Convention for the Protection of Industrial Property of 1883 and the Berne Convention for the Protection of Literary and Artistic Works 1886, defined IP rights in 1967 as shown in table 4-7 (Pichler,1987).

Table 4-7: WIPO Definition of IP

	Definition
WIPO	Intellectual Property Rights: namely authors rights, copyrights, proprietary rights, legal protection of industrial property, rights as well as other rights resulting from intellectual activity as defined in Article 2 VIII.

When considering IP rights in the context of OI, current legal research focuses on open source software or user generated content (Nari et al., 2010). This focus leaves a number of technology avenues uncovered and poses a key challenge to the application of OI in the highly regulated space sector for the following reasons:

- There are always multiple claimants who may have diverse interests when OI is applied;
- Existing IP law does not regulate how rights associated with co-inventors and co-owners are coordinated or managed;
- Protection of inventions and new ideas is difficult under the existing structure of Patent Law, as it tends to discourage open exchange especially before a patent is filed; (Nari et al., 2010)
- Unclearly defined contract terms can be interpreted as no contracts at all. (Nystén-Haarala et al., 2010).

In the current environment, even though there is an emergence of commercial entities looking to expand within the space sector, the majority of space activity is still conducted by governmental entities and states are still primary clients for commercial contractors. There is also an inherent tendency to protect commercial development, not only to give the creators a competitive edge in the market but also to ensure that entities don't fall foul of national export control and technology transfer regulations. The legal clarity that companies are familiar with under current operational procedures, or closed innovation, acts as a safety net and a deterrence to switch to an OI model where legal and fiscal uncertainty remain high.

While OI has been successfully applied in specific space industries, as discussed in this chapter, its future application to the broader sector and especially the involvement of commercial entities is critically dependent on:

- Removal of technology transfer barriers that encourages a stronger commercial marketplace;
- Modification of IP law to better manage rights associated with co-creators and co-owners;
- Protection of IP associated with tacit knowledge or related to main revenue source;
- Proven and viable business cases for OI in space, spearheaded by governments;
- Stabilization and clarification of the legal situation of international operation in outer space.

Socio-Economic Impact on Political Will

Political will refers to the political support offered by a government to sustain prolonged allocation of financial and human resources, as needed by a space project or mission. Political will can be seen as the sum of domestic and foreign policy concerns that consider the influence of national space activities on national security, the domestic economy, national prestige, influence on policy at regional and global levels, and on the development of technical capabilities (Broniatowski et al., 2008). International cooperation enhances the stability of a project since a change in political support would need to add diplomatic implications to their calculation (Broniatowski et al., 2006).

Due to the long time horizons of space projects and missions, the political will to support a given space project may be inconsistent due to socio-economic changes. Funding, for example, is a major concern affecting political will. Cost overruns in the space sector are common due to difficulties related to cost estimation including growing project complexity, contracting mechanisms with downward biases, and imperfect forecasting methods (Keller et al., 2013).These concerns resulted in the loss of US political will to continue funding the Constellation program (Review of US Human Spaceflight Plans Committee, et al., 2009), a major human spaceflight mission with the goal of returning humans to the moon by 2020.

OI has implications on the domestic and foreign policy concerns listed above and therefore is a key issue for political leaders. One related issue is the degree of collaboration required by OI models and the disincentive for states to collaborate due to concerns over unwanted technology transfer and military applications of dual-use technologies. For example a 2008 occasional paper by the European Union Institute for Security Studies recommends that the EU continue high technology cooperation with China while managing the risks of losing a competitive advantage in innovation and high technology (Stumbaum, 2008).

4.3 Examples of OI in Space

Despite limited research into the subject, some organizations in the space sector are already employing OI methods. This section examines how they applied OI successfully and unsuccessfully.

4.3.1 Neptec

Neptec Design Group Ltd. is a privately owned company located in Ottawa, Canada. The company was founded in 1990 and became a NASA prime contractor in 1995 providing the agency with robotic vision solutions that assisted with the construction of the ISS. Neptec has supported over 40 Space Shuttle missions and won NASA's George M. Low Award in 2011 for performance and quality. In 2011, Neptec Technologies Corp was founded to commercialize the technologies developed by Neptec Design Group.

The two companies have separate corporate structures and their client portfolios are very different. Working in the same building allows the two companies to share common services such as human resources and office administration. The exchange of institutional knowledge also gives both companies a competitive edge. The risks and rewards are shared between the two companies and they maintain a strong relationship.

Neptec's TriDAR is a 3D laser vision system that allows guidance of autonomous craft in a wide variety of lighting conditions for uncooperative targets whose shape, position, and orientation may not be known. The program was funded by the Canadian Space Agency (ASC-CSA) and tested on three Space Shuttle missions. The TriDAR system allows autonomous spacecraft or astronauts to rendezvous with equipment that has not been marked with visual docking markers. On July 13th 2014, a Cygnus commercial cargo resupply craft berthed successfully with the International Space Station (ISS) using the TriDAR vision system.

Building off successful innovations by Neptec Design Group such as TriDAR, Neptec Technologies Corp developed the OPAL commercial light detection and ranging (LIDAR) system. The OPAL is a rugged, 360 degree dust penetrating 3D vision system that is being marketed for low visibility military applications and situational awareness for heavy machinery in mining applications. The sensor is specifically designed for commercial markets, but incorporates many functionalities and technologies developed for space applications. The information transfer between these two companies has allowed them to use the knowledge gained in space to applications on Earth. Neptec Technologies is marketing the OPAL to terrestrial industries, which provides market diversification thus reducing dependency on space sector business. Neptec is also incorporating lessons learned from its commercial business that it can spin back into its space activities. This two fold innovation system allows both companies to contribute ideas to each other while sharing development risk and benefits across several industries and markets (Neptec, 2011).

4.3.2 MacDonald, Dettwiler and Associates

MDA is a Canadian company originally founded in 1969 that has grown into a global communications and information company and a major player in the Canadian and international space sectors. MDA is well known for its contributions to the space shuttle and international space station (ISS) programs that include: communication antennas, Canadarm, Canadarm2, Dextre and the Robotic Work Station - technology supporting the construction of the ISS and its daily activities; and space exploration: science Instruments on the Mars Science Laboratory, and Phoenix Mars Lander, and more recently a scanning LIDAR for NASA's OSIRIS-REx mission to provide a high resolution 3D map of an asteroid. In 2013, the Canadian 5 dollar bill was unveiled with a picture of Canadarm2 and Dextre on the reverse, recognizing Canadian innovation and contributions to the International Space Station.

Using the knowledge and expertise that was gained from the construction and operation of the Canadarm, MDA partnered with the University of Calgary to create the NeuroArm, a robotic system designed for neurosurgery. Working in collaboration with the Seaman Family MR Research Centre at the University of Calgary MDA engineers began designing a robot that would have advantages over a human operator. The control system designed for the Canadarm was adapted to allow the movements of a surgeon's hand to be more steady and sure when performing surgery. The NeuroArm system allows for updated MR images to be obtained during all phases of an operation. 3D stereoscopic and MRI generated views provide real-time data to the surgeon. The engineering team was embedded in the surgical room during the development process to understand the environment and surgical rhythm to ensure the switch to virtual controls was as seamless as possible. NeuroArm was used in 2008 in a groundbreaking surgery to remove an brain tumor from Paige Nickason and since then has gone on to perform more than 70 successful surgeries. (MDA Corporation, 2014).

4.3.3 Planetary Resources

Planetary Resources is an American company founded in 2010 with the long term goal of mining asteroids in deep space. Its short term goals include building and launching purpose-built telescopes for Earth observation and astronomy, growing their capabilities. Planetary Resources is developing low cost methods of building their telescopes using their own facilities. While the company has maintained a strong public presence using social media, the technical portions of their business remain closed.

Leveraging their social media abilities, the company started a Kickstarter crowdfunding campaign in May 2013 (Planetary Resources, 2013). The campaign was successful, surpassing their goal and raising over US$1.5 million dollars and raising awareness of the asteroid mining industry as a whole. The campaign was notable in their involvement of individual contributors as well as promising to open the platform for public use.

The most popular reward was a space selfie. The Arkyd 100 telescope will be equipped with a Liquid Crystal Device (LCD) screen and a small camera. An individual can upload a picture to the telescope once it is in orbit and the camera will take a selfie of the picture with the Earth as a backdrop. The accessible price point of US$25 and the novelty attracted more than 7,000 people to contribute. The other significant reward was the ability to rent time on the telescope for any project. Depending on the amount of money contributed, Planetary Resources would point the main optical camera at anything in the universe for various amounts of time. Schools and organizations can rent time to perform experiments and individuals can order vanity pictures of the universe that only they will possess.

4.3.4 Indian Space Research Organization

The Indian Space Research Organization (ISRO) Technology Transfer Group developed an artificial foot based on space technology in partnership with Bhagwan Mahavir Viklang Sahayta Samithi (BMVSS) (ISRO, 2008; Suresh, Personal communication, 2014). Prior to this technology development, Indians needing artificial feet could only obtain products that required shoes to operate. Indians are prohibited from wearing footwear inside holy places, which made the design of artificial feet problematic.

To address this issue, polyurethane, which is employed as a thermal protection system on rockets during liftoff, was investigated as a material for artificial limbs. It possesses the material properties required to make more durable artificial feet that do not require the user to wear shoes. Researchers developed a unique molding technique of this variable density microcellular elastomer to make these artificial feet more mobile, better looking, and pleasant to wear. Because of this partnership, amputees from India are able to enter holy places with their prostheses. The prestige of having this technology developed through partnering with a space agency no doubt increased its visibility and dissemination in Indian society.

4.3.5 Evaluation of Open Innovation Penetration in the Space Sector

To measure the degree to which OI methods have been applied in the space sector, the team reviewed space agency initiatives. We found several examples of agencies using OI initiatives, most of which were in the form of prize competitions. The data is grouped by development phase of a space mission (Figure 4-3).

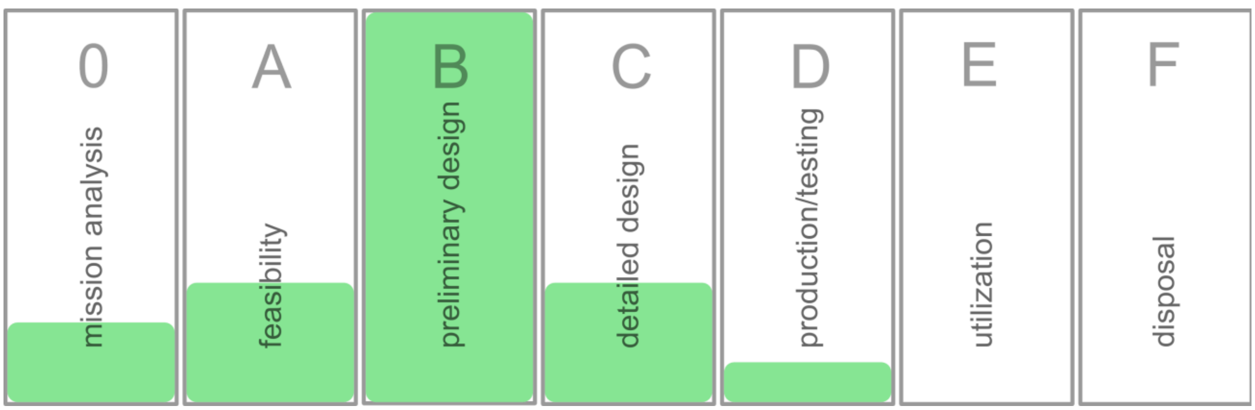

Figure 4-3: Examples of Open Innovation in the Space Sector

The findings show that NASA is the dominant actor in applying OI methods in the space sector. Specifically, NASA has sponsored a number of prize challenges to crowdsource solutions. 52.6% of the prizes were found in Phase B where contributions “define the project in enough detail to establish an initial baseline capable of meeting mission needs”. (NASA, 2007). There was a relatively low occurrence of prize competitions in Phases A and C, one case in Phase D, and we found no cases in Phases E and F.

A notable omission in the dataset is the European Space Agency (ESA) Innovation Prize that promoted the ESA Business Incubation Centers and European Space Incubators Network prize competitions in 2014. These examples were excluded due to a lack of data making it difficult for our team to verify whether this incubation network was consistent with our definition of OI.

5 CASE STUDY

5.1 ASTEROID MINING - A CASE STUDY

Conducting a case study will illustrate how applying OI can affect the cost, timeline, business and managerial, technical, legal, and social aspects of a project. This section presents the selection and sensitivity analysis leading to selection of our case study. It details plans and roadmaps envisioned by current companies involved in asteroid mining, our chosen case study. A survey was sent out to space agencies, companies in the space industry, and non-space companies to provide an overview of the current trends regarding OI strategies in the industry and to help us better assess their needs and expectations. Finally, the team presents ideas on how to implement OI in our case study and assesses the business opportunities or threats. The legal framework entailed in the application of OI for the selected case study is included in detail.

5.1.1 SELECTING A CASE STUDY

Asteroid mining became our case study of choice for the feasibility analysis of OI as applied to large space projects. This industry is relatively young; a handful of key players that have created forward-looking roadmaps to cover the various development stages of asteroid mining mission profiles.

Before deciding to research the asteroid mining case study, the project team collected and considered a number of topic proposals. In total, the group proposed eight topics. This number was reduced to three by scoring against criteria outlined in Table 5-1.

5.1.2 CASE STUDY SELECTION CRITERIA

The group identified criteria that the case study needed to fulfill. The aim of this exercise was to ensure the selected case was appropriate and within the scope of the report. Proposed topics were then scored by the team to reduce the number of topics to a more manageable list and bring the choice to a vote. They are shown below in Table 5-1.

These criteria were selected through discussion within the team to reflect the importance of each criterion in relation to other criteria. A weighting was then assigned based on sub-group discussion.

Table 5-1: Case Study Selection Criteria

Criteria	Weighting	Description
General Public Interest	10%	What is the gauge on public interest in this topic, including perceived feasibility?
Space Sector Interest	12%	What is the interest from the wider space industry and agencies?
Report Disruptiveness & Report Longevity	16%	Based on the choice of case study, what would be the impact and lasting legacy of the report?
Project Commercial Feasibility	16%	What is the potential for commercial growth of the project, taking into account economic and legal feasibilities?
Project Technical Feasibility	16%	Based on technology and current development, what is the feasibility of implementation of the project with current or future technological capabilities?
Ease of Undertaking the Case Study	15%	How easy (in terms of access to information and resources) will it be to research and deliver this case study?
Open Innovation Opportunities	15%	Can application of OI to this case study adequately illustrate conceptually the findings of the report?

5.1.3 Case Study Proposals

Our case study sub-group discussed and reduced the proposals to a list sufficiently short for a group vote. The sub-group team provided recommendations for their selections as well as a score for the whole project team to vote on a final topic selection. The following sections introduce and explain the proposed case studies and summarize the feedback for each.

To consolidate the results, each of the individual sub-group scores were entered in a spreadsheet, multiplied by an appropriate weight factor, and summed to an individual total. Then all of the individual totals were added together and averaged to a group total. The winning proposal was selected by group vote. Asteroid mining won both the criteria scoring and then won a vote among the leading three proposals.

Selected Case Study: Open Innovation Applications to Asteroid Mining

Taking a closer look at the final results of the selection process (Table 5-2), the topic of asteroid mining scored reasonably high when compared to other case studies in the areas of general public interest, and scored significantly higher on space sector interest and report disruptiveness. The case study team thought the topic would have a large potential impact to the space sector and to a society as a whole. Low scores for this case were seen in both commercial and technical feasibility. The primary reason for this is the assumption of the long lead time associated with asteroid mining missions and the large capital investments required. In the report it is considered preferable to favor missions with shorter lead times to make recommendations more actionable. This was not perceived as a negative because roadmaps in the asteroid mining community encompass both near term goals and long term capability development. Table 5-2 summarizes the results of the analysis, with the relative weightings included.

Table 5-2: Analysis Results

	Weight	1	2	3	4	5	6	7
General Public Interest	10%	3.00	2.77	1.23	3.62	2.54	2.08	2.38
Space Sector Interest	12%	4.08	3.54	3.31	3.08	2.38	3.85	3.62
Report Disruptiveness & Report Longevity	16%	4.38	3.54	2.92	3.31	2.62	3.08	3.54
Project Commercial Feasibility	16%	2.92	3.38	3.77	3.27	2.46	2.77	3.62
Project Technical Feasibility	16%	3.31	3.92	3.69	3.85	3.08	3.77	4.62
Ease of Undertaking the Case Study	15%	3.85	3.00	3.00	2.38	2.38	3.00	4.00
Open Innovation Opportunities	15%	4.00	3.69	3.46	3.85	2.00	2.92	3.23
Total Score		**3.66**	**3.44**	**3.15**	**3.33**	**2.50**	**3.10**	**3.64**

Legend:

	Case Study
1	Asteroid Mining and OI Applications
2	Commercializing the ISS and OI Applications
3	Concurrent Engineering and OI Applications
4	Public Health and Space, and OI Applications
5	Tesla/SpaceX and OI Rationale
6	Space Situational Awareness and OI Applications
7	Commercializing Big Data and OI Applications

Commercializing the ISS and Open Innovation Applications

The case proposal to commercialize the International Space Station (ISS) entailed considering whether OI could provide benefits to or increase the feasibility of commercializing the ISS once national agencies no longer supported its continuation. This proposal was to consider the development of a value chain for the ISS, from suppliers through space sector industries such as launch, operations and others.

Concurrent Engineering And Open Innovation Applications

The concurrent innovation and OI case study proposal was considered by experts from a range of fields who were brought in to contribute their knowledge and experience. This would be coupled with the concurrent engineering methodology so that during all periods of concurrent design, experts are pulled in to provide input to stimulate innovation.

Public Health, Space and Open Innovation Applications

This proposal was to consider one of the emerging fields of space applications within the life sciences, more specifically the benefits that space assets can provide to public health – both to support local infrastructure and aid in disaster management – and see how OI could best improve results.

Comparing SpaceX and Tesla

Tesla and SpaceX operate in very different ways, but are run by the same chief executive. The case study proposal was to compare and contrast the different business strategies and applications of OI methods used by the two companies.

Space Situational Awareness and Open Innovation Applications

Space situational awareness is the ability to detect and react to objects in space, such as objects in Earth orbit, Near-Earth Objects (NEO), and space weather. This has been of increasing interest and debate in recent years within the space sector. The case study proposal was to consider two primary areas- space debris and other space hazards – and see how OI methods could affect spacefaring and non-spacefaring nations in their development of such capabilities.

Commercializing Big Data and Open Innovation Applications

This proposal was to consider the commercialization of data from satellites in Low-Earth Orbit (LEO) using OI methods. There are a number of mature markets already in place, such as medium resolution imagery, global navigation satellite system (GNSS), and search and rescue. Our aim was to find more users and applications for LEO products. There is also a wealth of other data being generated in LEO such as radiometric and atmospheric data, as well as other forms of imagery that are less established in commercial markets.

5.1.4 Case Selection Sensitivity Analysis

A brief analysis was done to explore the concept of the case selection from the perspective of different potential stakeholders. The examples explored fell under general assumed priorities and are only represented by three parties: a government entity, a commercial entity, or an academic entity. In each of the following cases, the weighting of each of the criteria changed slightly to reflect the respective examples, but the importance OI opportunities was left at 15% to keep the subject of the case study at a high priority. The score values in each category do not change from those shown in Table 5-2. The weightings we examined are given in Table 5-3, and the resulting scores are given in Table 5-4.

Table 5-3: Sensitivity Analysis Weightings

	Weighting 1	Weighting 2	Weighting 3
General Public Interest	20%	10%	15%
Space Sector Interest	20%	15%	20%
Report Disruptiveness & Report Longevity	5%	15%	20%
Project Commercial Feasibility	10%	20%	10%
Project Technical Feasibility	20%	20%	10%
Ease of Undertaking the Case Study	10%	5%	10%
Open Innovation Opportunities	15%	15%	15%

Table 5-4: Sensitivity Analysis Total Scores

Case Study	Total Score		
	Weighting 1	Weighting 2	Weighting 3
1	3.57	3.61	3.75
2	3.42	3.50	3.42
3	2.99	3.22	3.00
4	3.42	3.44	3.35
5	2.52	2.53	2.47
6	3.11	3.14	3.09
7	3.55	3.64	3.50

Weighting 1 – Government Entity perspective

To test the selection system from the perspective of a governmental agency or space program, the weighting was set higher on general public and space sector interest to remain relevant and to solicit the most support and therefore potential funding. As a generally risk averse group, there was higher weighting placed on technical feasibility. In this situation, the winner was asteroid mining.

Weighting 2 – Commercial Entity perspective

To test the selection system from the point of view of a private commercial entity, the weighting of criteria was changed to emphasize commercial and technical feasibility. There was a relative increase in disruptiveness to reflect a company's desire to have a market advantage by being the first to move into an industry. Finally, the weight of general public interest and ease of adoption were decreased to reflect the necessity of thorough market research and testing before undertaking any project. By turning up commercial and technical feasibility, the winner in this scenario changed to Commercializing Big Data.

WEIGHTING 3 – ACADEMIC ENTITY PERSPECTIVE

To view the selection from an academic perspective, the weighting was focused on public and space sector interest to reflect the importance of a broad audience. Furthermore, there was a priority placed on report disruptiveness and longevity to ensure relevance and appeal. In this situation the winner was asteroid mining.

5.2 CURRENT COMPANIES

5.2.1 PLANETARY RESOURCES

Planetary Resources (formerly known as Arkyd Astronautics) is a Seattle-based company that was co-founded by Peter Diamandis and Eric Anderson in 2010. The company's goal is primarily to mine water-rich asteroids and eventually platinum-rich asteroids "to support our growth both on this planet and off" (Planetary Resources, 2013). Their plan of action is summarized by the following roadmap:

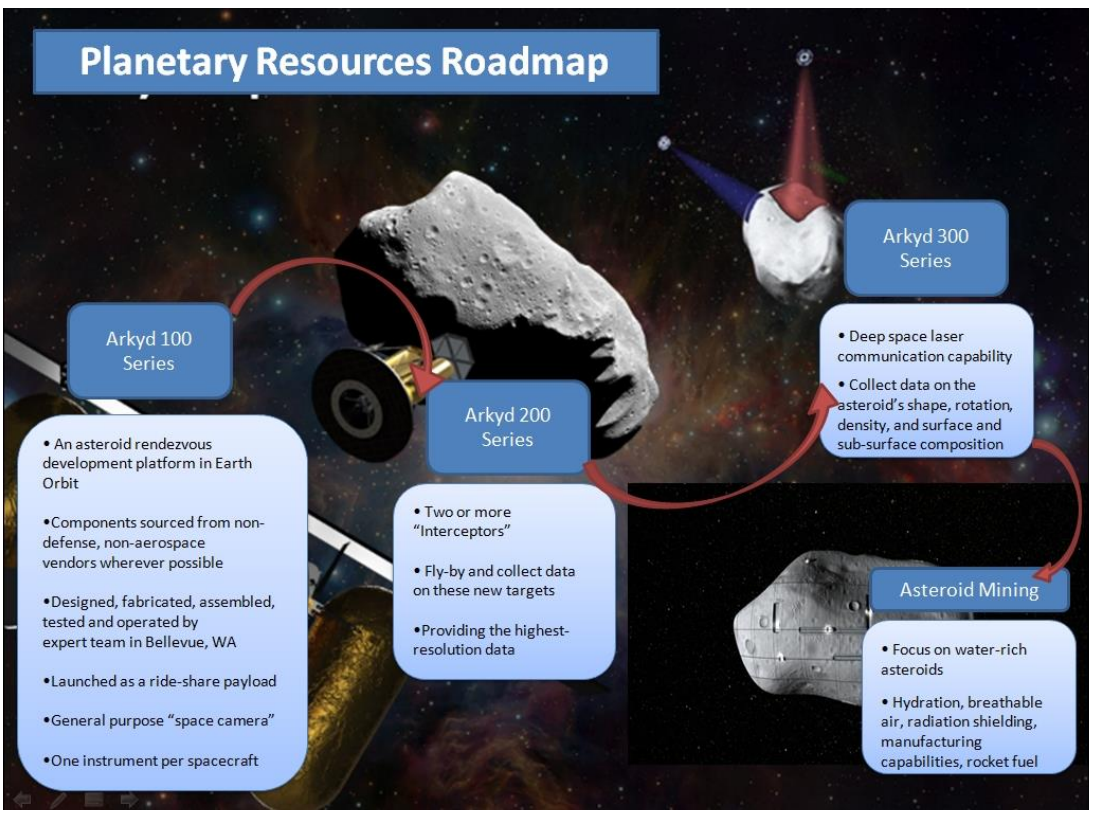

Figure 5-1: Roadmap of Space Missions Planned by Planetary Resources (Planetary Resources, 2013).

The company's strategic plan is to develop LEO space telescopes for both Earth observation and asteroid detection. The Arkyd 100 Series development was funded through a Kickstarter campaign that reached US$1.5 million in 2013 as described in Section 4.3.3. The Arkyd 200 space telescopes will be used to gather scientific data on the physical characteristics of asteroids within 10 to 30 Lunar-radii of Earth. The Arkyd 300 will characterize asteroids to enable full-scale mining operations (Planetary Resources, 2013).

5.2.2 Deep Space Industries

Deep Space Industries (DSI), who current chief executive officer is David Gump, was formed in 2012. The company states a clear mission to "locate, explore, harvest and utilize the vast numbers of asteroids in Earth's community" (Deep Space Industries, 2012).

The roadmap for DSI varies from that of Planetary Resources but features many similar milestones.

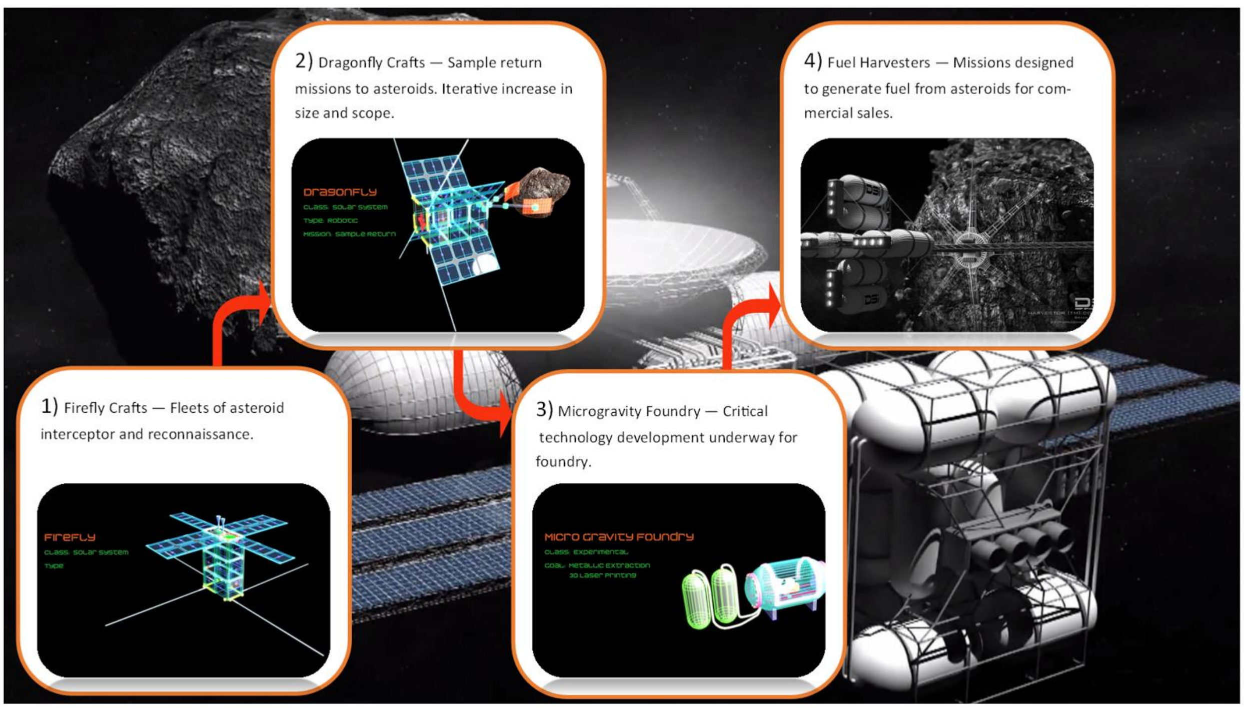

Figure 5-2: Deep Space Industries Mission Roadmap (Deep Space Industries, 2012).

The initial mission planned is to send microsatellites to fly by asteroids and return remote sensing data. This dataset includes information on surface composition and detailed measurements on asteroid mass and spin rates. This information will enable a follow on interception and sample return mission. The next stage of the roadmap is on-site harvesting of asteroid material, which will require the development of a number of critical technologies such as the microgravity foundry shown in Figure 5-2 (Deep Space Industries, 2012).

Currently there is no clear description of the timeline for any of these missions, although a press release states the first Firefly missions will begin in 2015 and material harvesting will begin within a decade (Wall, 2013).

5.3 Survey

A survey was created to gather opinions on asteroid mining and the potential of OI in the space sector from both space industry firms and space agencies.

The survey can be found in Appendix 8.4 and is split into three themes. The first section of the survey is an agreement poll on the implications and applications of OI. These questions are constructed to gain insight as to whether the principles of asteroid mining are understood to be the same by the various actors. These questions also examined if those actors consider OI favorably or negatively. These questions are answered numerically, from 1-5 for agreement, with 5 expressing strong agreement.

The second section of the survey contains written responses and covers perceived barriers to implementing OI, interest in asteroid mining, limitations of OI as applied to asteroid mining, and a section to allow for open response. The survey was sent to over one hundred actors from the global space sector, including national agencies, industry, and non-profit organizations. The responses and results are summarized in the sections below.

5.3.1 Survey Results and Discussion – Agreement Questions

Agency response

It should be noted that there are only four data points, which is a small dataset and not ideal for interpreting trends.

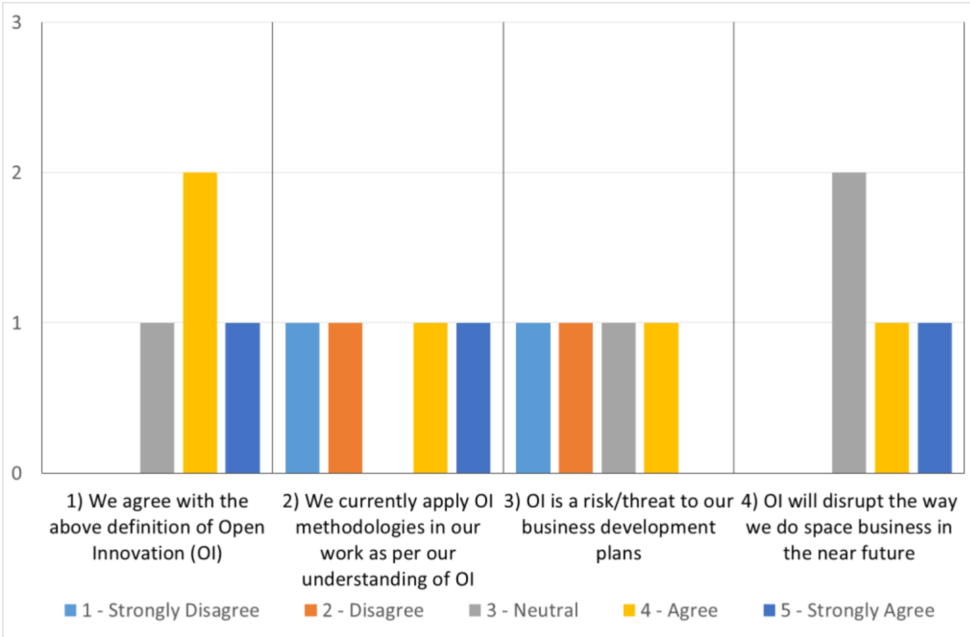

Figure 5-3: Survey Responses from Agencies – Questions 1 to 4

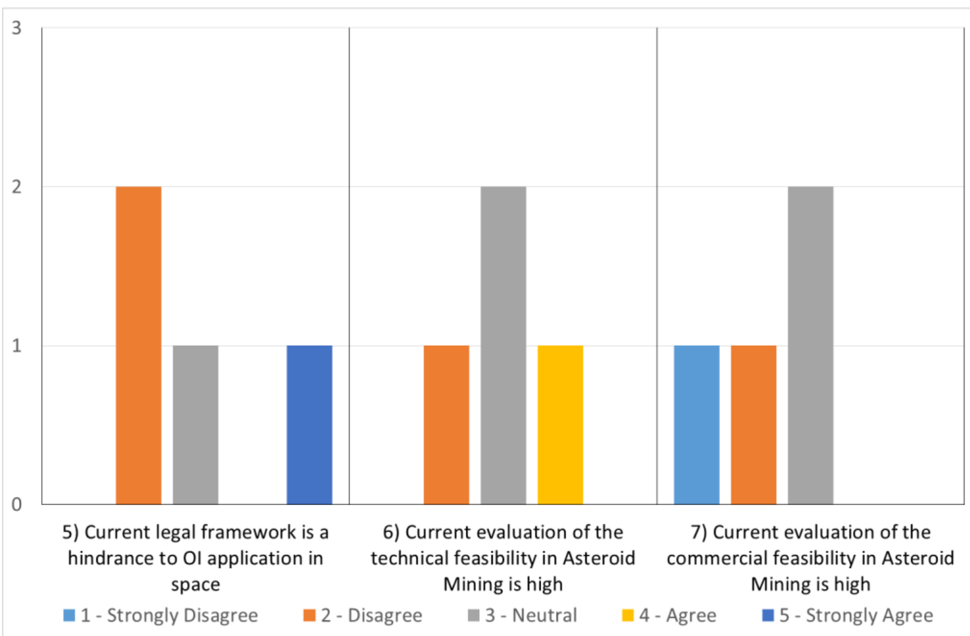

Figure 5-4: Survey Responses from Agencies – Questions 5 to 7

NON AGENCY RESPONSES

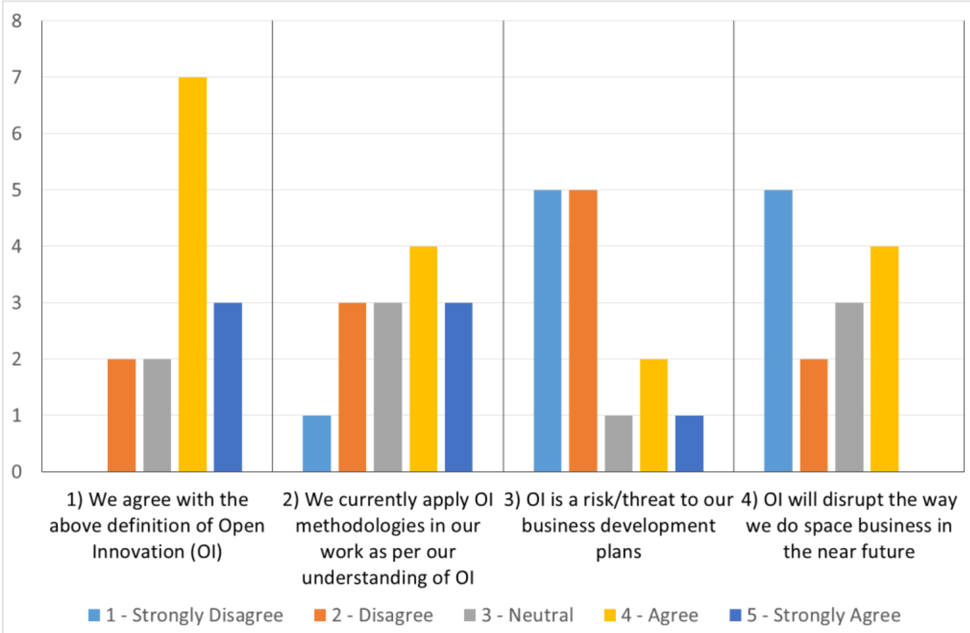

Figure 5-5: Survey Responses from Non-Agencies – Questions 1 to 4

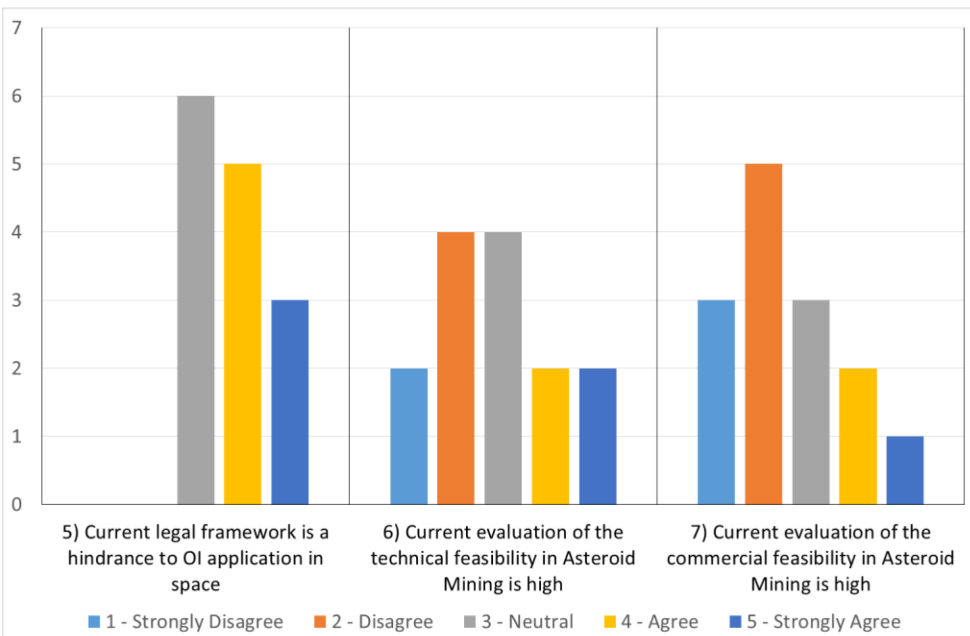

Figure 5-6: Survey Responses from Non-Agencies – Questions 5 to 7

1) We agree with the above definition of OI

The intention of question one is to introduce the survey user to the interpretation of OI used in the report. This will allow the project team to understand if the definition is in agreement with the wider interpretation of the term or if the definition is non-representative. To repeat Section 2.4, the definition of OI used in this project is: “Open innovation is the process of strategically managing the sharing of ideas and resources among entities to co-create value.”

For both agency and non-agency responses, we found a reasonably strong agreement with the definition (averages of 4/5 and 3.8/5, respectively). The outliers are statistically reasonably significant at approximately a value of 1 for each - showing that a reasonable proportion of the responses are neutral to the definition, neither agree nor disagree.

2) We currently apply OI methodologies in our work as per our understanding of OI

The second question, on current application, yielded some interesting results. While the sample size is small, it is interesting that the agency responses are split, with two agencies disagreeing and two agencies agreeing with the statement.

For non-agency responses, the average value of response was 3.4, close to the center of the scale, with a variance of 1.3. This implies that private entities believe that they are implementing some OI techniques, but it does not define their business model one way or the other. Out of fifteen responses there were three responses that strongly agreed with the statement that they were applying OI methodologies to their work, which demonstrates an increase of OI practices. As supported by a quote from the survey, “[company name] has and will utilize OI projects for design solutions for new products.” The large standard deviation also reflects some of the low scoring; one industrial company is quoted as saying “this is a detriment to competitive advantage and exposes us to ITAR issues.”

3) OI is a risk/threat to our business development plans

As previously mentioned in Section 3.3, one of the many considerations of OI is the potential risk implicit to opening up a firm’s core business processes to more interaction with other entities. Both agency and non-agency responses were, in general, in disagreement with the concept that OI poses a threat (averaging at 2.5 and 2.2, respectively). While the statistics imply that the majority of the sector does not consider OI a threat, there are outliers to this view as described in the quote from question two and another company that stated: “organizations would likely have to share company trade secrets that are directly tied to their main revenue source.”

4) OI will disrupt the way we do space business in the near future

As shown in Chapter 4, OI practices have only just begun to spread within the space sector. The fourth question was formulated to gauge the perceived impact of OI models. By asking how much OI would disrupt business, it became apparent that there was a difference between agency and non-agency positions. The agency responses averaged at 3.8, slightly agreeing with that statement. Non-agency responses slightly disagreed with the statement by an average score at 2.4.

It should be noted that there was quite close agreement between agency responses, with a standard deviation of 0.8, in comparison to a value 1.2 for non-agencies. Not largely significant, but it does provide more evidence that the response of industry to open innovation is more varied than government agency responses.

5) Current legal framework is a hindrance to OI application in space

The average scoring for agency was 3, making it neutral to the statement. The low sample number is particularly apparent here, with the agency that responded with strong agreement offsetting the two agencies that disagreed with the statement.

In the case of industrial actors, the graph is a notable output of the survey. The average value is 3.8 with a standard deviation of 1.2. The majority of this standard deviation derives from the responses that are in strong agreement to the statement. One company went as far as to state: "It would be useful to get the various national barriers to market size transfer removed, with another stating "Barriers would primarily be regulatory in nature."

This question suggests that there is indeed a disconnection between industrial actors and agencies regarding the legal frameworks to OI. These frameworks are covered in part in Section 4.2

6) Current evaluation of the technical feasibility in asteroid mining is high

In producing a survey on asteroid mining and OI, it is important to understand the perception of technical feasibility. As described in Section 4.1.4, generally there is a tendency for OI to be more easily applied at a low TRL. As a result, the low TRL of the asteroid mining supports a case to consider OI. It is also interesting to see that both industry and agency are, in the majority of cases, interested to see OI implemented in an earlier mission design phase rather than later.

Agency and non-agency responses yield average values of 3 and 2.9, respectively. This implies a neutral opinion and perhaps, by extension, that the nascent market is feasible to develop. An interesting result comes from the standard deviation; agency responses are in close agreement with a deviation of 0.5, yet industrial actors vary by 1.3. This is the largest standard deviation seen across all the questions, along with question two.

7) Current evaluation of the commercial feasibility in asteroid mining is high

Similar to question six, there is a relationship between commercial feasibility and the likelihood that a project will consider OI. The results of commercial feasibility follow a similar distribution as the previous question, with agency responses being in close agreement with one another and there being a large spread across the non-agency responses (0.7 and 1.23, respectively). Both agency and non-agency respondents rated the commercial feasibility to be below average at 2.25 for agency and 2.4 for industry. This is an interesting result, as a low result would imply that creating such a program would be commercially risky and may increase the opportunity for OI methodologies.

CONCLUSION ON THE SURVEY

Through the survey results, the team was able to better assess the expectations and opinions of different actors regarding the implementation of OI in their company or pertaining to asteroid mining, which helped refine the objectives of the case study. The following section will describe specific OI methods that apply to asteroid mining, building upon Planetary Resources' current mission road map.

5.4 IMPLEMENTATION OF OPEN INNOVATION ON PLANETARY RESOURCES

The current Planetary Resources roadmap was selected as the baseline for the case study. More specifically, the framework of the case study was limited to the mining of water-rich asteroids, mostly for developing in-space access to rocket fuel for long-distance missions. It is to be noted that the focus of this case study is not on the extraction of platinum group metals from asteroids. In providing a business case to assess the viability of using OI for water-rich asteroid mining missions, the findings presented in this section can be extended to different mission scenarios.

The key actors involved in the asteroid mining projects are identified to be the space agencies, private space companies, mining companies, and planetary defense organizations. In a context of closed innovation, the scope of application is very limited to a firm’s own industry. By using OI methods a firm can extend its innovative ecosystem. Maximizing innovative efforts can provide the necessary knowledge to overcome the barriers to entry associated with an industry as complex as asteroid mining. The team conducted a review of potential stakeholders in the implementation of OI within the asteroid mining industry. Figure 5-7 illustrates different stakeholders that could potentially collaborate with an asteroid mining company in the application of OI methods.

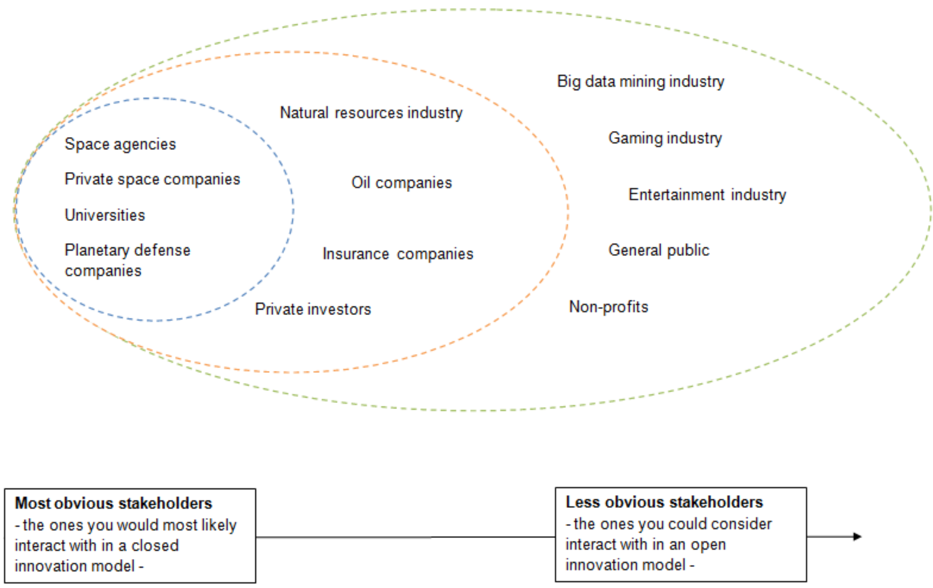

Figure 5-7: Link Between Openness and the Number of Potential New Users

The application of OI methods requires the management and interaction of many different entities. Figure 5-8 has been adapted from Figure 4-1 to better reflect the needs of integrating OI methods into the asteroid mining industry.

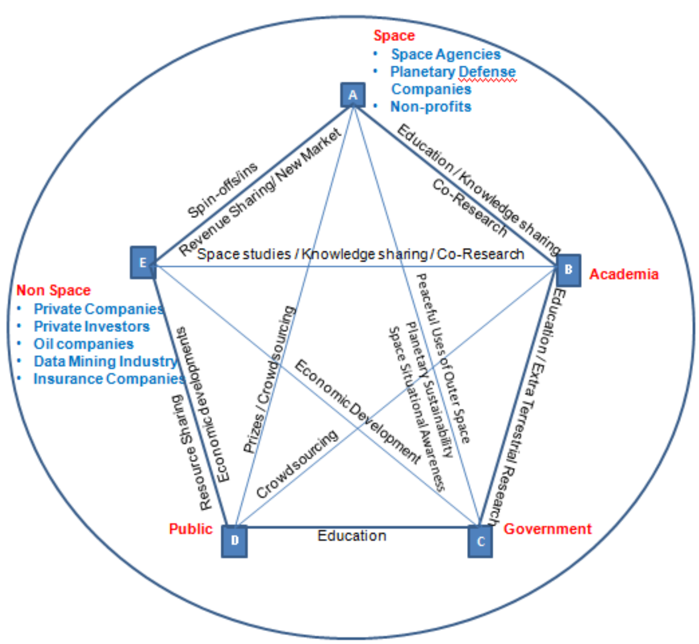

Figure 5-8: Advantages of Open Innovation for Asteroid Mining in Space and Non-Space

In different project phases, it is prudent to derive which OI methods would be most appropriate Phase 0 consists of identifying needs. Table 5-5 assesses the different needs for governmental, commercial, and academic actors.

Table 5-5: Phase 0 Needs Assessment

	Terrestrial Needs	Space Needs
Government	Public Interest ‘Futures and Planetary Sustainability Economic Development	Space Situational Awareness On-Orbit Resourcing Non-Terrestrial Refueling
Commercial	Public Interest Forerunners to Capture Market Economic Development	Revenue from Asteroid Resources On-Orbit Resourcing Non-Terrestrial Refueling
Academic	Public Interest Futures and Planetary Sustainability Man's Thirst for Knowledge	Space Situational Awareness Space Studies Extraterrestrial Research

Table 5-6 will continue the analysis of Phases A-F of the mission and identify requirements of each phase as well as potential OI methods that could be applied to each one.

Table 5-6: Requirements of Each Mission Phase and Identification of the Potential OI Methods

Milestones of the Asteroid Mining Project	
Phase A Feasibility	▪ Finding Potential Investors and Users ▪ Cost Breakdown / ROI analysis
Phase B Research and Preliminary Design	▪ Research and Development
Phase C Detailed Design	▪ Market Size Refinement ▪ Facility Development
Phase D Production and Ground Testing	▪ Testing Phases, and Production
Phase E Utilization and Operations	▪ Market Penetration, Operationalization
Phase F Disposal	▪ De-orbit Vehicles ▪ De-orbit or ‘Dispose’ of Asteroid
Rationale for OI	
Phase A Feasibility	▪ Requires Buy-in from Key Stakeholders in Projects ▪ Project is in Vulnerable Phase

Phase B Research and Preliminary Design	▪ Requires Capital and Expertise ▪ Project in Vulnerable Phase
Phase C Detailed Design	▪ Requires Capital and Expertise
Phase D Production and Ground Testing	▪ Requires Infrastructure and Logistics Support
Phase E Utilization and Operations	▪ Requires Operational Efficiency and Continued Improvement
Phase F Disposal	▪ Requires Capital and Expertise ▪ Require Infrastructure and Logistics Support ▪ Require Operational Efficiency
Potential Methods for OI	
Phase A Feasibility	▪ Crowdfunding ▪ Prizes
Phase B Research and Preliminary Design	▪ Crowdsourcing ▪ Crowdfunding ▪ Prizes ▪ Spin-ins/outs ▪ Co-Research
Phase C Detailed Design	▪ Crowdsourcing ▪ Crowdfunding ▪ Prizes ▪ Spin-in/outs
Phase D Production and Ground Testing	▪ Public-Private Partnership ▪ Fabrication Labs ▪ Spin-in/outs ▪ Test bed ▪ Ecosystem Management
Phase E Utilization and Operations	▪ Crowdfunding ▪ Crowdsourcing ▪ LivingLabs ▪ Spin-in/outs ▪ Test Bed ▪ Ecosystem Management
Phase F Disposal	▪ Crowdsourcing ▪ Crowdfunding ▪ Prizes ▪ Spin-ins/outs

Based on the assessment of needs of the stakeholders, the different OI methods mentioned above were introduced as potential candidates to be applied to the case study.

5.4.1 Methods of Open Innovation Applied to our Case Study

This section introduces a number of examples of OI methods and applications. To empower decision makers and businesses in the future, we have applied a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis to each example.

As shown in Section 3.2, OI can be implemented at the beginning and at the end of the innovation process to stimulate creativity and commercialization. We have selected a number of OI techniques that could be applied to the asteroid mining industry. Figure 5-9 shows a project timeline and the techniques we believe would be most effective.

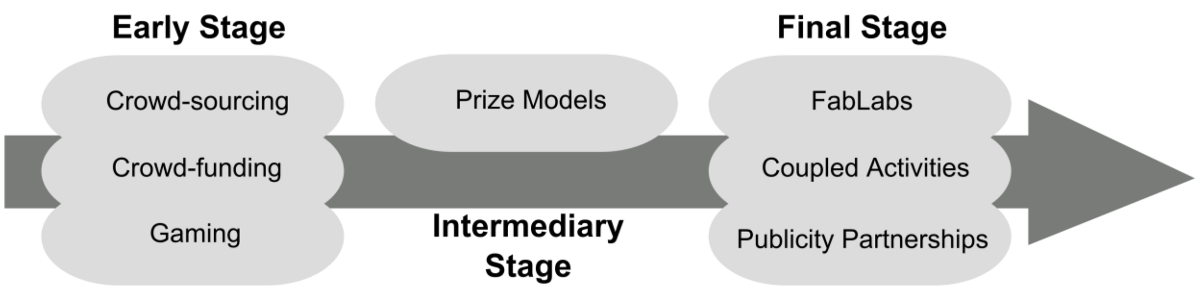

Figure 5-9: Applicability of Open Innovation in the Innovation Process of Asteroid Mining

5.4.2 Early Stages

Applying OI during the early stages of the innovation process stimulates the ideation process and increases the number and diversity of incoming ideas. In this section, we present the selected methods for the asteroid mining industry and offer recommendations of how they could be implemented in an OI model.

Crowdsourcing the Search for Near-Earth Objects

Crowdsourcing can be applied to various phases of an asteroid mining project, most effectively during the mission conception and mission design phases. The public can be invited to solve technical challenges, carry out design tasks, develop algorithms, or help to analyze large amounts of data.

The first phase of asteroid mining is to catalog the asteroids and identify those asteroids which are worthy for future mining activity. As of Feb, 2014, 11189 near-Earth asteroids are known to exist (NASA, 2014), However, little is known about these asteroids due to technical difficulties along with the fact that individual asteroid analysis is a time-consuming process.

There are a number of Near-Earth Object (NEO) discovery teams with support from national space agencies (Jet Propulsion Laboratory, 2014). Their primary purpose is to detect and track the NEOs as early as possible, especially the ones that may threaten Earth. Data and processes from these teams could be applied to asteroid mining to accelerate the process of identifying valuable asteroids.

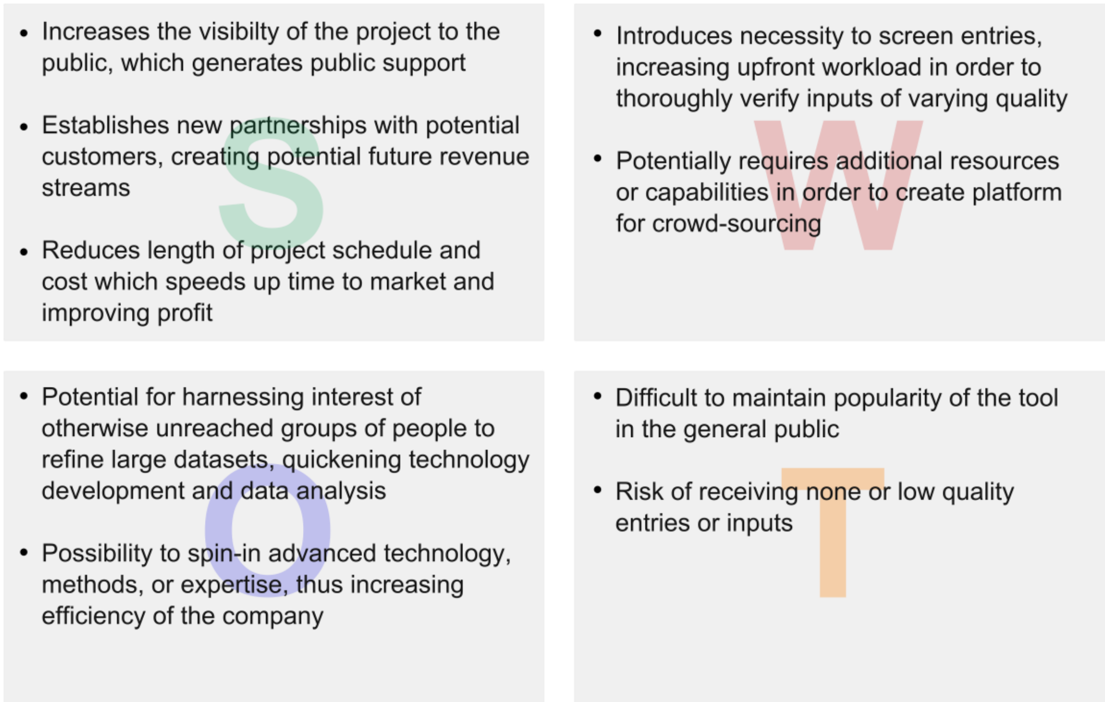

Figure 5-10: SWOT 1 - Crowdsourcing the Search for Near-Earth Objects

Partnerships Towards the Creation of a Constellation of Space Telescopes

Space or terrestrial telescopes are used to detect, track, and characterize asteroids. This infrastructure is expensive and takes a long time to build and install. Compared to building a new telescope, using the existing space and ground based infrastructure may prove to be more cost effective. When partnerships and collaborations can be established between government agencies, industry, and private telescope the sharing of data will benefit everyone involved. Finding a way to repurpose satellites at their end of life creates another revenue stream for operators and increases the available infrastructure for the asteroid mining industry.

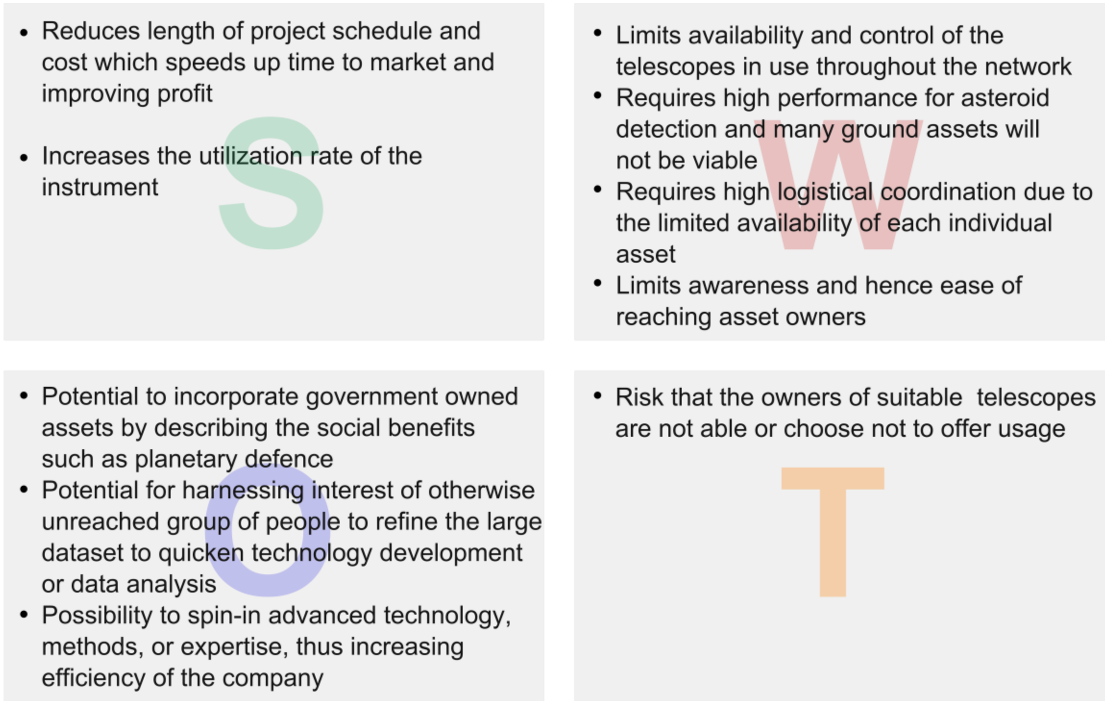

Figure 5-11: SWOT 2 - Partnerships Toward the Creation of a Constellation of Space Telescopes

Applications of Big Data Mining in Asteroid Mining

Data mining algorithms are needed to extract specific knowledge from huge quantities of data and identify trends where they are difficult to spot. Possible outputs of big data mining related to asteroid mining are situated in the following areas:

- Asteroid detection: co-creation of algorithms to automatically classify pictures that might be relevant to non-asteroid mining companies. NASA already opened the Asteroid Data Hunter contest for development of such an algorithm based on images from ground based telescopes (NASA, 2014).
- Tracking and predicting asteroid position over time, including visualization of this data can be reemployed by external actors for space situational awareness.
- Because the market size used for tracking asteroid is optical, another use of this market size can be envisioned by using such data to track space debris.

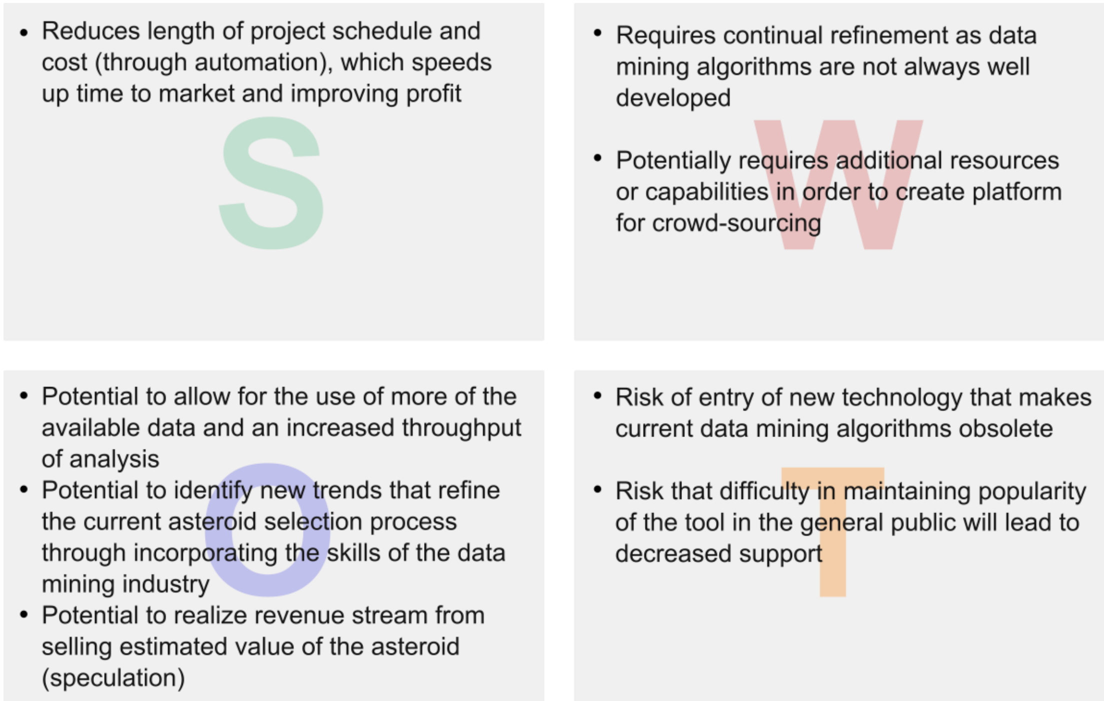

Figure 5-12: SWOT 3 - Applications of Big Data Mining in Asteroid Mining

CROWDFUNDING

Crowdfunding could be applied to raise money to develop nanosatellites for asteroid detection. Below are rewards that we recommend as incentives for individuals who contribute to a crowdfunding campaign. Varying sizes of financial contributions should be offered in parallel to include as many participants as possible.

Small contributions

- Pictures from the mission can be taken from the mission platform and given to participants
- Once material return missions are conducted in the near future, a company could sell the first access rights to the metals of the asteroid, for consumer use rather than industrial use. Unique jewelry could be created with the metal.
- During the course of the company's normal public outreach, mobile applications, web portals, and discussion forums could be created to give first access to participants.

Large contributions

- Contributors who want to play a larger part in the mission can pay to attend after parties, press conferences and launch events.
- Selling the naming rights for missions will raise substantial funds, and possible corporate sponsorship, while offering prestige for those individuals who will be forever associated with these missions.

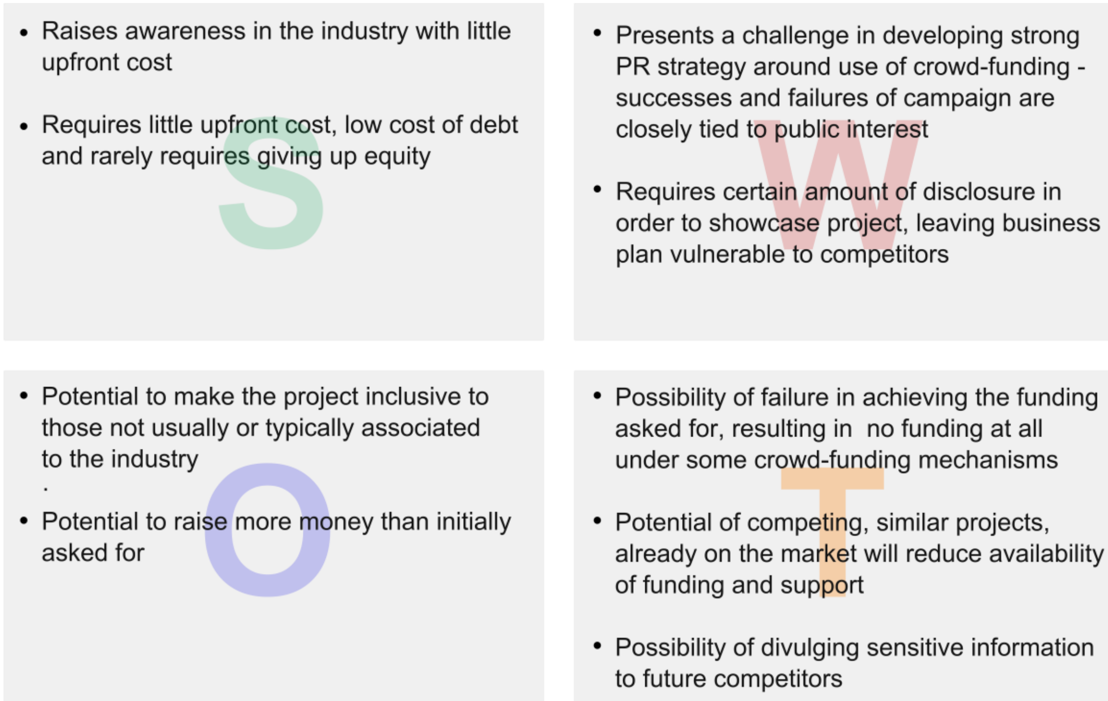

Figure 5-13: SWOT 4 - Crowdfunding

Using Gamification to Leverage the Power of the Crowd

By creating a framework in the form of interactive games, we can direct the player to solve complex real world problems; this is a process called *gamification* (Deterding et al., 2011). The fun aspect of the game can generate a paying audience, resulting in revenue streams and making the process potentially profitable.

Developing potential coupled strategies between the asteroid mining and video gaming industry will allow for more complex gamification to occur. The benefits of this include inspiring the general public and increasing the awareness of asteroid mining.

Applying this strategy to asteroid mining, we could identify a number of avenues for implementation of gamification concepts for solving particular challenges. For the initial phase of asteroid prospecting, an interactive game similar to *Asteroid Zoo* is envisioned for detecting asteroids by analyzing images from the Arkyd 100 telescopes.

For asteroid rendezvous missions, we identified an opportunity to create a more complex game where players can contribute to the mission design. Key challenges are the identification of key design parameters and the ability to visualize them in a way that people without engineering degrees can quickly comprehend.

S: • Generates innovations and earn money simultaneously from the process • Creates public outreach opportunities	W: • Is limited by nature of videogames and computer simulations in terms of effectiveness in connecting users to concept and creating fun and exciting spin on problems • Competes with cheaper and simpler methods to apply open innovation, for example 'prize' method
O: • Potential to tap into a very mature market with extensive infrastructure in terms of talent, tools and interest from general public	T: • Potential that the gaming market does not respond well to an educational and realistic game or trends in gaming shift in style

Figure 5-14: SWOT 5 - Using Gamification to Leverage the Power of the Crowd

To implement these different tools we propose to use a collaborative web platform. This would be a tool designed to help users to share resources and to coordinate their work in a collective way. Platforms can be customized to better fit with user needs. This customization allows improved knowledge transfer and collaborations between different actors to generate innovation. When actors work together on a platform, sharing data and knowledge, they are producing a public good (von Hippel and von Krogh, 2003). This way of collaborating stimulates knowledge creation and innovations in the community where people may not be motivated to collaborate and innovate strictly by their need to profit (von Hippel, 2011).

The proposed platform merges the crowdsourcing, crowdfunding, and gamification methods through two functionalities. The platform can be used for the development of applications and nanosatellites to improve asteroid detection through different projects. Each project aims at resolving a problem with the participation of the crowd. In each project there are two aspects; crowdsourcing where users can contribute with their ideas to the projects and crowdfunding where the users can fund and stimulate the development of the new application. The second functionality is based on crowdsourcing asteroid detection methods and on mission design through gamification, thanks to the data already processed in the platform. With a user-friendly approach, a large crowd can be recruited to contribute, providing information about asteroids such as localization, composition, distance from Earth, and orbit.

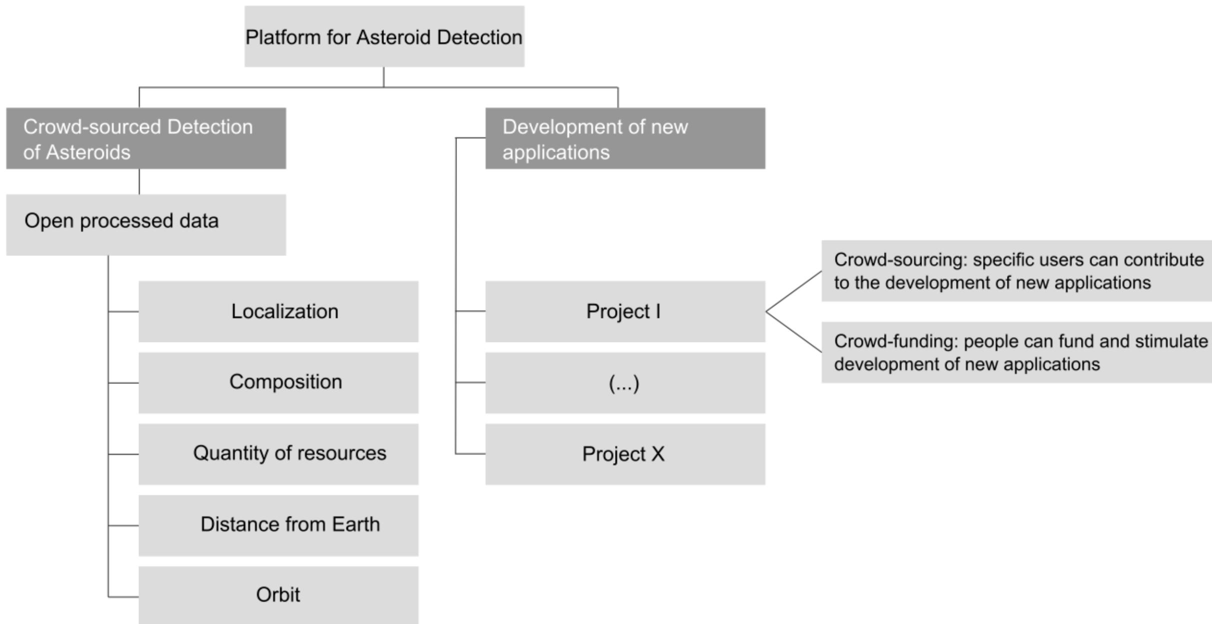

Figure 5-15: Open Innovation Platform for Asteroid Detection

5.4.3 Intermediary Stage of Innovation

As we have discussed throughout the report, it is important to find the right balance between closed and OI. Most of the activities of the intermediary stage are affecting the competitive advantage of the firm; therefore it is important for a firm to protect its core competencies. However, some OI practices can be implemented at an intermediary stage, such as the prize model.

Prize Model as a Market Stimulation Technique

As discussed in Section 4.1.4, prizes can be a positive way of stimulating the implementation of OI. If used successfully, prizes can help an entity to develop a solution to a problem and potentially catalyze the growth of an entire industry. Because the asteroid mining industry is not yet established and requires multiple breakthroughs to create the momentum it needs to grow, the prize method lends itself well to the relatively structured roadmap laid out by this case study.

Prizes used to develop market size solutions could be used to:

- Design a low-cost method to return asteroid material to Earth
- Design a vehicle capable of making a soft landing on an asteroid
- Design an asteroid drilling machine
- Design an asteroid processing and storage method for water
- Design an asteroid refining method for water

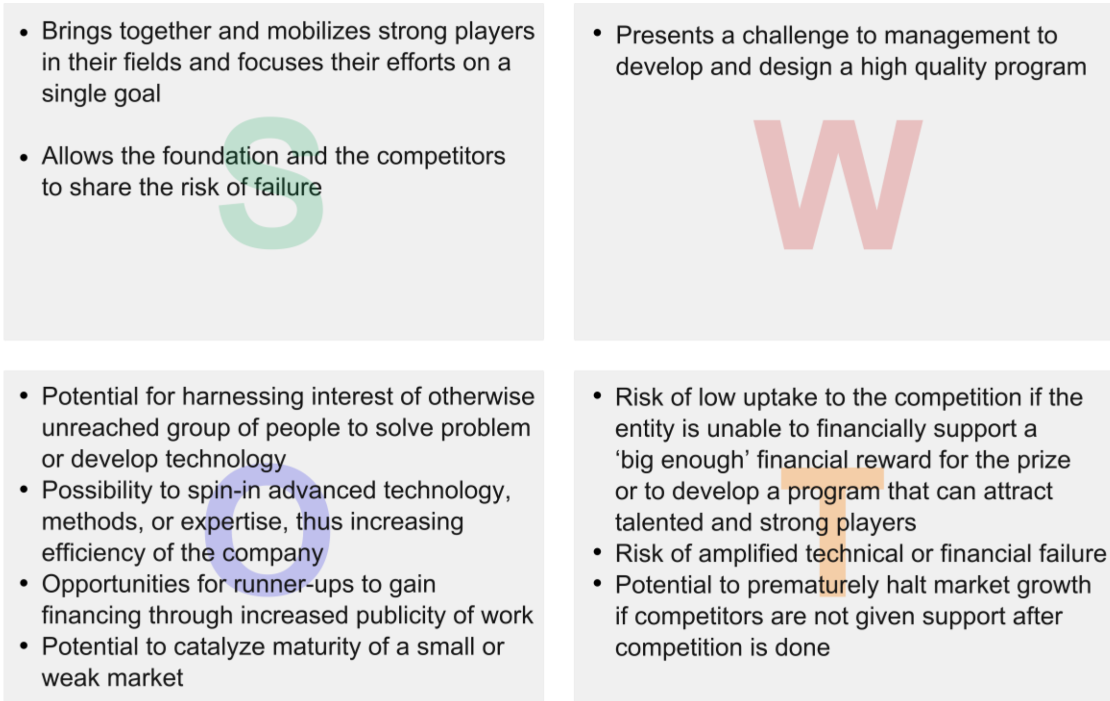

Figure 5-16: SWOT 6 - Prize Model as a Market Stimulation Technique

5.4.4 End Stage Commercialization

OI techniques are also very efficient at the end of a project because it accelerates the time to go to market and allow developing of new applications through co-creation with external actors. By implementing OI, industry and the market are able to grow by generating a new innovative ecosystem. The following tools will illustrate proposed applications of OI at the final stage of the innovation process in the asteroid mining industry.

Coupled Activities (Co-Design and FabLabs)

Coupled activities between the asteroid mining industry and other industries and organization can stimulate the scope of application of technology and knowledge used in the asteroid mining field. Organizing co-design workshops and co-creation activities with outside industries can improve commercialization of asteroid mining products, services or processes. This technique allows cross-fertilization of information and knowledge transfer between different industries and society at large.

An example of coupled activities between industries is FabLab, a digital fabrication facility originally ideated at MIT (Fab Foundation, 2014). Facilities such as these bring together actors from dissimilar background to solve complex issues. Collaboration among all these actors can lead to the co-design of new drilling methods or innovative sensing techniques for prospector satellites. Adopting such an approach would empower each of the actors to gain new skills using networks and viewpoints of people otherwise unavailable to them. This would foster the creation of a complete big picture mentality and common interest in a nascent industry. The exponential trends in technology, such as 3D printing, may create solutions that are not obvious at this time.

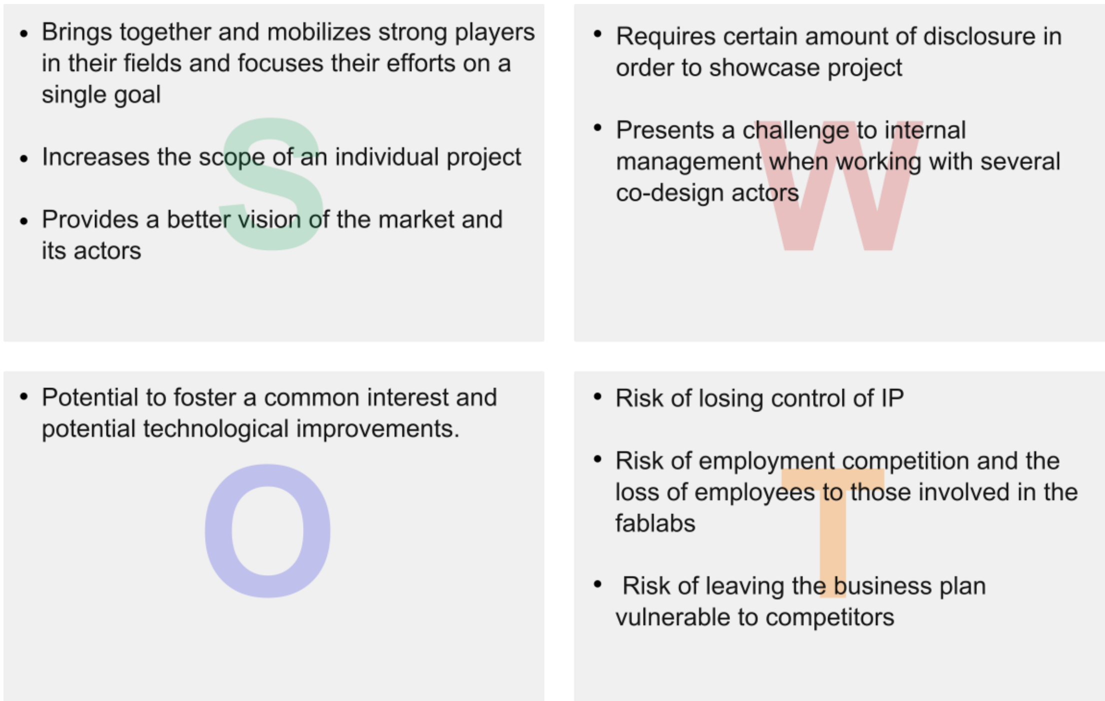

Figure 5-17: SWOT 7 - Using Co-Design and Fablabs

Publicity Partnerships

Publicity partnerships could enable an entity to leverage support from privately owned logistics companies and public entities such as regions, cities, and towns. This promotional strategy lets partners promote themselves as important contributors to the space mission and the space sector.

The following presents some recommendations to implement such a strategy:

- Partnerships with Logistics firms - A public logistics partnership call could be made for logistics providers to contribute towards the transportation of space hardware across a country or a continent where different logistics facilities are spread out. This would enable logistics providers to associate themselves officially with the project in return for reduced or free transportation for a stage of the transport to the next destination.
- Partnerships with Cities - Cities, towns, and regions can benefit from the publicity by proposing to have the transport of the space hardware move across their area. These entities then become official partners of the space mission and are officially named on a dedicated web portal, with the logos of the selected regions placed on the spacecraft that is launched.

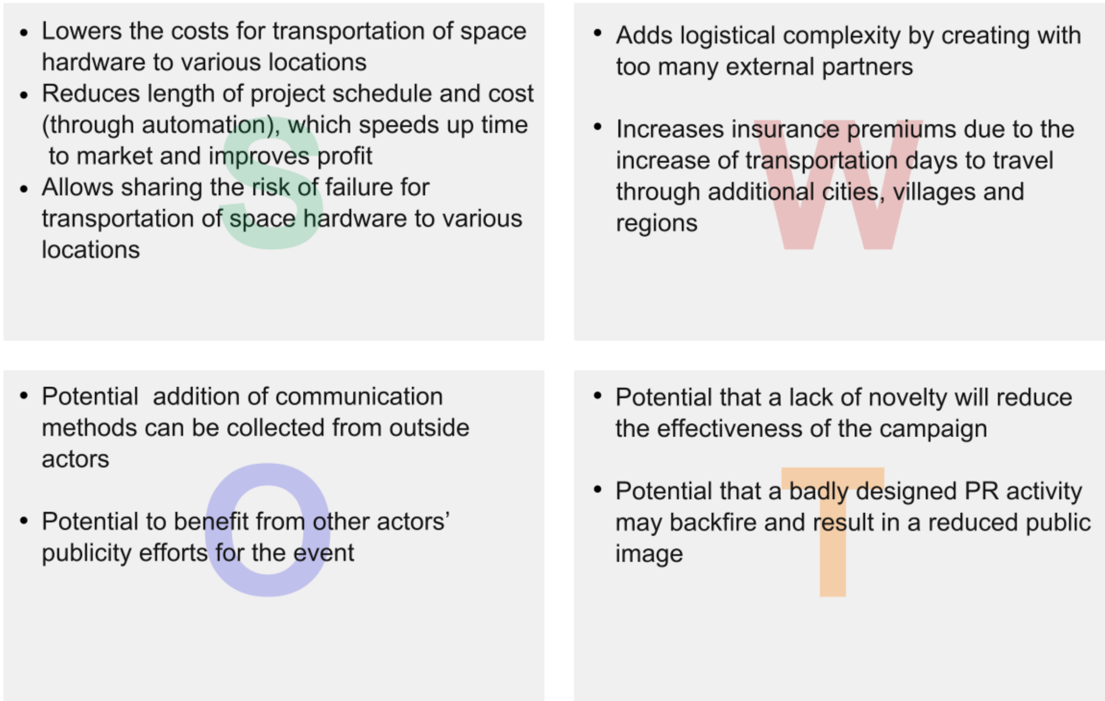

Figure 5-18: SWOT 8 - Publicity Partnerships

Outreach and Education Investment

There are a number of OI public outreach and education opportunities that succeed in increasing the overall visibility of space missions towards the general public. The motivation behind using OI in outreach and education is to leverage the creative potential of the crowd, causing an asteroid mission to go viral. This can be applied to various stages of the mission, ideally linked to key mission milestones, such as launch, arrival at asteroid, and asteroid capture. An example would be Hackathons: short events gathering programmers, designers, and managers around the co-creation of software for technology solutions. In practice, these events draw upon individuals from the same company or agency with the goal to foster creativity and build communities.

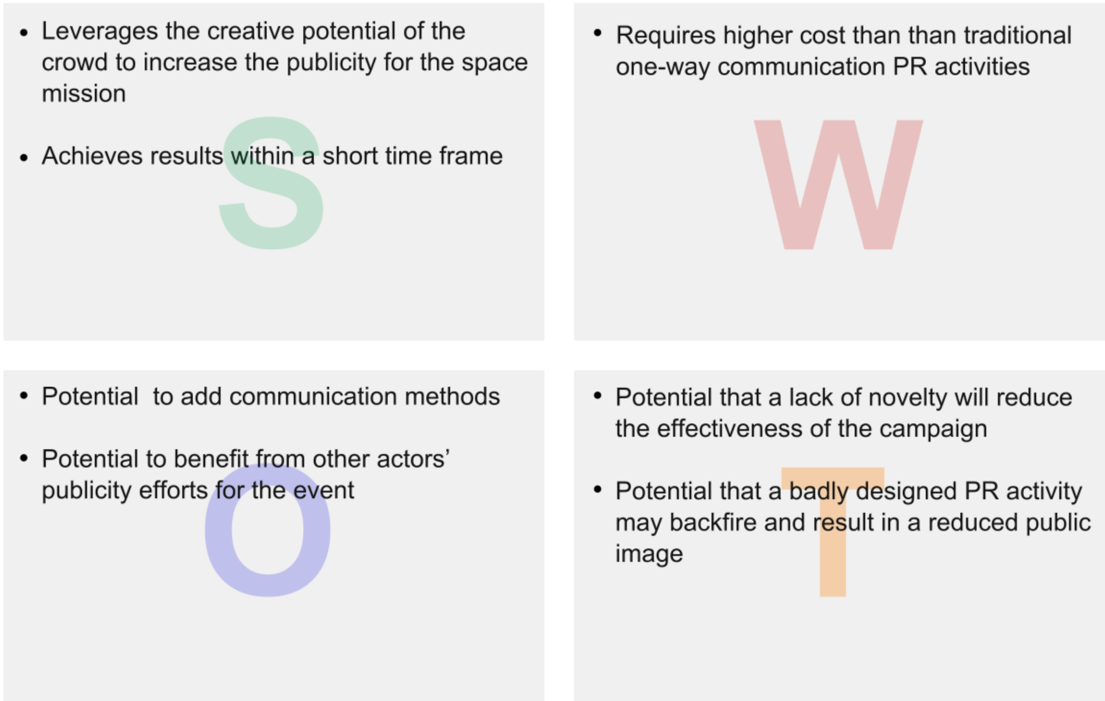

Figure 5-19: SWOT 9 - Outreach and Education Investment

Fostering the Development of Spin-ins and Spin-offs to Identify New Open Innovation Opportunities

A number of spin-ins and spin-offs have been identified by us and shown in Table 8-3. The list is not exhaustive; the intention is to identify some potential avenues for spin-in and spin-off. By splitting the mission into the phases as described earlier and considering each of the different mission profiles, the team intends to show examples of how OI can be used at mission phases. Prizes are an OI technique that was not included in this table, as prizes could be implemented at any phase in a project.

To summarize, the most important strengths, weaknesses, opportunities, and threats common to many OI methods are displayed in Figure 5-20.

S

- Increases the visibility and the scope of the project to the public, which generates public support
- Establishes new partnerships with potential customers, creating potential future revenue streams
- Reduces length of project schedule and cost which speeds up time to market and improves profit
- Brings together and mobilizes strong players in their fields and focuses their efforts on a single goal

W

- Presents a challenge to management and "business as usual" proven methods
- Requires certain amount of disclosure to showcase project, leaving business plan vulnerable to competitors
- Adds logistical complexity by creating with too many external partners

O

- Possibility to spin in advanced technology, methods, or expertise, thus increasing efficiency of the company
- Potential to identify new trends that refine the current industry by incorporating newly identified skills
- Brings together and mobilizes strong players in their fields and focuses their efforts on a single goal
- Potential to catalyze maturity of a small or weak market

T

- Possibility of failure in achieving the funding asked for, resulting in no funding at all under some crowd-funding mechanisms
- Potential of competing, similar projects, already on the market will reduce availability of funding and support
- Possibility of divulging sensitive information to future competitors
- Risk of losing control of IP

Figure 5-20: Overall SWOT Analysis of the Mentioned Open Innovation Techniques

Tools and Techniques to Compare Old and New Business Models

We propose to introduce a new technique to serve industries in general and the space sector in particular. The technique will assess and prioritize which resources of the business could benefit from using OI methods, and which methods might fit the purpose of each phase of the business. It also will consider the consequences of sharing these resources with an audience beyond the company.

The idea of this analysis stems from basic risk analysis. First, the company should choose core competencies of their business that have a large influence on their success, for example: IP, market size, knowledge needed, equipment needed, NDA and management, expected revenue, incentive price, knowledge leak hazards, cost of in-house R&D, timeframe, performance, artificial intelligence (AI), and research capacity.

The next step is to view these aspects through the lens of risk, essentially assigning a numeric value to the risk of success or failure in opening this aspect to OI - with one being closed and five being open. If an aspect presents a large risk to the success of the company by being open then this aspect would be assigned a one. For example, IP is often something that companies need to keep closed in order to maintain their competitive advantage. The lower the score, the higher the risk of OI, and the less beneficial to your company OI would be. The next step, as a risk analysis, is to multiply all the different scores together to get a final OI risk value.

To demonstrate how to use this tool, we will address three potential methods of OI to apply of our case study: asteroid identification, develop drilling technology and crowdfunding. The resulting OI risk level is an evaluation on the potential success and impact this method of OI would be to the case.

Table 5-7: Open Innovation Risk Analysis – Scale from High Risk (1) to Low Risk (5)

Important Aspects	Asteroid Identification through Crowdsourcing	Co-design of Drilling Tech	Crowdfunding
R&D Needed - risk of opening up R&D process	3	**1**	5
Knowledge Needed - risk of opening up expertise	2	**1**	5
Equipment Needed - risk of sharing equipment, infrastructure, or logistics	3	**4**	5
Investment - risk of opening financing and control of company	5	**3**	4
Timeframe - risk of opening time frame	5	**5**	3
Performance/Quality - risk of harming quality	4	**4**	3
Open Innovation Risk Level	1800	**240**	4500

A decision-maker presented with this Table would tend to consider more favorably the crowdfunding and asteroid identification through crowdsourcing as valuable OI ideas. This tool can thus be employed at a larger scale to assess the affordability for a company to bring OI to its different endeavors. This analysis should always be performed along with additional analyses, for example financial feasibility studies.

5.5 Business & Management

In order to elaborate on the operations and utilization phase of the mission, it is important to discuss the commercialization of asteroid mining. There is limited data available due to the fact that there has not been a successful asteroid mining venture to date. However high level business cases have been developed and these are utilized below.

OI presents both great opportunity and risk to any company wishing to apply it to their asteroid mining business. For example, the process of developing new drilling techniques, asteroid identification and geological confidence, simulations models, and remote sensing on asteroids involve new challenges for the development of a mission. For a new entity, it will be challenging to develop these processes and knowledge base from Phase 0 in isolation simply due to the scope of facilities and knowledge required. Below, we develop a case for why it could be more profitable to innovate with terrestrial companies; to leverage their resources and offer a complementary work focus. OI methods can be applied in many aspects and processes of the asteroid mining business, and examples and potential business implications are addressed.

5.5.1 New Business Challenges of Using Open Innovation

Overall challenges of OI have been discussed throughout this paper. However some specific challenges of OI in Asteroid Mining can also be identified which may arise across many different parts of the mission and company. Within the company itself, using OI methods will affect the organizational structure and data processes, including data archiving and flow. When companies create new roles for individuals to monitor OI projects involving multiple entities, challenges could arise in project management processes, employee loyalty, and asset distribution.

Another challenge lies in opening up the business to potential competitors and the wider public. Cooperation requires protecting intellectual property by monitoring how other entities are using it, along with the number and type of assets being shared; this monitoring can be mitigated for in the form of NDAs along with contract formulation and enforcement however there is an agency cost to the company in order to enforce these contracts.

5.5.2 Additional Business Benefits of Using Open Innovation

In the closed innovation model, government-run space sector projects involve stringent quality control process and arguably excessive performance testing to guarantee high quality. The nature of new space missions means that many components have not been tested in a real project environment and this drives high quality management costs. Balancing risk and cost is a constant challenge for a company. Because asteroid mining is a complicated business, introducing OI methods into quality control work can simultaneously reduce the costs of quality assurance as well as sharing of development cost control. Additional funding can be brought in from other entities and there is potential to use open innovation to secure upfront fund via crowdfunding etc. Furthermore allowing different entities to focus ensures that resources, including management, are not overly stretched across the multiple elements of the mission. If they can effectively outsource part of the mission and focus their own internal resource more specifically the organization will potentially be more effective in the work they undertake as part of the overall mission.

5.5.3 Business Cases

There are two key asteroid mining business opportunities; mining water or mining metals. The choice of resource to be mined will define the way OI is applied - especially since mining for water inherently suggests in situ usage and mining of metals, particularly platinum grade metals, requires delivery to Earth for terrestrial usage and sale. Our aim is to quantify the potential benefits of using OI methods in the asteroid mining business case, with specific focus on mining water, which is the initial business case of the Planetary Resources roadmap.

According to the research work of International Space University (2010) and Lee (2012), the costs from mission design to fulfilment involving an asteroid mining venture have been estimated at approximately US$100 billion. Separately a NASA funded study, Robotic Asteroid Prospector (RAP), proposes to build four water mining spacecraft over a six-year timeframe (Cohen, 2013). The cost of a mission to mine water has been estimated at of US$11.8 billion, and over the 25 year project timeline RAP study estimates they can mine 2250 tons of water from asteroids (cost US$5,200 per kilogram). The report states that it expects “to sell this water for $18 billion at a profit of $6.2 billion” (Cohen, 2013). This demonstrates is that the estimated cost of an asteroid mining mission varies widely.

Furthermore, it has not been possible to secure the cost estimates of Planetary Resources’ or DSI’s business model as their data is not publicly available. Therefore for the purpose of this business case assessment, RAP mission estimates have been determined as the most robust costings available and accordingly, the data for mining water from asteroids has been utilized and fully referenced below. The intention is to show that based on the academic exercise RAP have undertaken, the business case could be further improved if the recommended OI methods were leveraged.

Improving the Asteroid Mining business case with OI

NASA details the mission cost, time frame, and projected revenues of an asteroid mining mission, but has not indicated that they would leverage OI techniques. Using the RAP asteroid mining project for water plan (Cohen, 2013) as a base line, we have set out a case analysis that has been altered to reflect the effects of using three different OI methods.

In Section 5.4.1 several OI methodologies which can be leveraged in an asteroid mining mission have be identified. For the purpose of illustrating this business case analysis we have selected three specific OI methodologies relevant to asteroid mining:

1. Crowdsourcing for mapping potential candidate asteroids

2. Prizes similar to Google X Prize for developing drilling technologies

3. Crowdfunding offering upfront investments for underpinning a secondary revenue stream e.g. naming of mined asteroids and associated merchandising, jewelry, etc.

These three examples were selected for a number of reasons. They demonstrate the broad spread of potential OI methods which can be applied across the full lifecycle of an asteroid mining mission. Furthermore data was available for these examples and this can bring some justification to the overall business case. As was previously noted, hard data is difficult to obtain for asteroid mining and some effort has been made to develop the numbers which can really demonstrate the application of OI to the existing RAP case.

Crowdsourcing can be used to map the near Earth asteroids and companies can save large amounts in terms of working hours which both reduces costs but can also accelerate timescales to ultimate selection. According to NASA, the asteroid identification community has reached circa 600,000 members and there are about 100 new asteroids identified each month. If we are to extrapolate these numbers and assuming on average that each person invests 5 hours per month on asteroid detection, this means that 30,000 hours are needed to find each new asteroid, although this does not factor in how many of these detected asteroids are both strong candidates for mining and are deem accessible. To continue at this pace, finding new asteroids would be costly and not altogether time effective. By opening up the platform to include more members searching at the same pace, a mission can save at least $240,000 USD per asteroid. If 20% of all detected asteroids are deemed accessible (Bottke et al., 2000), and based on other sources we assume that only 10% of asteroids have enough value to create a compelling case to mine (Aron, 2013), a saving of $12 million per asteroid mission could be attributed to use of a crowdsourcing platform. In our model, we have spread this cost over the first five years development phase.

The second OI method considered is the use of a prize incentive to find and select drilling technologies. In the past, the USA, USSR and China would forecast similar budget requirements to develop space technologies independently. This is to say regardless of the agency or company, the cost of a specific part developed in-house will be roughly the same regardless of which agency undertakes the work.

In the case of drills, the cost for development of the technology is estimated at US$40 million. The estimate comes from the budget of US$107 million over three years that the ASC-CSA has used to develop drilling and terrestrial based rover technologies (Pugliese, 2013), however we have assumed roughly between one-half and one-third of this cost would be allocated specifically to drilling (where the balance is for the rover technology). In this case a reasonable value for OI Prize has been assumed to be around US$20 million, similar to what was offered for technology demonstration in the Google Lunar X-Prize. This amount is paid out at the end of the development period however there are instances where the prize value increases if won before a certain deadline. As discussed in previous sections, there are additional soft benefits to the prize method from additional public relations and stimulating market growth. For the purpose of the business case we assume a US$20M saving spread over the first five years of the project.

Finally, the case of using crowdfunding to gain additional revenue from auxiliary asteroid products is explored to increase incomes during the first 5 development years. From this proposed crowdfunding exercise, the company will sell a number of auxiliary products - such as naming right to asteroids, future allocation of sales, or other merchandising products e.g. jewelry - with the aim to raise US$9 million over the first 5 years. The aim would be to reach 9,000 buyers at US$1,000 per sale. The design of this type of crowdfunding campaign could come in waves targeting circa 1,000 customers at a time to keep it manageable but significant in terms of an early revenue stream. The aim is to secure upfront funding to offset the long lead time for the main revenue stream to begin and reduce cash flow deficits. This would also help to stimulate public awareness prior to any launches and aiding in marketing and potentially finding other early supporters and co innovators for the mission.

Figure 5-21 shows the advantage of an open innovation approach to asteroid mining. Through collaboration, costs of any single actor are reduced, and the time to commercialization is shortened.

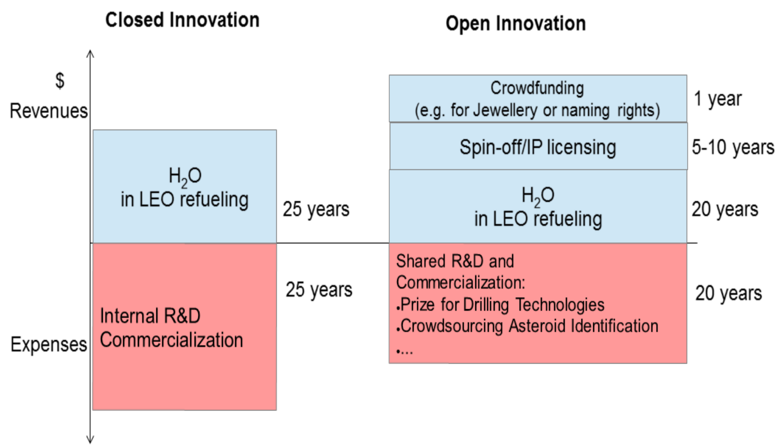

Figure 5-21: Advantages and Disadvantages of Applying Open Innovation

Moreover, although revenue from the core activity (water refueling in LEO) is less with the open innovation approach due to revenue sharing with collaboration partners, the total revenue is greater because of OI techniques applied before commercialization (crowdfunding and spin-offs).

In each of the above three scenarios, potential costs savings figures have been offered. Furthermore, it is our assumption and expectation that the mission timeline would be positively impacted by use of these open innovation methods, especially through asteroid searching and developing drilling technologies. More manpower in the former and use of private industry and leverage off the terrestrial mining industry knowledge for the latter is the basis of our assumption.

At this stage, we make a comparison of OI vs. closed for the asteroid mining mission considering costs and timeframes. We have developed two new scenarios to describe both a reasonable full estimate and a conservative estimate of OI savings over and above the RAP original base example.

The first "OI-Full Estimate" assumes a US$32M saving due to crowdsourcing of asteroid hunting (US$12M) and outsourcing development of the drilling technology (US$20M), both of which would also contribute to an accelerated project timeline where the mission begins to realize revenue starting one year earlier than RAP's original projection of 10 years from project inception. Additional revenues of US$9M will also come from crowdfunding in this scenario.

The “OI-Conservative” estimate takes the assumption that the timeline for a project is shortened by only 6 months, that the savings will be half of the US$32M, and that the incremental revenue increase with the crowdfunding project only yields half of the projected US$9 million.

To normalize these three scenarios, the Net Present Value (NPV) of each has been calculated. NPV is the most common and widely tool used for understanding the value in today’s money of a proposed long term project. A discount rate of 2.5% has been used in the calculation as this was the rate used by NASA (Cohen, 2013) in their own estimates.

The original NASA project, without use of OI methods, is shown in blue as “Closed Innovation” and would offer a NPV of $2.33B. By leveraging the OI methods discussed we see the potential for an NPV of US$3.31B in the “OI-Full Estimate” curve.

Even by utilizing what is deemed to be conservative savings figure for an asteroid mining mission we note a US$2.82B NPV, and although it is accepted that there are a number of estimated figures used in the calculations set out above, it is the belief of this team that OI can bring a quantifiable benefits to an asteroid mining mission and the OI techniques should therefore be fully explored and utilized in any future missions.

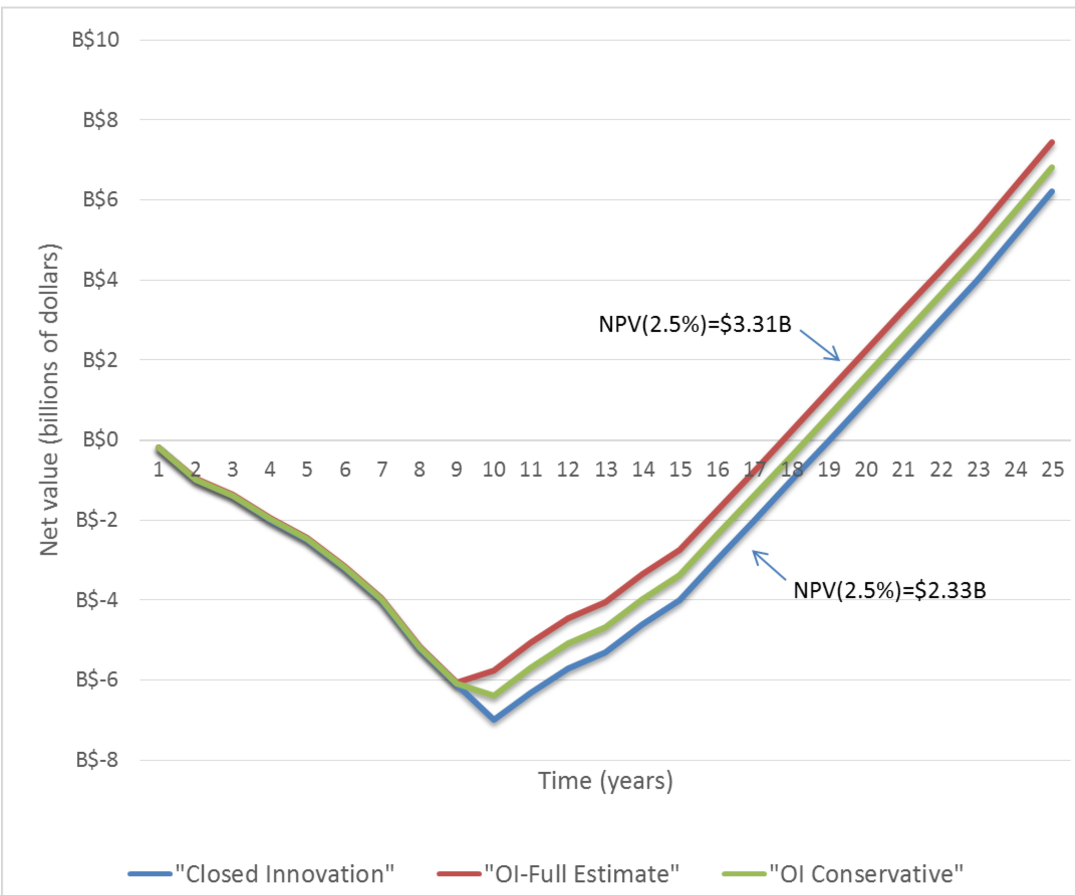

Figure 5-22: Projected Net-Present-Value of an Asteroid Mining Business with Different Innovation Framework

5.5.4 Business and Management Conclusions

At the time of writing, asteroid mining is a new and high risk venture being pioneered by a few private companies and government agencies; it is yet to be proven as a viable business. All work to date revolves around research and theory, which makes a clear demonstration of a business case almost impossible. Specific challenges to anyone undertaking this venture have been set out within the case study, and some of these challenges present specific opportunities for application of OI to add direct value to the business. Examples of where OI can be used range from asteroid hunting, mapping, and selection to developing additional markets.

The key requirement for a business considering application of these OI methods is to quantify the benefit they will bring. In Section 4.1.1 we have shown that using OI methods can help to reduce cost, reduce mission schedules, and increase revenues. In section 5.5.4.1 we have attempted to quantify the value these methods would bring to an Asteroid Mining mission.

It is common that mission costs will decline as the market size and industry matures. We have also seen that Planetary Resources has used aspects of OI in the past, with the most prevalent of these being Crowdsourcing in the search for NEOs and Crowdfunding to address upfront mission costs. We believe that other OI methods, such as the example of awarding prizes for developing the required drilling technology, will further contribute to the trend towards market efficiencies and the eventual feasibility of asteroid mining missions. It is our belief that these private industry companies will continue to develop and benefit from efficiencies and innovations in a way that agency like NASA sometimes cannot obtain. Furthermore, from our research throughout this paper, we believe that there is still more value to be brought to asteroid mining from OI; examples include:

- Constellation of a telescope network to support space mining
- Applications of Big Data Mining in asteroid mining
- Prize model as a market stimulation technique
- Co-design, Fablabs
- Space App Hackathon
- Publicity Partnerships: Logistics Partnership Call

Based on these examples, we hypothesize that the full leverage of OI to an asteroid mining mission such as that set out by NASA could potentially bring hard benefits of US$40B and one year acceleration in timelines.

5.6 Societal Issues of Applying Open Innovation to Asteroid Mining

By its nature, OI is a collaborative process that requires the cooperation of several actors to be effective. Relationships between these actors will develop during the course of a project development cycle such as asteroid mining. A personal relationship is key to solving complex problems posed by such an endeavor; people are much happier to work and compromise with others when they have developed positive personal relationships. The relationship-building nature of OI, in the specific case of asteroid mining, has spin-off benefits far beyond the project's main goal with important outreach implications in terms of engaging the general public in space activities and sparking curiosity and dreams of space exploration among the younger generations.

Large international projects such as the ISS require many nations, companies, contractors, and individual players all working together. The level of cooperation and coordination required to maintain a project of the magnitude of the ISS demonstrates that the spirit of OI is scalable to mega-projects.

Using an OI model to manage projects will have the actors interacting and building relationships. As the ISS experience has shown, these personal ties are stronger than clauses in a contract to keep a team together during extreme circumstances. These relationships can be extended to the case of asteroid mining when tackled by a large community of actors as OI fosters, showing their strength outside of the project where employees will be more likely to take positive actions in their communities and social circles. This feedback loop will continually strengthen trust between members, causing them to solve problems cooperatively rather than in an adversarial manner.

Space in particular requires cooperation by all who use it for it to remain viable. Spectrum allocation for communication purposes, orbital allocations for satellites and the issue of orbital debris affect all space faring nations. By cooperating in these areas that asteroid mining encompasses, the actors will build a collaborative framework that can be incorporated into other global issues.

5.7 Legal and Policy issues with Regards to Asteroid Mining

It is not the team's intent to propose a new regulatory framework, but based on existing legal challenges the team does make recommendations on both new and existing models of international cooperation. Specifically, the recommendations touch on how cooperation can be leveraged to gauge international perception about enacting legislation to enable asteroid mining in the future. The recommendations also consider the role OI could play in the near, medium, and long term.

5.7.1 Open Innovation and the Legal Framework

The team has defined OI as "*the process of strategically managing the sharing of ideas and resources among entities to co-create value.*" When considering the application of OI to the space sector in the context of the team's definition, both national and international law must be considered.

Industries within the sector might be able to apply OI on a national level, but might be restricted in similar application when choosing international partners. For example, commercial entities within the United States could use OI to work together and collaborate under national law, but their involvement in international projects could be subject to ITAR (national law) and the United

States' commitment under international treaties and bilateral or multilateral agreements (international law).

CHALLENGES RELATED TO NATIONAL LAW

States use national laws to provide a legal framework and clarity with respect to how governmental and commercial entities may operate with national jurisdiction. In certain countries such as the United States and India, national law is used as a baseline, which may impose further legal obligations on entities operating within their jurisdiction. In such cases, entities are required to comply with both state and national law when conducting any commercial activity. The key issues under national law (as discussed in section 4.3.2) that restrict the application of OI to the space sector are export control policies, IP regulations and the retention of IP by private entities, clarification of property rights, and uncertainty associated with future national legislation.

5.7.2 INTERNATIONAL LEGAL CHALLENGES TO ASTEROID MINING

International law applies to States rather than individual entities. The onus is on the State to ensure that entities acting on its behalf or operating within its jurisdiction conform to the State's obligations under international law. Under space law, the State is responsible for the authorization, licensing, and continuing supervision of national space activities to ensure compliance with international law.

The primary source of space law is the OST as described in Section 4.2.1, that considers the exploration and use of outer space as the province of all mankind. The OST guarantees freedom of access to space for all nations, prohibits national appropriation by claims of sovereignty or any other means, prohibits placement of weapons of mass destruction in outer space, prohibits military uses of celestial bodies and outlines a State's responsibility and potential liability related to its national space activity.

States that are parties to the OST are bound by it under general international law, and other supplementary treaties, as special law, to which they are also parties. States that are not signatories to the OST are arguably bound to its key principles, which are generally considered to have become customary international law.

Numerous publications have discussed and debated the application of the OST and the other space treaties, arguing the various articles and their implications on State actors (ISU SSP, 1990; 2010). Rather than restating these arguments, the team would like to put forth certain points that require further clarification at an international level before the future prospects of asteroid mining can be considered.

CLARIFICATION OF DEFINITION

1. Celestial Body: Under existing space law, there is currently no legal definition of the term Celestial Body, although the term is extensively used in the OST and the Moon Agreement. Before States or entities licensed by a State begin asteroid mining missions

there might be a need of an international agreement on the legal definition of the term. However, the term celestial bodies is generally understood to include “comets, stars, asteroids, meteorites of most varied shapes and sizes-which populate outer space,” as has been correctly asserted by Judge Manfred Lachs, who was the Chairman of the Legal Subcommittee of the UN Committee on Peaceful Uses of Outer Space at the time of the drafting and adoption of the 1967 Outer Space Treaty (Lachs, 1972, 2010) In the absence of a proposed agreement, this common understanding will continue to apply as ordinary meaning of the term Celestial Body.

If a Celestial body were defined as the planets and their moons within the solar system then the OST and Moon Agreement may not apply with respect to mining because asteroids would be excluded from the definition. On the other hand if we were to define a Celestial body as a natural object that orbits around a planet or the Sun, commercial entities claiming exclusive property rights to either the surface of the sub-surface would be contravening articles in both the OST and the Moon Agreement. An example of such a claim would be one filed by Orbital Development against NASA, who claimed ownership of Eros asteroid and asked NASA to pay a parking fee for landing their Near Earth Asteroid Shoemaker spacecraft. In response, NASA general counsel Edward A Franke, declined to pay the requested fee citing Article 2 of the OST that states “Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means” (OrbDev, 2001)**.**

2. Liability: Under the provisions of the OST the launching State is liable for damage caused to another State party irrespective of whether the damage is caused in outer space, in air space, or on Earth (OST, 1967, Art. VII; LC, 1972, Art. II and III). This principle is echoed by the Registration Convention, which holds the State responsible for the actions of its citizens, (LC, 1972, Art. I; RC, 1976, Art. I), and by the Liability Convention that holds the State liable for any damage caused by any entity operating within its jurisdiction (LC, 1972, Art. II and III).

   The current wording of the Liability Convention only covers damage caused by a space object, which, in terms of accountability, would imply a manmade object launched by a given State.

   To clarify liability issues associated with asteroid mining, the international community would need to clearly define a State's liability when damage results directly from an asteroid mining mission, either from extraction of substantial resources that alter the mass and in turn the trajectory of the asteroid or as a result of moving an asteroid to a parking orbit. There would be future clarification required in reference to liability associated with 3D objects printed in space. For missions where the spacecraft is developed as a joint project, how would liability and sovereignty extend to the printed object?

3. Appropriation: Article 2 of the OST states that outer space including the Moon and other celestial bodies are not subject to appropriation by claim of sovereignty, by means of use

or occupation, or by any other means, making exploration of the Moon and other celestial bodies a province of mankind. Article 6(1, 2) of the Moon Agreement give States the right to carry out scientific experiments and to collect and remove samples of minerals from the Moon's surface. Based on the provisions of the OST as discussed above, a bundle of legal rights from terrestrial property law, such as the rights of possession, control, and exclusion would not apply.

If asteroids were classed as celestial bodies, there would need to be further clarification on how the term sample. Currently, the size of the sample is only limited by a States ability to return said sample to the Earth's surface. Furthermore, if and when feasible, what legal framework is in place to ensure that States do not use commercial entities to return samples that may be commercially exploited in the name of scientific experiments?

4. Common Heritage of Mankind: Common Heritage of Mankind (CHM) is a principle of international law of the sea whereby a defined territorial area is protected from exploitation by commercial and national entities, to protect humanity's natural and cultural heritage for future generations (Baslar, 1998). To date, only the Moon Agreement (Moon Agreement, 1984) and the United Nations Convention on the Law of the Sea (UNCLOS, 1994) of the Sea incorporate the CHM principle. The principle does not apply to the exploration of the natural resources of the Moon and other celestial bodies under the current Moon Agreement, though it could be made applicable through future international legal regime that is envisioned to be established under article 11(5) of the Moon Agreement, "To govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible."

   Unlike other treaties that have been ratified by a majority of the UN States, only 16 States, none of who are major space-faring states, have ratified the Moon Agreement. The CHM principle, which includes equitable sharing, is considered by some to a sticking point for State's and commercial entities interested in asteroid mining.

   Equitable sharing, would mean that States or commercial entities sanctioned by a given State to conduct resource mining must share financial, technological, and scientific benefits derived from their activities under Article 11(5) of the Moon Agreement. Equitable benefit sharing, keeping in mind the needs of developing nations, can be achieved without sharing of actual mineral resources or derived profits. Instead, we can argue that services or products derived from mineral extraction on the Moon or other celestial bodies provide a tangible benefit for humankind in line with the principles of the OST. For example, it can be argued that a commercial asteroid mining company would provide indirect benefits to nations outside its country of operations the same way as a commercial satellite company provides global benefits by operating telecommunication satellites.

The Future Role of the UN

Since the inception of the OST, the United Nations has managed to bring together 102 countries that agree in principle to the regulatory framework set out by the treaty. As these States accept the principle of non-appropriation by claims of sovereignty, by means of use or occupation, or by any other means, it may be possible to bring States together to consider how lessons learnt from treaties applicable here on Earth such as UNCLOS could be adapted to support New Space initiatives in the future. It may be worth looking at the operational structure of the International Seabed Authority and seeing if a similar model would be practically viable for asteroid mining activities.

Lunar Landing Sites: US Heritage vs. World Heritage

In July 2010 NASA released a document that made recommendations to space faring entities on how to preserve the historic and scientific value of US artifacts on the Moon (NASA, 2010). The document states:

> "NASA is seeking to promote the development and implementation of appropriate recommendations, such as those provided herein, with interested private sector entities and, as appropriate, working within the US and with foreign governments" (NASA, 2010).
>
> Subsequent to recommendations made by NASA, in July 2013, a bill was proposed in the U.S House of Representatives titled "Apollo Lunar Landing Legacy Act" (Johnson, 2013). The bill suggests establishing the Apollo lunar landing sites as a national historical park so that they could be protected for generations to come. By doing so compliance with laws applicable to the National Park System, The National Park System Organic Act (16 U.S. Code § 1 et seq.), the Act of August 21, 1935 (16 U.S. Code § 461 et seq.) in the US would be required of the administration of the historical park.
>
> The bill also suggests, that within one year of the park being established, the site should be proposed to the United Nations Educational, Scientific and Cultural Organization (UNESCO) for designation as a World Heritage Site.
>
> The lunar sites also could be designated as World Heritage Sites under Article 1 of the UNESCO charter (UNESCO Charter, 1972) and under point 3 of the selection criteria which states (UNESCO, 2003):
>
> "To bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared"
>
> By proposing the national park site be considered by UNESCO, the U.S. would assume that UNESCO's jurisdiction extends to the Moon. As the UNESCO charter is a subset of the UN charter and mandated by the UN, the US must assume that UN jurisdictional authority extends beyond Earth.
>
> Should this case come before UNESCO, the international community must come together to declare the lunar landing sites as world heritage sites, thereby extending UN jurisdiction

beyond Earth. This action would allow the UN to deal with matters related to asteroid mining in the same way UNCLOS deals with deep-sea mining activity. The team sees the UN's future role as a licensing body for asteroid mining where no sovereignty is assumed, while being able to hold States accountable under international law.

5.8 Case Study Conclusions

The case study was successfully conducted to illustrate how the concepts of Open Innovation could apply to a specific space venture: asteroid mining. The team has proposed a tool to assess the potential success of OI methods for a specific project. The layout of Planetary Resources' roadmap shows ways to implement several Open Innovation ideas at different phases of the missions. The relevance of that particular example pertains to the better comprehension it brought on how OI could help reduce the cost or the timeline of a space project. More specifically, it is by bringing together different players -- borrowed from the same or from different industries – and letting them manage the sharing of ideas and resources that make the co-creation of innovation and value a sustainable strategy for a company, based on the business case comparison between closed and open innovation.

6 RECOMMENDATIONS AND CONCLUSIONS

Throughout this report, we have striven to provide a balanced and nuanced perspective on the applicability of OI in the space sector. To do so, we have first introduced a contextual outlook on the social, economic and business forces that push a growing number of organizations to open up their innovation practices and to revisit both the nature and the intensity of their interactions with external entities. Theoretical and real-world examples used in the report have demonstrated the need for different innovation practices, at times strategically closed or purposely open. No one model exists in a pure form; however, each may display a different degree of openness at one point or another along the innovation process. Perhaps more importantly, no one model alone can guarantee success. Closed and open models of innovation are not mutually exclusive, rather they should be able to co-exist. As Birkinshaw et al. (2011) explain: "open innovation is not the future, but it is certainly part of the future, and the smart approach is to use the tools for open innovation selectively."

This report has also portrayed a space sector that is growing increasingly complex, probably more than other sectors. Space projects and missions require a substantial investment of technical, financial, and human resources over a prolonged period of time. They also require intense collaboration between different disciplines, actors and rationales in order to meet their objectives. These conditions have created challenges in terms of schedule, cost, and quality. Yet, they have also created opportunities to engage both differently and more broadly with new actors to solve these challenges. It is up to organizations to make the most of this complexity to develop value-creating collaborations. To help organizations achieve this, we have explored the benefits and limitations of OI in their application to the space sector in general and to asteroid mining specifically. In this section of the report we present actionable recommendations derived from our findings.

6.1 RECOMMENDATIONS LIST

During the course of the report our team gained insight on how to strategically apply OI to various activities in the space sector. Below is a set of general, and legal and policy recommendations as well as ones tailored for national space agencies and private companies.

6.1.1 GENERAL

Recommendation #1: Organizations should find the right balance between open and closed innovation.

It is important to note that the authors do not suggest abandoning closed innovation practices entirely, but rather to examine OI as complementary to the existing business model. Entities should consult the OI funnel (see Figure 2-7) as a tool to diagnose and analyze how to successfully engage external actors. The innovation process should not be entirely open or closed; the focus should be on implementing the right balance to take advantage of the OI benefits and managing the related risks.

Recommendation #2: Organizations should consider how to apply Open Innovation at all phases of the innovation process.

OI may provide value in all phases of the innovation process. In the early stages of innovation, OI is useful in the ideation process to tap the competencies of external actors, stimulating creativity and improving the quantity, quality, and diversity of ideas. In the later phases, spinoff applications of specific technologies or knowledge can be leveraged to benefit other sectors.

Recommendation #3: Organizations should adapt their managerial and research and development structures by implementing Open Innovation.

Recognize that relevant talent exists outside the organization and consider the possibility of the first-to-market approach over first-to-patent to achieve market success. This can be leveraged by empowering employees to openly collaborate both internally and with external partners to add value to the company by providing the appropriate resources to do so (e.g. time, facilities, recognition, etc.).

Recommendation #4: Researchers should develop a toolkit of Open Innovation methods to assist space sector actors in identifying the viability of an Open Innovation approach.

Our findings suggest that OI is underutilized within the space sector. An OI toolkit will provide a roadmap on how to apply OI methods at specific phases of a mission or project. Space sector actors should invest in such a toolkit to better manage future projects.

6.1.2 Space Agencies

Recommendation #5: National space agencies should consider how to apply Open Innovation in mission phases A, B, and C at the beginning of each project.

OI methods are effective at generating ideas and can help accelerate the mission phase process, particularly in the early phases. Prize challenges have been used to crowdsource solutions in the past. This is an effective OI method that could be considered at several mission levels.

Recommendation #6: National space programs should advance a mechanism to resurface discontinued research projects to take advantage of existing innovative ideas.

National space programs control a large amount of unused IP generated by discontinued projects. This latent value can be activated by selectively opening this unused IP to external entities, which would promote spinoff applications.

6.1.3 PRIVATE COMPANIES

Recommendation #7: Private entities should determine at what Technology Readiness Levels Open Innovation can best be implemented. This decision should be made in reference to particular business and operational models.

OI allows organizations to accelerate commercialization. This can take place at any phase in the TRL scale, although as noted in the survey results there is a perception that application at the early TRL phases is more likely to yield the greatest value. In addition to the more traditional spin-off and spin-in opportunities, OI can also unlock many other paths to market which may not have even been perceived at the outset.

Recommendation #8: Asteroid mining companies should use more Open Innovation methods to accelerate the project development process.

Even though asteroid mining is still in its infancy, a number of OI methods are already being used. Notwithstanding, potential to apply OI to specific asteroid mining milestones remains, such as through crowdsourcing for detection, big data for tracking, prize models for characterization and co-design for mining operations.

6.1.4 POLICY AND LEGAL RECOMMENDATIONS

Recommendation #9: The United Nations along with national entities should provide further clarity on regulatory frameworks to allow new applications in the space sector.

It is the team's recommendation that the UN along with International partners consider how the application of OI could benefit the space sector and how this process could be implemented. It would be best to consider how existing treaties and regulations in other sectors could be adapted to develop a future legislative framework that supports asteroid mining and the application of OI.

6.2 CONCLUSIONS

By exploring the potential means by which OI could help grow the space sector, we have ventured in rather uncharted territory. Yet, doing so is precisely the nature of any endeavors that pertain to space. As such, we hope that this report can spur both a debate about the applicability of OI and tangible changes in the sector. This should extend beyond a technological focus and onto the role of space agencies in the future, the need to foster a proper organizational culture to support OI, and the ways to better harness the many talents of the people who want to contribute to these projects. What the space industry needs at this time is not just a new rocket. Rather, it needs new processes to enable collaboration between all of its stakeholders to ensure the development of sound, safe and promising innovations. To borrow from Pixar CEO's Ed Catmull (Hill et al. 2014), we believe that innovation in space is "not just about making up how to do [rockets, but about] making up how to run [organizations] of really diverse people who can make something together that no one could do alone". This does not come easy, but OI is one first step organizations can take to get there. And as we all know by now, space legacy is often built on these very first small steps.

7 REFERENCES

Allen R. C., 1983. Collective invention. *Journal of Economic Behavior & Organization,* 4 (1), pp. 1-22.

Amin, A. and Cohendet, P., 2004. *Architectures of knowledge: firms, capabilities and communities.* Oxford: Oxford University Press.

Anderson, C., 2012. *Makers: the new industrial revolution.* New York: Random House.

Andriopoulos, C., & Lewis, M. W., 2009. Exploitation-exploration tensions and organizational ambidexterity: Managing paradoxes of innovation. *Organization Science,* 20 (4), pp.696-716.

Appstori, 30 July 2014. *Appstori Official Website* [online]. New York, USA., Available from: <http://www.appstori.com> [Accessed 1 August 2014].

Aron, J., (2013). Alien-hunting equation revamped for mining asteroids. *New Scientist*, (05 December 2013). [Online] Available from: <http://www.newscientist.com/article/dn24696-alienhunting-equation-revamped-for-mining-asteroids.html - .U-A9_vldXQh> [Accessed 29 July 2014].

Balka, K., Raasch, C., and Herstatt, C., 2010. How Open is Open Source? Software and Beyond. *Creativity and Innovation Management,* 19 (3), pp.256-263.

Barney, J., 1991. Firm resources and sustained competitive advantage. *Journal of Management,* 17 (1), pp.99-120.

Baslar, K., 1998. *The concept of the common heritage of mankind in international law.* The Hague, The Netherlands: Martinus Nijhoff Publishers.

Beiji, P., 1998. *Technological change in the modern economy: basic topics and new developments.* Cheltenham: Edward Elgar.

Berman, S. and Korsten, P. (2010). *Capitalizing on complexity, Global Chief Executive Office Study: 76*. IBM Institute for Business Value.

Birkinshaw, J., B., C., and Barsoux, J.L., 2012. The 5 myths of innovation. *MIT Sloan Management Review,* 52 (2), pp.28-33.

Bottke, W.F., Jedicke, R., Morbidelli, A., Petit, J.-M. and Gladman, B., 2000. Understanding the distribution of near-Earth asteroids. *Science.,* 288 (5474), pp.2190-2194.

Brazilian Space Agency (2005). *National Program of Space Activities: PNAE / Brazilian Space Agency*. ed. Brasilia: BSA.

Broniatowski, D.A., Faith, G.R. and Sabathier, V.G. 2006. *The Case for Managed International Cooperation in Space Exploration*.

Broniatowski, D.A., and *et al*., 2008. A framework for evaluating international cooperation in space exploration. *Space Policy,* 24, v4, pp.181-189.

Brynjolfsson, E. and McAfee, A., 2012. Winning the race with ever-smarter machines. *MIT Sloan Management Review,* 53 (2), pp.53-59.

Center for Development of Scientific investigation, 2014. *Center for Development of Scientific investigation (in Spanish).* [online]. Available from: <http://www.cedic.org.py/english/CEDICEN/CEDIC.html> [Accessed 03 August 2014].

Chao, P., Young, T. and Ballhaus, B., 2008. Health of the US space industrial base and the impact of export controls. *Center for Strategic International Studies*, pp.1-63.

Chesbrough, H.W., 2003. The Era of Open Innovation. *MIT Sloan Management Review,* 44 (3), pp.35-41.

Chesbrough, H.W., 2003. *Open innovation: The new imperative for creating and profiting from technology.* Boston, Massachussetts: Harvard Business Press.

Chesbrough, H.W., 2006. The era of open innovation. *Managing innovation and change,* 127 (3), pp.34-41.

Chesbrough, H.W., 2011. Bringing open innovation to services. *MIT Sloan Management Review,* 52 (2), pp.85-90.

Chesbrough, H.W., 2012. Open innovation: where we've been and where we're going. *Research-Technology Management (RTM) Journal,* 55 (4), pp.20-27.

Chesbrough, H.W. and Teece, D.J., 1996. When is virtual virtuous. *Harvard Business Review,* 74 (1), pp.65-72.

Christensen, C., 1997. *The Innovator's Dilemma.* Boston: Harvard Business School.

Cohen, M.M., and *et al.* (2013). *Robotic Asteroid Prospector (RAP) Staged from L1: Start of the Deep Space Economy*. ed. Washington DC: NASA.

Cohen, W.M. and Levinthal, D.A., 1990. Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly.,* 35 (1), pp.128-152.

Cohendet, P. 2014. *Open Innovation at ISU*. International Space University. 25 June 2014.

Cohendet, P., Farcot, M. and Pénin, J., 2006. Entre incitation et coordination: repenser le rôle économique du brevet d'invention dans une économie fondée sur la connaissance (in French). *Management International,* 10 (2), pp.65-83.

Cohendet, P. and Simon, L., 2007. Playing across the Playground: Paradoxes of knowledge creation in the video-game firm. *Journal of Organizational Behavior,* 28 (5), pp.587-605.

CRIAQ, 2014. *CRIAQ Official Website, section Intellectual Property* [online]. Available from: <http://www.criaq.aero/Projets_A/detailFonctionnement/6097892392/Intellectual Property.html> [Accessed 28 July 2014].

CUNY., 2013. *Ten-Year Trends in Enrollement in Science, Technology, Engineering and Math (STEM) disciplines* [online]. New York, Available from: <http://www.cuny.edu/about/administration/offices/ira/ir/data-book/current/stem-enrollment-degrees/STEM_enr_10yr_trends.pdf> [Accessed 27 July 2014].

De Arias, A.R., and *et al.*, 2014. Living Labs, Spaces for Open Innovation and Technology Transfer. An Alternative to the Solution of Social Problems in Paraguay. *Social Sciences,* 3 (3), pp.74-79.

Deep Space Industries, 2012. *Mission: It is Time to Begin the Harvest of Space* [online]. Available from: <http://deepspaceindustries.com/mission/> [Accessed 01 August 2014].

Deep Space Industries, 2012. *Deep Space Industries* [online]. McLean, Virginia, United States, Available from: <http://www.deepspaceindustries.com/> [Accessed 30 July 2014].

Deterding, Sebastian, et al. "Gamification. using game-design elements in non-gaming contexts." *CHI'11 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2011.

Diedriks-Verschoor, I.H.P. and Kopal, V., 2008. *An Introduction to Space Law.* (3rd ed.). Alphen aan den Rijn, The Netherlands: Kluwer Law International.

Ding, R., (2012). XiaoMi company business model and innovation (in Chinese). *Business*, [Online] Available from: <http://www.doc88.com/p-665134815205.html> [Accessed 28 July 2014].

Dosi, G., 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research Policy,* 11 (3), pp.147-157.

Dubois, L.-É., Le Masson, P., Weil, B. and Cohendet, P., 2014. *From organizing for innovation to innovating for organization: how co-design fosters change in organizations.* Paper presented at the Association Internationale de Management Stratégique (In French), Rennes, France.

Dutil-Bruneau, É. and D' Etcheverry, J.-A., (2014). The Consortium for Aerospace Research and Innovation in Canada (CARIC) Launches Today. *New Wire Canada*, (17 April 2014). [Online] Available from: <http://www.newswire.ca/en/story/1340903/the-consortium-for-aerospace-research-and-innovation-in-canada-caric-launches-today> [Accessed 28 July 2014].

Enkel, E., Gassmann, O., & Chesbrough, H., 2009. Open R&D and open innovation: exploring the phenomenon. *R&D Management,* 39 (4), pp.311-316.

Fab Foundation, 2013. *What is a Fab Lab?* [online]. Available from: <http://www.fabfoundation.org/fab-labs/what-is-a-fab-lab/> [Accessed 02 August 2014].

Foust, J., 2014. *NASA Facing New Space Science Cuts* [online]. Washington D.C., National Geographic. Available from: <http://news.nationalgeographic.com/news/2014/05/140530-space-politics-planetary-science-funding-exploration> [Accessed 29 July 2014].

Franke, N. and Piller, F., 2004. Value creation by toolkits for user innovation and design: The case of the watch market. *Journal of product innovation management,* 21 (6).

Gassman, O. and Enkel, E., 2004. *Towards a theory of Open Innovation: Three core processes archetypes*. Paper presented at the R&D Management Conference, Lisboa, Portugal.

Goldman, N.C., 1992. *Space Policy: An Introduction-92.* Iowa City: Iowa State Press.

Handberg, R.B., 2010. Public Sector Actors. In: E. Sadeh, Ed. *The Politics of Space: A Survey*. Taylor & Francis.

Hatchuel, A., Garel, G., Le Masson, P. and Weil, B., 2009. L'intrapreneuriat, compétence ou symptôme?. *Revue française de gestion,* 21 (5), pp.159-173.

Hertzfeld, H.R., Williamson, R.A. and Peter, N. (2005). *Launch Vehicles: An Economic Perspective*. Space Policy Institute, The George Washington University.

Hill, L.B., G. Truelove, E. & Lineback, K., 2014. *Collective Genius : the art and practice of leading innovation.* Boston: Harvard Business Press.

Howe, J. and Robinson, M. 2006. *The Rise of Crowdsourcing*. Institution. June 2006.
Howkins, J., 2002. *The creative economy: how people make money from ideas.* London: Penguin UK.

Huff, L.C. and Robinson, W.T., 1994. Note: the impact of leadtime and years of competitive rivalry on pioneer market share advantages. *Management Science,* 50 (10), pp.1370-1377.
Huizingh, E.K., 2011. Open innovation: State of the art and future perspectives. *Technovation,* 31 (1), pp.2-10.

Hune-Brown, N., 2012. Celebrating the the golden age of American Innovation. *Canadian Business,* 85 (7), pp.66-67.

Huston, L. and Sakkab, N., 2006. Connect and Develop, Inside Procter & Gamble's New Model For Innovation. *Harvard Business Review,* 84 (3), pp.58-66.

International Space University SSP., 1990. *International Asteroid Mission (IAM) : Team project report*. International Space University.

International Space University SSP., 2010. *ASTRA: Asteroid Mining, Technologies Roadmap, and Applications*. International Space University.

Indian Space Research Organization, 2014. *Technology Transfer & Industry Cooperation.* [online]. Available from: <http://www.isro.gov.in/scripts/industrialinterface.aspx> [Accessed 28 July 2014].

Jet Propulsion Laboratory, 2014. *Near Earth Object Program* [online]. Available from: <http://neo.jpl.nasa.gov/stats/> [Accessed 30 July 2014].

Johnson, E.B. 2013. *To establish the Apollo Lunar Landing Sites National Historical Park on the Moon, and for other purposes*.US House of Representatives (H.R. 2617).

Kaufman, R., Hertzfeld, H. and Lewis, J., 2008. *Space, Security and the Economy,* Economists for Peace and Security. ed. Annadale-on-Hudson, USA: Economists for Peace and Security.

Keller, S., Collopy P., and Componation P., 2014. What is wrong with space system cost models? A survey and assessment of cost estimating approaches. *Acta Astronautica,* 93, pp.345-351.

Kline, S.J. and Rosenberg, N., 1986. An overview of innovation. In: R. Landau, & Rosenberg, N., Ed. *The positive sum strategy: Harnessing technology for economic growth*. ed. USA: National Academies Press, pp.275-305.

Lachs, M. (1972). The Law of Outer Space. *An Experience in Contemporary Law Making, Sijthoff Leiden*.

Lachs, M. (2010). *The Law of Outer Space: An Experience in Contemporary Law-Making, by Manfred Lachs, Reissued on the Occasion of the 50th Anniversary of the International Institute of Space Law*. Martinus Nijhoff Publishers.

Lambe, C.J. and Speckman, R.E., 1997. Alliances, external technology acquisition, and discontinuous technological change. *Journal of Product Innovation Management,* 14 (1), pp.102-116.

Lee, R.J., 2012. *Law and Regulation of Commercial Mining of Minerals in Outer Space.* (P. R. Jhaku Ed.): Springer.

Lee, S.M., Hwang, T. and Choi, D., 2012. Open innovation in the public sector of leading countries. *Management Decision.,* 50 (1), pp.147-162.

Lewicki, C. 2012. Planetary Resources Inc. ed. 7th Meeting of the NASA small bodies assessment group, 10 July 2012, Pasadena, California.

Loilier, T. and Tellier, A., 2011. Que faire du modèle de l'innovation ouverte? *Revue française de gestion,* 22 (1), pp.69-84.

Lukaszczyk, A. and Williamson, R., 2010. The role of space related non-governmental organizations (NGOs) in capacity building. *Advances in Space Research,* 45 (3), pp.468-472.

Mahr, D., Lievens, A. and Blazevic, V., 2014. The Value of Customer Cocreated Knowledge during the Innovation Process. *Journal of Product Innovation Management,* 31 (3), pp.599-615.

March, J.G., 1991. Exploration and exploitation in organizational learning. *Organization Science,* 2 (1), pp.71-87.

Marinova, D. and Phillimore, J., 2003. Models of Innovation. In: L. Shavinina, Ed. *The international handbook on innovation*. ed. Oxford: Elsevier.

Martins, E.C. and F., T., 2003. Building organisational culture that stimulates creativity and innovation. *European Journal of Innovation Management,* 6 (1), pp.64-74.

MDA Corporation, 2013. *MDA technology celebrated on back of Canadian five-dollar bill.* [online]. Available from: <http://is.mdacorporation.com/mdais_canada/News/FeaturedStories/fs112011.aspx> [Accessed 26 July 2014].

Mineiro, M.C., 2011. An inconvenient regulatory truth: Divergence in US and EU satellite export control policies on China. *Space Policy,* 27 (4), pp.213-221.

Minister of Industry, 2014. *Canada's space policy framework* [online]. Available from: <http://www.asc-csa.gc.ca/eng/publications/space-policy/> [Accessed 28 July 2014].

Nari, L., Nysten-Haarala, S. and Huhtilainen, L. (2010). *Interfacing intellectual property rights and OI*. Department of Industrial Management.

National Aeronautics and Space Administration, 2007. NASA Program/Project Life Cycle. In: Ed. *NASA Systems Engineering Handbook*. ed. Washington DC: NASA.

National Aeronautics and Space Administration, 2013. *NASA Initiative Idea Synthesis Workshop* [online]. Available from: <http://www.nasa.gov/sites/default/files/files/Asteroid-Idea-Workshop-Abstracts(1).pdf> [Accessed 1 August 2014].

National Aeronautics and Space Administration, 2014a. *Astroid Hunter Initiative* [online]. Available from: <http://www.nasa.gov/press/2014/march/be-an-asteroid-hunter-in-nasas-first-asteroid-grand-challenge-contest-series/ - .U9k4jPldUTV> [Accessed 30 July 2014].

National Aeronautics and Space Administration, 2014b. *Near Earth Object Program* [online]. NA, NASA. Available from: <http://neo.jpl.nasa.gov/links/> [Accessed 28 July 2014].

Nelson, R.R., 2004. The market economy and the scientific commons. *Research Policy,* 33 (3), pp.455-471.

Nelson, R.R. and Winter, S.G., 1982. The Schumpeterian tradeoff revisited. *The American Economic Review,* 72, pp.114-131.

Neptec, 2011. *Neptec's TriDAR technology to take off on Orbital's Cygnus Spacecrafr* [online]. Ottawa, On, Available from: <http://www.neptec.com/media/news.php?news_id=170> [Accessed 25 July 2014].

Nystén-Haarala, S., Lee, N. and Lehto, J., 2010. Flexibility in contract terms and contracting processes. *International Journal of Managing Projects in Business,* 3 (3), pp.462-478.

Obama, B. (2010). *National Space Policy of the United States of America*. Executive Office of the President, Washington D.C.

OrbDev, 2001. *NASA's Reply to Eros Parking Fee Invoice by OrbDev* [online]. Available from: <http://www.orbdev.com/010309.html> [Accessed 04 August].

Ordanini, A., 2001. Infomediation and competitive advantage in b2b digital marketplaces. *European Management Journal,* 19 (3), pp.276-285.

Ordanini, A., 2009. Crowd-funding: transforming customers into investors through innovative service platforms. *Journal of Service Management,* 22 (4), pp.443-470.

Organisation for Economic Co-operation and Development (2011). *OECD Handbook on Measuring the Space Economy*. ed. Paris: OECD.

Organisation for Economic Co-operation and Development (2012). *OECD Science, Technology, and Industry Outlook 2012*. ed. Paris: OECD.

Peck, M.J., 1986. Joint R&D: The case of microelectronics and computer technology corporation. *Research Policy,* 15 (5), pp.219-231.

Perlin, J., 2014. *The Story of Vanguard* [online]. Available from: <http://www.deepspace.ucsb.edu/outreach/the-space-race/the-story-of-vanguard> [Accessed 03 August 2014].

Pichler, M.H., 1987. Copyright Problems of Satellite Transmissions of Programme- Carrying Signals in Western Europe. *Proceedings,* 29.

Ping, G.Q. and Zu, G.S., 2011. Research Status and Prospects of open innovation (In Chinese). *Science Research Management*.

Pisano, G.P. and Verganti, R., 2008. Which kind of collaboration is right for you? *Harvard business review,* 86 (12), pp.78-87.

Planetary Resources, 2013. *Planetary Resources Webpage* [online]. Planetary Resources. Available from: <http://www.planetaryresources.com/> [Accessed 30 July 2014].

Platzer, M.D. (2009). *US Aerospace Manufacturing: Industry Overview and Prospects*. Library of Congress, Congressional Research Service.

Poetz, M.K. and Schreier, M., 2012. The value of crowdsourcing: can users really compete with professionals in generating new product ideas? *Journal of Product Innovation Management,* 29 (2), pp. 245-255.

Porter, M.E., 1987. From competitive advantage to corporate strategy. *Harvard Business Review,* 59 (1), pp.21-40.

Prahalad, C.K. and Ramaswamy, V., 2004. Co-Creation Experiences:The Next Practice in Value Creation. *Journal of Interactive Marketing,* 18 (3), pp.5-15.

Pugliese, D., 2013. *Canada Drills for Role in International Moon, Mars Missions* [online]. Available from: <http://www.spacenews.com/article/civil-space/37466canada-drills-for-role-in-international-moon-mars-missions> [Accessed 1 August 2014].

Radjou, N., Prabhu, J. and Ahuja, S., 2012. *Jugaad Innovation: Think Frugal, Be Flexible, Generate Breakthrough Growth.* San Francisco: Jossey-Bass.

Review of US Human Spaceflight Plans Committee, and *et al.*,(2009). *Seeking a human spaceflight program worthy of a great nation*. National Aeronautics and Space Administration (NASA), 2009.

Saldanha, F.P., Cohendet, P. and Pozzebon, M. To be published. *The sacred and the profane in crowdsourcing: The case of Fiat Mio in Brazil.* HEC Montreal.

Sawhney, M., Wolcott, R.C. and Arroniz, I., 2011. The 12 different ways for companies to innovate. *MIT Sloan Management Review,* 52 (2), pp.28-45.

Schmookler, J., 1962. Economic sources of inventive activity. *The Journal of Economic History,* 22 (1), pp.1-19.

Schumpeter, J.A., 1934. *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle.* New Jersey: Transaction Publishers.

Segrestin, B., 2005. Partnering to explore: The Renault–Nissan Alliance as a forerunner of new cooperative patterns. *Research Policy,* 34 (5), pp.657-671.

Sharma, T., 2012. *Vacuum Maglev: An International Endeavour for a Global Space Program.* Thesis (DPhil.). University of Sussex, Brighton, U.K.

Sharma, T., Chatwin, C., Young, R. and Birch, P., 2012. *United Space Alliance for neospace exploration*. Paper presented at the Global Space Exploration Conference, Washington D.C.

Sharma, T., Chatwin, C., Young, R. and Birch, P., 2013. *A development framework for local and regional programs and its impact on the global space domain*. Paper presented at the 64th International Astronautical Congress, Beijing, China.

Space Foundation (2014). *The Space Report 2014*, Colorodo Springs, Colorado 2014.

Stewart, J. and Hyysalo, S., 2008. Intermediaries, users and social learning in technological innovation. *International Journal of Innovation Management,* 12 (3), pp.295-324.

Stumbaum, M.-B., 2009. Risky Business? The EU, China and dual-use technology. *European Union Institute for Security Studies,* 80.

Svenja, P., 2013. *The role of human resource management in open innovation: exploring the relation between HR practices and OI.* Thesis (Master of Management). Hasselt University, Hasselt, Belgium.

Szajnfarber, Z., Vrolijk, A. and Crusan, J., 2014. *Exploring the Interaction Between Open Innovation Methods and System Complexity*. Paper presented at the 4th International Engineering Systems Symposium, Hoboken, NJ.

Tesla Motors, 2014. *Tesla Motors Website* [online]. Available from: <http://www.teslamotors.com> [Accessed August 1 2014].

Tsai, W.T., Wu, W. and Huhns, M.N., 2014. Cloud-Based Software Crowdsourcing. *Internet Computing, IEEE,* 18 (3), pp.78-83.

Tushman, M.L. and Reilly, O., 1996. Evolution and revolution: mastering the dynamics of innovation and change. *California Management Review,* 38 (4), pp.8-29.

United Nations (1982). *United Nations Convention on the Law of the Sea, 1833 UNTS 3/[1994] ATS 31 / 21 ILM 1261 (1982), Entered into force 16 November 1994 (Article 308)*. Montegnaro Bay, Jamaica, United Nations.

United Nations Conference on Trade and Development (2010). *Creative Economy Report 2010*. United Nations (UNCTAD/DITC/TAB/2010/3).

United Nations Education Scientific and Cultural Organization (2013). *Operational Guidelines for the Implementation of the World Heritage Convention*. UNESCO (WHC. 05/2), Paris 2013.

United Nations Educational Scientific and Cultural Organization (1972). *Convention concerning the protection of the world cultural and natural heritage,* Paris, 1972.

United Nations Office of Outer Space Affairs (1967). *United Nations, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other celestial bodies; 610 United Nations Treaty Series 205 (opened for signature 27 January 1967.), 610 UNTS 205 referred to as the Outer Space Treaty (OST) 1967.* United Nations Office of Outer Space Affairs (ST/SPACE/61/Rev.1).

United Nations Office of Outer Space Affairs (1972). *1972 Convention on International Liability for Damage Caused by Space Objects (Liability Convention), Adopted 29 November 1971, Date of entry into Force 1 September 1972 (Article XXIV), 24 UST 2389 / TIAS 7762 / 961 UNTS 187*. United Nations OOSA.

United Nations Office of Outer Space Affairs (1975) *Convention on the Registration of Objects Launched into Outer Space (Registration Convention)* Date of adoption: 12 November 1974, New York, Date of Entry into Force 15 September 1976 (Article VIII), 1023 UNTS 15.). United Nations OOSA.

United Nations Office of Outer Space Affairs (2002). *Convention on International Liability for Damage Caused by Space Objects* United Nations (ST/SPACE/11), New York 2002.

United Nations Office of Outer Space Affairs (2002). *Convention on Registration of Objects Launched into Outer Space* United Nations (ST/SPACE/11), New York, 2002.

United States Patent and Trademark Office, *U.S. Patent Statistics Chart Years 1963 - 2013* [online]. USPTO. Available from: <http://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm> [Accessed July 25].

von Hippel, E., 1978. A customer-active paradigm for industrial product idea generation. *Research Policy,* 7 (3), pp.240-265.

von Hippel, E., 1986. Lead users: a source of novel product concepts. *Management Science,* 32 (7), pp.791-805.

von Hippel, E., 2005. *Democratizing innovation.* Boston: MIT Press.

von Hippel, E., 2011. People don’t need a profit motivate to innovate. *Harvard Business Review,* 89 (11), pp.36-37.

von Hippel, E. and von Krogh, G., 2003. Open source software and the “private-collective” innovation model: Issues for organization science. *Organization Science,* 14 (2), pp.209-223.

Wall, M., 2013. *Asteroid-Mining Project Aims for Deep-Space Colonies* [online]. Space.com. Available from: <http://www.space.com/19368-asteroid-mining-deep-space-industries.html> [Accessed 30 July 2014].

West, J. and Bogers, M., 2014. Leveraging external sources of innovation: a review of research on open innovation. *Journal of Product Innovation Management,* 31 (4), pp.814-830.

West, J. and O'Mahony, S., 2008. The role of participation architecture in growing sponsored open source communities. *Industry and Innovation,* 15 (2), pp.145-167.

West, J., Salter, A., Vanhaverbeke, W. and Chesbrough, H., 2014. Open innovation: The next decade. *Research Policy,* 43 (5), pp.805-811.

Williamson, O.E., 1985. *The economic institutions of capitalism: firms, markets, relational contracting.* New York: Free Press.

Wood, D. and Annalise, W., 2012. A framework for evaluating national space activity. *Acta Astronautica,* 73, pp.221-236.

XiaoMi, 2012. *XiaoMi company's innovation (in Chinese).* XiaoMi. 09 May 2012.

Xiong, S.S., and *et al* .(2013). The analysis of innnovation about XiaoMi company (in Chinese),*Baidu Library,* 8 December.
The analysis of innovation about XiaoMi company (in Chinese). *Baidu Library*, (08 December 2013). [Online] Available from: <http://wenku.baidu.com/view/2374911e2af90242a895e5ab.htm> [Accessed 28 July 2014].

8 APPENDIX

8.1 Key Concepts of Open Innovation Theory

Table 8-1 below summarizes the key concepts presented throughout Chapter 2. List of the main authors that have laid the theoretical foundations on which it builds is also provided.

Table 8-1: Summary of Key Open Innovation Theory Concepts

Key Concept	Definition	Authors
Absorptive Capacity	Base of knowledge created that help firms capitalize on outside ideas, identify relevant external input and make sense of trends or information.	Cohen & Levinthal (1990)
Ambidexterity	The ability of firms to solve the exploration-exploitation dilemma by resorting to separate or sequential activities. OI can seen as a form of network ambidexterity.	Andriopoulos & Lewis (2009); Tushman & O'reilly (1996)
Closed models	The linear (technology-push, demand-pull) and interactive processes by which firms conduct internally and control the entire scope of innovation activities (from idea to market).	Schumpeter (1939); Schookler (1962); Nelson & Winter (1982); Kline & Rosenberg (1983)
Coupled process	The combination of outside-in and inside-out approaches to OI, by which firms draw external ideas and allow outsiders co-create value.	Enkel et al. (2009); Grassman & Enkel (2004)
Exploration-Exploitation	The dilemma firms face when devoting resources to innovation (exploration of new ideas) or operations (exploitation of current knowledge and IP).	March (1991)
Innovation	More than just ideas (inventions) that reach the	Hatchuel et al. (2009); Sawhney et al. (2011)

	market, innovations create value for users by changing one dimension of a firm's existing products, services or internal processes	
Inside-out process	The outbound flow of knowledge by which firms allow external actors to access its resources, create applications for unused IP or develop new opportunities for its IP.	Chesbrough (2003;2006; 2011, 2012); (West and Bogers (2014)
Open models (OI)	The process of strategically managing the sharing of ideas and resources among entities to co-create value	Chesbrough (2003;2006; 2011, 2012); (West and Bogers (2014)
Outside-in process	The inbound flow of knowledge by which firms draw on external ideas to create value for their own purpose.	Chesbrough (2003;2006; 2011, 2012); (West and Bogers (2014)

8.2 Technology Readiness Level

Table 8-2: Technology readiness level (European Space Agency, 2008)

TRL	Description: Level of maturity of a technology
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof of concept
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 5	Component and/or breadboard validation in relevant environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment
TRL 7	System prototype demonstration in an operational environment.
TRL 8	Actual system completed and qualified through test and demonstration.
TRL 9	Actual system proven through successful mission operations.

8.3 SPIN-INS AND SPIN-OUTS FROM ASTEROID MINING CASE STUDY

Table 8-3 Identified Spin-in and Spin-outs for Use in the Asteroid Industry

Asteroid Detection and Observation	
Phase 0 Identifying Demand and Mission Analysis	Couple: creating algorithms for handling big data sets, becoming more efficient in handling data. Spin-in: Geological academics and related industry for detailed understanding. Including jewelers, construction, etc.
Phase A Feasibility	Com: Aiding other companies to create a space economy so there is someone to sell materials to.
Phase B Research and Preliminary Design	Spin-in/Spin-out: Fablabs - a dedicated facility akin to an incubator but encouraging multiple industrial experts.
Phase C Detailed Design	Spin-in: Earth sensing techniques can be used to develop or supplement the development of prospecting equipment.
Phase D Production and Ground Testing	Spin-in: Logistic companies for support during testing and transportation. Spin-in: Modern aircraft, automotive manufacturing experts and techniques (mass production)
Phase E Utilization and Operations	Couple: Use the technology developed in remote sensing to aid in terrestrial applications. Crowd: Amateur telescope coordination to aid in detection Crowd: Catalog known asteroids for science
Phase F Disposal	Spin-out: Develop deorbiting technology for use on the satellites; Rent the time to educational and private institutions once survey is done.
Asteroid Flyby and Tracking	
Phase 0 Identifying Demand and Mission Analysis	Spin-in: 3d scanning technology to better visualize and understand the asteroids. Couple: Communication deep space networks to handle the data throughput of these missions and others.
Phase A Feasibility	Crowd: Crowdsourcing video game players to help with trajectories and mission profiles; Public engagement.
Phase B Research and Preliminary Design	Spin-out: Using the artificial algorithms developed to flyby in terrestrial robotics. Spin-in: Use simulating experts and game designers to provide an interactive scenario for companies to show and test products. Open up utilization to wider

	communities?
Phase C Detailed Design	Spin-off: Helping secure supply lines for high volume commercial output; standardizing satellite platform. Couple: Partnership with public entities to focus contactors in one area.
Phase D Production and Ground Testing	Com: selling successful algorithms to airlines, Unmanned Aerial Vehicles (UAV) and self-driving cars Spin-in: Surveying companies beta testing hardware on Earth (product verification)
Phase E Utilization and Operations	N/A
Phase F Disposal	Spin-out: Sending the probes to deep space locations to survey planets and moons after they are done with the asteroid.
Detailed Asteroid Characterization	
Phase 0 Identifying Demand and Mission Analysis	Spin-in: using the expertise of terrestrial surveying companies to develop techniques.
Phase A Feasibility	N/A
Phase B Research and Preliminary Design	Spin-out: Aiding the exploration and classification of exoplanets and future remote sensing missions to the moons around the outer planets.
Phase C Detailed Design	N/A
Phase D Production and Ground Testing	N/A
Phase E Utilization and Operations	N/A
Phase F Disposal	N/A
Asteroid Mining	
Phase 0 Identifying Demand and	Spin-in: using terrestrial process engineers to develop Piping and Instrumentation Diagrams (P&ID) for mining plants, deep sea mining.

Mission Analysis	Spin-in: Pressure vessel terrestrial technologies for transportation (e.g deep sea or gaseous transport).
Phase A Feasibility	Spin-out: collaborating with Lunar / Mars mining missions, other in-situ developments.
Phase B Research and Preliminary Design	Spin-out: Microgravity manufacturing to other space companies. Com: Standardizing orbital servicing procedures to better sell H2O to clients Spin-in: Medical algorithms and hardware from surgery applications, including control algorithms.
Phase C Detailed Design	Couple: Use the design process of terrestrial mining companies.
Phase D Production and Ground Testing	Spin-out: test on ISS, other stations before launching. Sell to space stations.
Phase E Utilization and Operations	Spin-out: exotic merchandise
Phase F Disposal	N/A

8.4 Survey Submitted to Agencies and Non-Agencies

This section of the Appendix shows the questions submitted to Agencies and Non-Agencies as the survey produced by the poject. The actual format used was an automated form:

OI Questions to stakeholders

1. Our team defines Open Innovation (OI) as : “Open innovation is the process of strategically managing and sharing ideas and resources among entities to co-create value”.

   1 Strongly Disagree, 2 Disagree, 3 Neutral, 4 Agree, 5 Strongly Agree

1. We agree with the above definition of Open Innovation
2. We currently apply OI methodologies in our work as per our understanding of OI
3. OI is a risk/threat to our business development plans.
4. OI will disrupt the way we do space business in the near future
5. Current legal framework is a hindrance to OI application in space.
6. There is an opportunity for OI application to Asteroid Mining.
7. Current evaluation of the technical feasibility in Asteroid Mining is high.
8. Current evaluation of the commercial feasibility in Asteroid Mining is high.
9. To which phase would to consider OI application suitable?
   - Mission design
   - Hardware manufacturing
   - Execution phase
   - Resource exploitation

Agency Questions (250 words or less)
Questions related to Open Innovation:

- Q1 - What is your understanding of Open Innovation and what are the barriers to using OI methodologies within your organization and the industry at large?
- Q2 - Would you support, fund, or incentivize OI projects within your industry? Could you elaborate on that?
- Q3 - Do you perceive that OI will inhibit the ability of national agencies to guide industrial roadmaps and limit the influence of PPP?

Questions related to our Case Study (Application of OI to asteroid mining)

- Q4 - Does your organization have an interest in asteroid mining? What is the scope and roadmap of your current involvement and interests?
- Q5 - What changes (political, legal, financial, technical, etc.) would you like to see that would encourage your organization to increase your pursuit of asteroid mining?
- Q6 - Regardless of your agency's level of interest in asteroid mining specifically, what Technology Readiness Levels (TRL) are best suited for open innovation? (For instance, low TRL might be best suited for OI in fundamental research, while OI in medium TRL may lend itself to spin-offs, etc.)
- Q7 - Are there any aspects of OI or Asteroid Mining that you would like to elaborate upon or mention that has not been covered in this survey?

Industry/Non-Government Questions (250 words or less)
Questions related to Open Innovation:

- Q1 - What is your understanding of Open Innovation (OI) and what are the barriers to using OI methodologies within your organization and the industry at large?
- Q2 - Would you support, fund, or incentivize OI projects within your industry? Could you elaborate on that?
- Q3 - Where do you think OI is best applied internally within your organization and across your supply chain?

Questions related to our Case Study (Application of OI to asteroid mining)

- Q4 - Does your organization have an interest in asteroid mining? What is the scope and roadmap of your current involvement and interests?
- Q5 - What changes (political, legal, financial, technical, etc.) would you like to see that would encourage your organization to increase your pursuit of asteroid mining?
- Q6 - For which Technology Readiness Levels (TRL) could open innovation best be used? (For instance, low TRL with fundamental research taking ideas from outside, medium TRL with spin-offs, etc.)
- Q7 - Are there any aspects of OI or Asteroid Mining that you would like to elaborate upon or mention that has not been covered in this survey?

INNOVATION IN SPACE

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