HOW DO PRIZES INDUCE INNOVATION?

LEARNING FROM THE GOOGLE LUNAR X-PRIZE

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To my family

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NOMENCLATURE

AXP	Ansari X Prize
NGLLC	Northrop Grumman Lunar Lander Challenge
GLXP	Google Lunar X Prize
XPF	X Prize Foundation
PC	Prize Challenge
PIs	Prize incentives
TIs	Technology incentives
PTOs	Prize technology outputs
IP	Intellectual property
TRL	Technology readiness level
DARPA	U.S. Defense Advanced Research Projects Agency
FAA	U.S. Federal Aviation Administration
JAXA	Japan Aerospace Exploration Agency
NASA	U.S. National Aeronautics and Space Administration
NACA	U.S. National Advisory Committee for Aeronautics
USAAF	U.S. Army Air Forces

SUMMARY

Inducement prizes–where cash rewards are given to motivate the attainment of targets—have been long used to stimulate individuals, groups, and communities to accomplish diverse types of goals. In the 18th and 19th centuries, prizes encouraged scientific research and may have also been decisive to develop early innovations such as the marine chronometer and induce the initial development of the aviation industry in the 20th century. Lately, prizes have increasingly attracted the attention of policy-makers, managers, philanthropists, and the media due to their potential to induce path-breaking innovations and accomplish related goals, such as economic recovery or the engagement of social groups to create innovation communities. Academic research, however, has barely investigated these prizes in spite of their long history, recent popularity, and notable potential.

This research investigates prizes and the means by which they induce innovation. In particular, four questions that are relevant from the viewpoint of both scientific inquiry and policy-making are addressed: (1) How do different types of incentives weigh in the overall motivation of prize entrants? (2) What are the characteristics of prize R&D activities and how do they differ from traditional industry's R&D activities? (3) What are the characteristics of the prize technology outputs and how do they relate to the characteristics of prize entrants and their R&D activities? (4) Do prizes spur innovation over and above what would have occurred anyway?

This research uses an empirical, multiple case-study methodology and multiple data sources to investigate three cases of recent aerospace technology prizes: a main case

study, the Google Lunar X Prize (GLXP) for robotic Moon exploration; and two pilot cases, the Ansari X Prize (AXP) for the first private reusable manned spacecraft and the Northrop Grumman Lunar Lander Challenge (NGLLC) for flights of reusable rocket-powered vehicles. This research also introduces an innovation model to investigate prizes that focuses on the competition as unit of analysis and articulates internal and external factors that can potentially explain the effect of prizes on innovation.

The investigation unveils the dynamics of prizes and contributes a better understanding of their potential and disadvantages in a context in which more traditional mechanisms are used to induce innovation.

The incentives offered by prizes attract entrants with diverse characteristics, including unconventional entrants—individuals and organizations generally not involved with the prize technologies. Entrants are generally attracted by the non-monetary benefits of participation (e.g. reputation, visibility, opportunity to participate in technology development and accomplish other personal and organizational goals) and the potential market value of the technologies involved in competitions. Many more volunteers, collaborators, and partners also participate—though only indirectly—and support official entries as they also perceive opportunities to accomplish personal and organizational goals. The monetary reward is not as important as other prize incentives, yet it is still important to position and disseminate the idea of the prize.

Prizes can induce increasing R&D activities and re-direct industry projects to target diverse technological goals, yet the evolution of prize competitions is generally difficult to anticipate. The overall organization of prize R&D activities depends on entrant-level factors such as goals, strategies, and resources, and can only be indirectly influenced by setting specific competition rules. The most remarkable characteristic of prize R&D activities is their interaction with fundraising efforts which, in some circumstances, may constrain the activities of entrants. Prizes can also selectively focus the advancement of technologies at different levels of maturity (e.g. experimental research, incremental developments, commercialization,) yet the quality of the technological outputs is also generally difficult to anticipate and depends on entrant-level factors as well.

Prizes can also induce innovation over and above what would have occurred anyway, yet their overall effect depends significantly on the characteristics of the prize entrants and the evolution of the context of the competition. The ability of prizes to induce innovation is larger when there are larger prize incentives, more significant technology gaps implicit in the prize challenge, and open-ended challenge definitions. Moreover, prizes can induce technological breakthroughs but complementary incentives (e.g. commitments to purchase technology) or support (e.g. seed funding) may be needed in some circumstances.

This research shows that prizes are a more complex mechanism and their investigation requires analyzing entrant- and context-level factors generally not considered by the literature. Prizes complement and not replace patents and other incentive mechanisms. The ability of entrants to retain IP rights on their technologies enables the R&D process and hybrid prize schemes that include financial support for qualified entrants (e.g. R&D grants) or commitment to purchase prize technologies (e.g. procurement contracts) are optional designs for these competitions.

Prizes are only one of the forms of intervention to stimulate technological innovation, but are particularly appropriate to, for example, explore new, experimental methods and technologies that imply high-risk R&D; induce technological development to break critical technological barriers; accelerate technological development to achieve higher performance standards; and, accelerate diffusion, adoption, and/or commercialization of technologies. Prizes can selectively target certain technologies, R&D performers and geographic areas, and also leverage funding significantly due to their widespread, decentralized impact. They involve, however, higher programmatic risks than other more traditional mechanisms and their routine use, and/or challenge definitions that overlap, can weaken the incentive power of the mechanism. Successful implementation of competitions requires many parameters to be properly set.

CHAPTER 1

INTRODUCTION

Prizes are incentives that have long been used by public or private sponsors to elicit effort from individuals and organizations and attain diverse goals, including scientific discovery and technology development. For instance, in the 18th and 19th centuries, prizes were used to encourage basic research by compensating research results with monetary rewards or medals (MacLeod, 1971; Brunt et al., 2008). Prizes may have also been decisive to develop early innovations such as the marine chronometer and induce the initial development of the aviation industry in the 20th century. One of the most popular aviation prizes was, for example, the Orteig Prize for the first aviator to fly nonstop from New York to Paris (won in 1927 by Charles Lindbergh) (Davis & Davis, 2004; Maryniak, 2005; Mokyr, 2009). More recently, policy-makers, philanthropists, companies, and the media have become increasingly interested in prizes due to their potential to induce path-breaking technological innovations or achieve related goals such as economic recovery, technology diffusion, and the creation of innovation communities.

This research investigates prizes and the means by which they induce innovation or other effects related to technological development. The focus is on four main aspects of prizes: the motivations of prize entrants, the organization of prize R&D activities, the prize technologies, and the overall effect of prizes on technological innovation. This research uses an empirical, multiple case-study methodology and multiple types of data sources to investigate three cases of recent aerospace technology prizes: a main case study, the Google Lunar X Prize (GLXP) for robotic Moon exploration; and two pilot cases, the Ansari X Prize (AXP) for the first private reusable manned spacecraft and the Northrop Grumman Lunar Lander Challenge (NGLLC) for flights of reusable rocket-powered vehicles.

During the last fifty years, prizes proliferated in different formats and in many sectors as a widespread social process (Best, 2008). However, it is since the 1990s that a handful of successful global technology prizes have revitalized the interest in this topic. These competitions include the cases studied by this research and others such the $10 million Progressive Insurance Automotive X-Prize to create a car that radically reduces oil consumption and harmful emissions, the $1 million Netflix Prize to improve Netflix, Inc.'s movie recommendation system, and the $3.5 million DARPA Urban Challenge to develop autonomous robotic vehicles. Prizes have also attracted the attention of U.S. policy makers and sparked further discussion between a number of government stakeholders (NAE, 1999; NRC, 2007; Stine, 2009) to the extent that new legislation has been enacted to authorize federal agencies to use prizes widely. Moreover, prizes have received extensive media coverage which has attracted even more attention to this type of incentives (see for example Boyle, 2004a; Richtel, 2007; Harford, 2008; King, 2008; Taylor, 2008).

Despite their long history, recent popularity, and notable potential, academic research has barely investigated these prizes and their effects on technological innovation. The prize literature has developed mostly theoretical, economic approaches (see, for example, Wright, 1983; de Laat, 1997; Shavell & van Ypersele, 1999; Newell & Wilson, 2005; Brunt et al., 2008) and, to a lesser extent, empirical case studies (see, for example, Davis & Davis, 2004; Saar, 2006). Most of the scholarly works have focused on comparing prizes with other incentive mechanisms and not on probing the real features and ultimate effects of prizes on technological innovation. The increasing interest in the use of prizes to attain diverse goals related to technological development calls for further empirical research to close significant knowledge gaps and inform increasing policy-making activities in this area.

This work draws upon prize literature insights and more general innovation literature to address four main questions that are not only deemed relevant from the viewpoint of scientific inquiry but also considered to have significant implications for policy-making for the design of effective and more efficient technology prize competitions: (1) How do different types of incentives weigh in the overall motivation of different types of prize entrants? (2) What are the characteristics of prize R&D activities and how do they differ from traditional industry's R&D activities? (3) What are the characteristics of the prize technology outputs and how do they relate to the characteristics of prize entrants and their R&D activities? (4) Do prizes spur innovation over and above what would have occurred anyway?

To address those questions and probe corresponding propositions, this research introduces an innovation model that focuses on the prize competition as unit of analysis and articulates internal and external factors that can potentially explain the effect of prizes on innovation. To the author's knowledge, no framework or model of this kind has been offered by the academic literature to study the effect of prizes on innovation. This model is built upon six main dimensions identified in the prize literature, namely: prize design, motivation of prize entrants, R&D activities, technology outputs, characteristics of entrants, and the interplay between prize and its context or technology sector. The model is used to pursue an iterative approach to empirical case study research. First, the model is tested and improved with two case studies of finished prizes, the AXP and NGLLC. Second, a refined version of the model is applied to investigate the main case study, the GLXP, and elaborate implications for theory and future research.

The GLXP is a $30 million multi-year global competition organized by the X Prize Foundation and sponsored by Google, Inc. It was announced on September 2007 and has not found a winner yet. The GLXP requires participants to land a robot on the Moon, among other secondary goals, by December 2015. Thirty-five international teams entered the competition and participants from more than 40 countries have been involved. This prize has exceptional significance because (a) it is an opportunity to gather valuable real-time data from ongoing R&D activities in a high-tech competition; (b) it is interrelated with the strategic U.S. aerospace and defense industry sectors; and, (c) it has global reach, which offers the opportunity to observe the broadest impact of prizes. The AXP is a $10 million prize offered in 1996 for the first non-government organization to launch a reusable manned spacecraft into space twice within two weeks. It engaged 26 teams from seven countries. The U.S. firm Scaled Composites won this prize in 2004. The NGLLC, part of the NASA Centennial Challenges, is a $2 million multi-year prize offered for building and flying a rocket-powered vehicle that simulates the flight of a vehicle on the Moon. It involved 12 U.S. teams between 2006 and 2009. The U.S. firms Masten Space Systems and Armadillo Aerospace shared the prize money.

The analysis of these three case studies unveils their dynamics and contributes a better understanding of the potential effects of prizes on innovation. This investigation also highlights the advantages and weaknesses of prizes under certain circumstances and provides insights for effective prize design and implementation. Many instructive methodological considerations also emerge throughout the analysis to inform further empirical research on technology prizes.

This work is structured as follows. Section 2 describes recent prize developments, reviews the more general literature that compares prizes with other incentive mechanisms, describes the types of prizes, and discusses aspects related to the use of innovation prizes in government. Section 3 reviews the literature that is relevant to each of the four research questions and posits four corresponding hypothetical explanations. Section 4 discusses methodological aspects, introduces the innovation model to study prizes, and describes the data and data gathering process. Section 5 presents the analysis and findings of the AXP and NGLLC case studies, and presents considerations for model improvement and further research. Section 6 presents the analysis and findings of the GLXP case study. The findings are organized in subsections to address the six dimensions of the case study in three levels: the prize, the context, and the prize entrants. Section 7 discusses those findings and probes the anticipated effect of prizes. This section also seeks to advance the analysis and connect findings from the three case studies with the prize literature and insights of the broader innovation literature. Section 8 seeks to contribute new building blocks for the development of prize theory and presents policy considerations based on the findings on the three case studies. Section 9 provides concluding remarks. This document also includes Appendix sections with relevant tables, figures, and data gathering summaries and instruments. At the end of the document, there is also a list of references cited throughout this work.

CHAPTER 2

INNOVATION AND PRIZES

2.1 Prize renaissance

Recent reports account for a flurry of activity around prizes in the last 20 years (Table 2.1). For example, McKinsey & Co. estimates that that sector may be worth as much as $2 billion if rewards offered by all types of prizes are included. Inducement prizes (with a number of targets, including technology development) are those that have grown the most since 1991, offering rewards for about $236 million between 1991 and 2007 (McKinsey & Company, 2009). Scholars also note that increasing activity in technology prizes, with at least 38 innovation inducement prizes since 1990 (KEI, 2008; Masters & Delbecq, 2008). That activity includes part of the early U.S. federally-funded prizes, with 14 competitions already organized by different federal agencies (Stine, 2009).

Except for the list of federally-funded prizes (which is limited to U.S. government prizes) the other lists do not have extensive coverage and prizes are not systematically categorized. The top technology areas of prize implementation vary depending on the data source. Aviation/aerospace, climate/environment, and medicine are among the top areas. Other areas include transport (e.g. automotive,) energy, defense, computing/software, and chemistry. In spite of the variety of technology areas, a significant use of prizes in the aviation sector since the early 20th century, and in aerospace since the 1990s, suggests that prizes may be more effective in particular areas. The size of prize rewards varies considerably as well. Within the datasets reported in Table 2.1, the smallest technology development prize—excluding other forms of awards—was offered by the Dutch Society for the Encouragement of Agriculture for "extracting sugar from native plants" in the 18th century (less than $100,) and the largest was offered by Bigelow Aerospace for “transporting a 5-person crew into orbit for 60 days, twice” ($53 million, never claimed.)

Table 2.1: Prize datasets recently compiled by the literature

	Knowledge Ecology International (2008)	**Masters & Delbecq (2008)**	**McKinsey & Company (2009)**	**Stine (2009)**
Dataset content	204 awards and prizes	89 technology prizes	219 prizes worth $100,000 or more	14 U.S. federally-funded innovation inducement prizes
Coverage (years)	1567-2007	1567-2008	1769-2007	2004-2011
Rewards (cumulative total in parentheses)[a]	From $2.56 to proposal of $80 billion (>$80 billion)	From less than $50,000 to $53 million ($400 million)	From $100,000 to $30 million ($357 million)	From $250,000 to $10 million ($51 million)
Top technology areas (share of prize competitions in parentheses)	Medicine (18%) Aerospace (8%) Agriculture/food (8%)	Aviation (20%) Medicine (11%) Transport (10%)	Climate/Environment (11%) Medicine (9%) Aerospace (5%)[b]	Aerospace (43%) Energy (29%) Defense (14%)

Notes: a. total estimate rewards comprise amounts for each edition of recurring prizes but do not include commitments to purchase inventions (values are estimates in U.S. dollars for year of publication of dataset); b. non-technology prizes (e.g. arts, literature, etc.) are excluded.

Source: KEI (2008), Masters & Delbecq (2008), McKinsey & Company (2009), Stine (2009).

The context in which modern prizes are implemented is considerably different to the context of the early 18th century’s contests. Most importantly, recent successful prize competitions, including the X-prize series organized by the X Prize Foundation (XPF,) are organized by specialized organizations and have truly global participation enabled by the Internet and new communication means and virtual collaboration tools. The same technologies allow media coverage and increasing visibility for the competitions, the participants, and their sponsors. This has attracted both people interested in technical challenges and potential new sponsors (e.g. philanthropists, government agencies, corporate officials) interested in using prizes to meet diverse goals.

In the U.S., several federally funded innovation prizes have been authorized since 2003. These prizes have been aimed at inducing research, development, testing, demonstration, and deployment of technologies (Stine, 2009). For example, NASA's Centennial Challenges program has used prizes to attract new entrepreneurs to develop aerospace technologies commercially. The U.S. Department of Defense has used prizes to find innovative solutions in defense-related technologies, with, for example, the Wearable Power Prize to develop long-endurance, lightweight power packs for war fighters, and the DARPA Grand Challenges to develop autonomous ground robotic vehicles. The U.S. Department of Energy implemented the Bright Light Tomorrow Prize (L-Prize) competition to spur the development of ultra-efficient solid-state lighting products to replace the common light bulb. The U.S. Department of Health and Human Services has implemented prizes as well. Most of these prizes have offered cash rewards between $250,000 and $10 million to solve challenges broadly related to the agencies' missions.

Private companies also use prizes to improve their businesses or create prize-enabled enterprises. For example, the online Innocentive[1] and NineSigma[2] have created platforms where companies post prizes and communities of independent solvers work to find solutions and win cash rewards. Other examples are the $1 million Netflix Prize announced by Netflix, Inc. (the film rental website that offers recommendations based on what customers watch) in 2006 to improve its movie recommendation system; and the $250,000 Cisco I-Prize global innovation competition developed in 2010 to encourage collaboration among entrepreneurs and help in identifying new potential billion-dollar business ideas for Cisco.

Some private organizations have also been created specifically to administer prizes in the last 15-20 years. For example, the XPF is an educational, non-profit

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[1] http://www.innocentive.com
[2] http://www.ninesigma.com

corporation established in 1994 to inspire private, entrepreneurial advancements in space travel, and have sought to achieve such a mission by implementing prizes primarily with philanthropic support. This foundation organized the AXP with private, philanthropic sponsors, and NASA's NGLLC, both case studies of this research. Another non-governmental organization that has organized prizes is, for example, CAFE Foundation, which seeks to create and advance the understanding of personal aircraft technologies. Lately, this foundation has implemented the $1.65 million NASA-funded CAFE Green Flight Challenge for the development of quiet, practical, and green aircraft. CAFE Foundation has also organized some of NASA's Centennial Challenges prizes.

Reports and other works have attributed a variety of effects and technological impacts to prizes. For example, the DARPA Grand Challenge 2005 for the development of autonomous vehicles led to many technical accomplishments and remarkable improvement in several technologies related with autonomous driving (DARPA, 2006). NASA's Astronaut Glove Challenge 2007 for the development of spacesuit gloves induced technology commercialization when the winner started a company and gained a contract to provide gloves to a spacesuits manufacturer (Stine, 2009). The AXP for the development of a suborbital spacecraft induced a total R&D investment by all prize participants of about $100 million, which is ten times the cash purse (Newell & Wilson, 2005). The $1 million Netflix Prize announced by Netflix, Inc. formed a problem-solving community of more than 34,000 developers worldwide (McKinsey & Company, 2009). The Cisco I-Prize engaged 2,900 participants from 156 countries and received more than 800 new potential billion-dollar business ideas for Cisco (Cisco, 2010).

2.2 Types and structure of prizes

There are two types of prizes according to the achievement rewarded by prize sponsors. *Targeted prizes* reward the achievement of challenges in the form of performance standards that must be met to claim the prize. These prizes have discrete success, since there is (or there is not) achievement of the prescribed challenge and the characteristics of the achievement are more or less pre-specified by the prize rules. For example, in the recent AXP, the first participant to launch a reusable manned spacecraft into space twice within two weeks was declared winner of the prize. On the other hand, *blue-sky prizes* (usually referred to as *awards*) are open-ended prizes that reward achievements that were not identified in advance. In this case, achievement is a matter of opinion, since judges are allowed to know the winning achievement "when they see it." The Nobel Prize is a well-known example of these awards (Scotchmer, 2005; Masters & Delbecq, 2008).

This work focuses on targeted prizes that reward achievements associated with technological development (hereafter, "technology prizes") and their effects on innovation. Technology prizes are generally organized as competitions in which participants are asked to attain a *prize challenge* (PC.) The PC is defined in terms of the technological problem to be solved, the *deadline* to find the solution or prize expiration date, and, sometimes, the means to be used to solve the problem. The *prize sponsor* defines the PC according to its interest in meeting certain goals and offers what is generally a cash reward to the first participant to achieve that challenge. Modern technology prizes generally have *sponsors* that contribute the cash purse and *organizers* that manage the competition. They may be individuals, private organizations, government agencies, or groups thereof. The sponsor and the organizer are the same entity in some cases. Otherwise indicated, this research refers to both indistinctively. The PC also links the prize competition with certain technological fields and/or market segments and represents a technological gap that has to be reduced or closed by the participants. If no entrant achieves the PC, the prize expires and the sponsor does not have to pay the reward. *Prize entrants* or participants are generally organized as teams of diverse composition and may include companies, universities, entrepreneurs, or simply individuals attracted by the prize.

Technology prizes can be structured and classified according to different criteria. This research refers to the classifications based on the following criteria:

- Required technological output:
    - *Prizes for technology demonstration* that explicitly require building and demonstrating capabilities of a technology (e.g. NGLLC, AXP)
    - *Prizes for technology-based achievements* that involve using unspecified methods to accomplish a feat or perform certain functions (e.g. GLXP.)
- Way to find the winner:
    - *First-to-achieve prizes* that define the challenge as a concrete technological goal that entrants have to achieve before the deadline to be eligible to claim the cash purse. The first entrant to achieve the challenge is considered the winner.
    - *Best-in-class prizes* that define the challenge as a set of minimum standards of performance that entrants have to attain to be eligible to claim the cash purse. In this case, the winner is the entrant that performs the best according to those standards. In best-in-class prizes, there is typically a "race" in which all participants come together to compete for the cash purse. In this case, the PC may also be defined as a set of intermediate milestones or qualifying rounds to guide the effort of the participants and

allow only the most qualified entries to be selected for a final round. If no participant achieves the minimum standards required by the sponsor in that final event, the prize is considered expired.

- Number of awards:
  - *Winner-takes-all prizes* that award all the prize money to the winner of the competition.
  - *Multi-prize competitions* that offer rewards not only for the winner but also to the runner-ups (e.g. 2^{nd} and 3^{rd} places.)

2.3 Prizes and other incentives for innovation

Prizes are only one of the approaches used to stimulate technological innovation. Other much more widely utilized incentives include the patent system, research grants, and R&D contracts. Indeed, most of our understanding of prizes is based on intuitive comparisons of prizes with those instruments and theoretical analyses to find what the optimal incentives are under certain circumstances. Little empirical evidence and some anecdotal accounts from recent prize experiences have also contributed to our understanding on this topic.

Much emphasis of the literature has been on the debate patents versus prize rewards because the latter, theoretically, may be able to solve one of the main defects of the patent system. The patent system grants inventors exclusive intellectual property (IP) rights on their inventions and makes them monopolists. The problem with the monopoly pricing is the deadweight loss that occurs when patent owners set prices above the marginal cost and produce less than the socially desirable output (Polanyi, 1944; Abramowicz, 2003; Scotchmer, 2005). In theory, prizes can reduce or eliminate that deadweight loss by, instead of granting rights, awarding innovators with an amount of money equivalent to the social value of the innovation and requiring them to place their technologies in the public domain. This suggests that prizes may be more effective in areas where the social losses due to intellectual property rights are likely to be high (such as in the development of pharmaceuticals, computer software, and recorded music and visual products) (Shavell & van Ypersele, 1999) or where patents are expected to substantively distort cumulative innovation (Williams, 2010).

Both prizes and patents reward innovators for their research outputs, yet present four important differences in their practical application (Davis, 2002). First, prizes encourage the development of specific technologies that satisfy the requirements of the sponsor and innovators bear the initial costs and risks of R&D. Patents, contrarily, incentivize innovation indirectly as innovators decide what to invest in according to their private information and assessments, being punished by markets if they do not invest in the most valued technologies (Wright, 1983; Gallini & Scotchmer, 2001). Second, prizes give innovators limited development lead times when the sponsor sets a specific prize deadline to find a technical solution to the prize challenge. In the patent system, companies control the lead times of their R&D activities and strategically advance or postpone deadlines if necessary. Third, the prize reward is a fixed amount of money generally awarded to the winner of the competition and its value is linked to the goals of the sponsor and not necessarily to the market value of the technology. The winning entry does not need to be the best available technical solution or the most affordable. On the contrary, the value of patents is linked to the commercial merit of the technology and the ability of the inventor to introduce the new technology in the market. In other words, the test of the new technology is performed in the market and not by the sponsor according to its requirements. Fourth, the role of prizes is limited to incentivizing the development of technologies chosen by the sponsors. The patent system is a more complex, decentralized decision-making system in which inventors decide based on their private information and a coordination mechanism that signals the location of competences, eases technology trading, and helps inter-firm collaborations (Penin, 2005).

There are also important differences between prizes and research grants. First, while prizes reward innovators for their research outputs, grants pay for research inputs. Prize sponsors pay only for research results in the technological field of their choice (i.e. the prize originates with a specific need,) independently of the cost of R&D activities of inventors or researchers. Contrarily, the grants scheme operates as a self-selection system whereby researchers propose ideas to invest in and the funding agency decides whether to fund them. Second, prizes generally do not require the pursuit of any specific approach to achieve the prize challenge, which allows introducing novel approaches and technological solutions. Research grant administrators are required to choose between different methods for achieving a particular goal, even when that includes the possibility of excluding nontraditional approaches (Kalil, 2006). Moreover, grant proposals generally describe the expected output of the research whereas prizes do not anticipate what the ultimate characteristics of the winning entry are. Third, prize entrants are only paid upon the achievement of the challenge and, thus, bear the financial and R&D risks of their activities. Prize sponsors do not need, in principle, to monitor the activities of those that enter the competitions. Contrarily, grants provide researchers with upfront funding and the grant giver generally assumes the R&D risks. Moreover, there may be a moral hazard problem as grantees' effort cannot be costlessly monitored.[3] Both grants and prizes are similar in the sense that non-monetary incentives operate behind both types of mechanisms. As science grows and professionalize, its reward system has become more elaborated and honorific rewards (including peer recognition and awards) have become increasingly important as well (Merton, 1973). Similarly, as discussed in the

[3] However, future grants are contingent on previous success and, therefore, grantees have to be honest about their ideas and perform as proposed (Gallini & Scotchmer, 2001).

following paragraphs, prizes offer non-monetary incentives such as reputation and publicity for their participants.

Prizes also work significantly different from R&D contracts. First, contracts establish *ex-ante* purchase conditions for the innovator that is chosen to procure R&D whereas prizes only offer a fixed cash reward to the winner. Second, while prizes make entrants to bear R&D risks, contracts typically stipulate terms that promote risk sharing between buyer and contractor. That risk depends upon the uncertainty that each project faces, which gives origin to different types of contracts (Samuelson, 1986).[4] Third, ideally, contracts require the buyer to be able to monitor R&D costs or innovation efforts which is costly in practice. Moreover, when external monitoring is difficult, there are fewer incentives for cost control by researchers (Wright, 1983; Rogerson, 1994). This gives advantage to other more decentralized incentives such as prizes, in which the sponsor focuses on the achievement of the challenge and not on the method to achieve it. Defense procurement has traditionally been one of the main applications of R&D contracts.

Similarly to prizes, R&D contracts are competitive when they include an initial phase of prototype competition and/or pre-selection.[5] However, competition in R&D contracts is sometimes limited to design proposals and, only depending on the program, competitors are asked to submit detailed studies or working prototypes (Rogerson, 1989). Contracts may not be efficient when it is difficult for the buyer to distinguish between high- and low-cost R&D performers on the basis of bids or costs submitted in the competitive phase. In this regard, prizes and contracts are similar as none of them guarantee that the superior idea, the most affordable product, or the technology with the largest commercial merit is actually chosen (Scotchmer, 2005).

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[4] For example, cost-plus-incentive-fee contracts are more likely to be used when uncertainty is high, while fixed-price contracts are more likely to be used when uncertainty is low (Anton & Yao, 1990).
[5] For example, there has been U.S. Air Force defense contracts organized in three-step processes comprising proposal (including bid for initial production,) pre-selection and prototype competition, and final selection and production (Rogerson, 1994).

These incentive mechanisms for innovation are optimal only under certain conditions. Among the most notable works discussing this aspect are those by Wright (1983), de Laat (1997), Shavell & Ypersele (1999), Scotchmer (1999), and Newell & Wilson (2005). Wright (1983) maintains that it is only exclusively private information of researchers what affects the optimal choice between incentives and that the potential advantages of prizes—compared to patents and research contracts—can be better appreciated in areas where the supply of research is inelastic and there are intermediate success probabilities of research projects. de Laat (1997) arrives at a similar conclusion yet maintains that information asymmetries about markets can only be used to justify patents—rather than prizes—when the R&D process is sufficiently competitive. Shavell & Ypersele (1999) maintain that intellectual property rights do not possess a fundamental social advantage over reward systems and that an optional reward system under which innovators choose between rewards and intellectual property rights is superior to only intellectual property rights. Scotchmer (1999) argues that it is optimal to grant patents in exchange for a fee—rather than using prizes—when sponsors do not have complete information on the benefits of the innovation because, by that means, the value of the reward is linked to its potential market value. Finally, assuming complete information about costs, benefits, and probability of success, Newell & Wilson (2005) maintain that prizes, compared to other mechanisms, change the profits maximization function of firms and can induce different levels of research investment, offering an alternative option to policy-makers to produce the optimal amount of research.

There are multiple other developments that are generally ignored and can enhance that theoretical debate over the optimal choice of incentives under certain circumstances. For example, while at the core of the comparison of prizes with patents is the choice of the inventor based on private or public information, empirical research has found that firms commonly rely on secrecy—and not patents—to protect their technologies (Levin et al., 1987; Cohen et al., 2000). In those cases, factors other than the information on markets and research costs would have to explain the decision to enter prize competitions. Moreover, there are recent works that challenge the mainstream prizes-patents comparison that assumes that firms use the patent system only in order to be granted a short-term commercial monopoly rent. For example, Penin (2005) argues that in many industries most firms also use patents as strategic devices to trade technologies and to ease R&D collaborations, which suggests additional considerations in the patent-prizes debate.

In addition, scholars and commentators have suggested intuitively a number of factors that can make prizes more effective tools to promote innovation. For example, Mowery et al. (2010) argues that prize competitions must specify precise output or performance targets to be effective and fair, and that the ability of entries in any competition to meet these targets must be readily verifiable, which may not be possible in some technology fields with diverse technologies and applications. Masters & Delbecq (2008) suggest that timing is key to the impact of prizes as technological progress changes achievable possibilities, and socioeconomic conditions influence the desirability of those possibilities. Kalil (2006) suggests that prizes have to posit achievable yet difficult goals to be able to induce innovation. Newell and Wilson (2005) maintain that successful prizes have to offer a clear measure of success or target in a field where achievement is desirable but measurement had been lacking.

2.4 Prizes and S&T and innovation policy

Lately, there was much increased interest in the use of prizes by governments, to promote innovation or pursue other related goals. A number of studies have addressed the use of prizes in the U.S. government since the late 1990s, such as those by the National Academy of Engineering (NAE, 1999), the National Research Council (NRC, 2007), the

Congressional Research Service (Stine, 2009), and the author of this research (Kay, 2011). Academic research has also contributed some theoretical insights in this regard.

There are certain advantages of prizes that attract policy makers and prize advocates. First, theoretically, the financial risk of the R&D activity in prizes rests with the competitors and their financiers as the monetary reward is only paid if there is a winner that achieves the proposed target. In conventional instruments such as R&D contracts and grants, that financial risk rests largely with the taxpayers when the R&D activity is publicly funded. Second, prizes can reduce the bureaucratic and accounting barriers to entry that accompany the grant and contracting processes and allow smaller players to enter the R&D arena (Newell & Wilson, 2005). That can be a great advantage for the introduction of novel methods and R&D approaches because smaller participants are likely to be less risk-averse than institutionalized competitors and pursue more technologically radical concepts (Nalebuff & Stiglitz, 1983). Third, prizes may prevent distortions in R&D spending caused by, for example, lobbyists in R&D contracts if they are properly implemented and result in fair and transparent competitions (Cohen & Noll, 1991). Fourth, prizes might be effective to target a full range of scientific and technological goals, including research, development, testing, demonstration, and deployment (Stine, 2009). Fifth, prizes may also target broader social and economic goals beyond technological development (NAE, 1999; NRC, 2007). For example, prizes may engage different social groups, including underrepresented groups, for training within a competitive environment. Competitions may also advance technologies while having significant economic development impact by creating jobs and new businesses.

There are other considerations that suggest a word of caution about the use of prizes in government. Most importantly, governments may lack information on the benefits or feasibility of inventions before they have been invented, which makes difficult the crafting of prize challenges and the calculation of monetary rewards (Kremer, 1998). This increases the risk of program failure because the more difficult to describe or measure objectively the innovation to identify the reward recipient, the more difficult to enforce the prize (Che & Gale, 2003; Newell & Wilson, 2005). A very instructive historical example is the Longitude Prize, implemented by the British Parliament in 1714 for the development of a method to measure longitude at sea. The inventor that built a technical solution was ultimately awarded the prize, yet the scientific committee created to evaluate the innovation failed to judge it opportunely and objectively and, therefore, the reward was paid late and only partially (Sobel, 1996). Moreover, this uncertainty on whether the prize will ultimately be awarded—for reasons such as bureaucracy, budget cuts, or changes in administration—may weaken, if not eliminate, the incentives to compete (Macauley, 2005). This may also limit the scope of technological targets of government prizes as prizes with longer lead times are likely to introduce more uncertainty. On the other hand, while R&D grants and contracts provide funding up-front to support early stages of technology development, prizes only reward the innovator upon the achievement of the prize challenge and, hence, create a barrier for small teams willing to participate. Finally, the most efficient use of funding has to be considered in prize programs. The administration of prize programs may cost several times the amount of the cash purse. For example, the total funding available for the DARPA Urban Challenge 2007 was $24 million: $12 million for the competition (including $3.5 million in prizes) and $12 million in seed funding to support a few qualified teams. Excessive budgets to fund experimental prize programs may lead to their termination. Potential solutions to this include alternative cost-bearing structures to alleviate the burden of costly programs. For example, agencies may partner with other organizations to have their prize programs administered at no cost, which is the case of NASA's NGLLC. Moreover, recent legislation authorizes government agencies to accept external funds for cash prizes from other agencies or private organizations (Kay, 2011).

The lack of empirical evidence and the short experience with government-sponsored prizes emphasizes the need for further research to inform the decision of using prizes versus other incentives and the implementation of more efficient prize programs. To date, government prizes represent only a small share of the government's efforts to promote R&D and innovation. In the U.S., federally-funded technology prizes represent only about 0.05 percent of the federal R&D spending and about 0.5 percent of the federal tax preferences granted for R&D (Figure 2.1).[6] Compared to industry's R&D expenditures, the amount of rewards in government prizes is insignificant as well. Sill, these government prizes represent about 20 percent of the total prize rewards offered since 2000.

In the U.S., the federal government enacted new legislation in 2010 to support the use of prizes by federal agencies and launched the Challenge.gov online platform with prizes offered by more than 20 departments and agencies of the federal government. As of January 2011, there were over 55 announced competitions on that platform, with prize rewards that range from relatively small amounts of money ($200) to large amounts of money ($15 million) (see Table 2.2 with examples.) The America COMPETES Act has provided all U.S. federal agencies with broad authority to conduct prize competitions and includes provisions for different aspects of prize design, implementation, and oversight. This Act authorizes the use of prizes for one or more of the following: find solutions to well-defined problems; identify and promote broad ideas and practices and attract attention to them; promote participation to change the behavior of contestants or develop their skills; and, stimulate innovations with the potential to advance agencies' missions. The legislation also allows agencies to enter into agreements with private, nonprofit entities to administer a prize competition, and requires reporting prize activity for each fiscal year.

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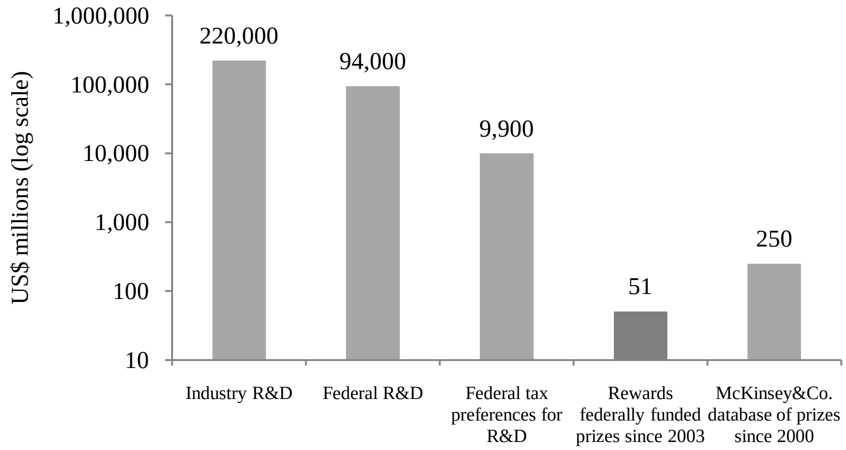
[6] The research and experimentation tax credit provides an incentive to undertake new research by giving firms a credit for expenses related to those new activities against the taxes they owe. In addition, R&D expenses that are not covered by the credit can be fully deducted from income as a business expense when incurred (CBO, 2007).



Notes: industry and federal R&D spending as of 2006; federal tax preferences for R&D are an estimate of forgone revenues for 2006 (CBO, 2007); total rewards of federally funded prizes is an estimate shown as benchmark, for all prizes of this type since 2003 until today (Stine, 2009), and do include competitions that offer procurement contracts as reward; McKinsey & Co. database of prizes is available in McKinsey & Company (2009).

Sources: NSF Science and Engineering Indicators 2008, otherwise indicated.

Figure 2.1: Amount of U.S. federally-funded prize rewards compared to U.S. R&D spending, R&D incentives, and total philanthropic prize rewards.

Table 2.2: Recent prize competitions posted on Challenge.gov (selected examples)

- **The Bright Tomorrow Lighting Prize ($15 million):** Sponsored by the U.S. Department of Energy, the L Prize competition is aimed to substantially accelerate America's shift from inefficient, dated lighting products to innovative, high-performance products. The L Prize is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency solid-state lighting products to replace the common light bulb.
- **The Progressive Automotive X Prize ($10 million)**: The U.S. Department of Energy, Progressive Insurance, and the X Prize Foundation partnered to sponsor this prize, which was awarded in 2010. The goal of the prize was to inspire a new generation of viable, super-efficient vehicles that help break our addiction to oil and stem the effects of climate change. A project of the X Prize Foundation, the Progressive Automotive X Prize was an independent, technology neutral challenge for teams from around the world to compete in a multi-stage competition to produce clean, production-capable vehicles that exceed 100 miles-per-gallon energy equivalent (MPGe).
- **The Strong Tether Challenge ($2 million):** NASA sponsors this challenge in materials engineering as part of its Centennial Challenges. The tether developed by each team is subjected to a pull test and, in order to win the $2 million prize, the tether must exceed the strength of the best available commercial tether by 50 percent with no increase in mass. A tether that can win this challenge would be a major step forward in materials technology. Such improved materials would have a wide range of applications in space and on Earth.
- **The Nano-Satellite Launch Challenge ($2 million)**: Another NASA Centennial Challenges prize competition is to deliver two small satellites to Earth orbit in one week. Objectives of the competition include: a) safe, low-cost, small payload delivery system for frequent access to Earth orbit; b) innovations in propulsion and other technologies as well as operations and management for broader applications in future launch systems; c) a commercial capability for dedicated launches of small satellites at a cost comparable to secondary.

Source: Challenge.gov

CHAPTER 3

RESEARCH QUESTIONS AND HYPOTHESES

3.1 Incentives and motivations of prize entrants

The discussions on the motivations to participate in prizes are generally focused on the incentive provided by the monetary reward. In the scholarly literature, the calculation of a usually unique, appropriate reward has generally risen to the forefront. The analyses suggest that there is no accurate formula or algorithm to translate the theoretical concepts of private and social value of research and innovation into monetary amounts to determine prize rewards (Wright, 1983; Kremer, 1998; Shavell & van Ypersele, 1999; Abramowicz, 2003; Maurer & Scotchmer, 2004; Scotchmer, 2005; Wei, 2007).

Theoretically, rewards should reflect the social value of the invention. Prize sponsors would prefer to pay only up to that amount if R&D costs were observable, but it is generally difficult for sponsors to observe and/or determine both the social value and the costs of R&D (not only for prizes but for other incentives as well.) Moreover, government and philanthropic sponsors are less likely to have information about the value of research and innovations than researchers and companies. Governments might have a better estimate of the social value only in certain cases that make prizes preferable to patents (e.g. when the social benefits of new medicines are known.) Non-optimal prize rewards have various effects. If the reward is lower than the social surplus created by the invention, the incentive to invest in R&D would be inadequate and inventors would not be willing to compete for the prize. A very low reward may not even cover the costs of

R&D. If the reward is equal to or exceeds the social surplus, the excessive incentive to invest in R&D would lead to inefficient duplication of investment.[7]

The literature has also discussed alternative rewarding schemes to address those issues related with information asymmetries in the use of prize incentives. To find optimal types of incentives, scholars have suggested, for example, schemes whereby the winner chooses between a monetary reward or a patent (Shavell & van Ypersele, 1999), a patent buy-out mechanism to harness private information on the market value of inventions (Kremer, 1998), and a prize reward conditional on a verifiable performance standard of the invention (Scotchmer, 2005). Some of these solutions had positive effects on innovation when implemented in the past. For example, Kremer (1998) mentions the case of the Daguerrotype patent, purchased and placed in the public domain by the French government in 1839. This led to a worldwide adoption and innumerable technical improvements on that photography system. Other economic works have investigated what the optimal rewarding schemes are to make prizes efficient. For example, in competitions with elimination stages, Rosen (1986) maintains that a distinguishable, large first-place prize is required in competitions with elimination stages to induce competitors to aspire to higher goals independent of past achievements. In multi-prize contests (i.e. with first- and second-place prizes,) Moldovanu & Sela (2001) argue that the optimal-prize structure depends on the cost function of the prize entrants and that the right proportion between prize values depends on the number of entries, the distribution of abilities in the population, and the curvature of the cost function of entrants as well.

Lately, a number of works—a few of them empirical—examined and brought the attention to non-monetary incentives offered by prizes. For instance, in the empirical examination of the Royal Agricultural Society of England (RASE) prizes offered between 1839 and 1939, Brunt et al. (2008) found that a prestigious gold medal had

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[7] Overinvestment in innovation from the social welfare point of view may exist with other incentives as well, when for example competing firms try to get ahead of one another’s innovation programs (Dasgupta & Stiglitz, 1980).

greater entrant effect than cash rewards and that competitors viewed annual exhibitions of inventions as a powerful form of advertising. The same study found that cash rewards covered only around one-third of the total cost of the inventions exhibited by successful prize entrants, reinforcing the idea of the presence of other motivations. On the contrary, in his investigation of the Royal Medals of the Royal Society of the 19th and early 20th centuries, MacLeod (1971) concludes that the medals induced competition yet, rather than encouraging fresh scientific discovery within British science as originally planned, became a highly subjective means of personal recognition and legitimization of scientific paradigms. Moreover, MacLeod also concludes that medals had to be combined with financial stipends if they were to be successful incentives for scientific discoveries. From their case studies of 20th century prizes, Davis & Davis (2004) conclude that reputation, credibility, and visibility alone can provide the economic justification for a sponsor to design the contest and for contestants to enter. They also suggest that learning through technology spillovers and best practices diffusion is another potential motivation to participate in prizes. Also Davis & Davis (2004) and Saar (2006) found that the potential market value of the prize technologies were a strong motivation for entrants in case studies of 19th and 20th century technology prizes. Several other scholars also suggest the existence of those non-monetary incentives (Maurer & Scotchmer, 2004; Schroeder, 2004; Kalil, 2006; Anastas & Zimmerman, 2007; Culver et al., 2007). In addition, other works suggest that prizes can reduce bureaucratic and accounting barriers that accompany typical grant and contracting processes and thus attract smaller firms or independent researchers, for example. Most importantly, some argue, the openness of the prize process may allow the participation of *unconventional innovators*, i.e. individuals and organizations that are not generally involved with the development of the prize technologies and use non-traditional approaches to pursue the prize challenge (see, for example, Schroeder, 2004; Newell & Wilson, 2005; Culver et al., 2007). Finally, in concordance with the literature, direct observation of recent prize competitions have allowed program managers to identify cases in which the costs of development by prize entrants exceeded the cash purse considerably (see, for example, Davidian, 2007), calling into question the importance of the monetary reward and suggesting the presence of other types of incentives.

Certainly, there may be cases in which prize entrants are not aware of the theoretical private/social benefit concepts addressed by economists in the study of incentive mechanisms. For instance, scientists or engineers that participate in prizes are unlikely to make their decisions about participation based on those terms and, instead, possibly focus their evaluation on other personal or professional aspects such as professional career, personal finances, and/or other personal achievements. Even the exclusive consideration of monetary incentives may be misguiding in the interpretation of the primary motivations of entrants. For example, Paul MacCready, aeronautical engineer, decided to compete in (and ultimately won) the Kremer Prize of 1977 because he owed money for exactly the reward amount. In a later account, he explained:

> "*I did recall, with no special emphasis, this £50,000 prize that Henry Kremer had put up 17 years earlier. And then, one day I happened to notice that at that time the pound was worth just two dollars. Suddenly, this great light bulb just glowed over my head: the prize was $100,000, my debt was $100,000. There just may be some interesting connection between these two. So my interest in human-powered flight zoomed up to high level, and I fussed away at it, and eventually it worked."* (Academy of Achievement, 1991)

This research investigates the types of incentives offered by prizes and seeks to understand how different types of incentives weigh in the overall motivation of different types of prize entrants. A better understanding of these topics may have at least three important implications. First, new evidence on the perception of incentives would allow a better understanding of prizes as a phenomenon that may include features that cannot be analyzed in economic terms. Second, empirically-based understanding on the actual incentives perceived by entrants would be able to inform more precisely the process of implementation of prize competitions and, particularly, the process of calculation of the monetary and the design of non-monetary rewards. Third, a better understanding of how different types of entrants respond to different types of incentives would shed light on what types of prizes are better at attracting specific groups of individuals and organizations or creating problem-solving communities.

Question 1: *How do different types of incentives weigh in the overall motivation of different types of prize entrants?*

This research introduces two assumptions that include general classifications of incentives and entrants to be able to respond Question 1 (Q1.) The first assumption is that there are at least two types of incentives: a) *prize incentives* (PIs) defined as those that are offered exclusively by the competition and would not exist if the prize was not announced; and b) *technology incentives* (TIs) defined as those that are linked to the value of the prize technologies. By definition, PIs can be set by the sponsor with certain precision to produce the desired effects. They include, for example, monetary incentives (e.g. cash prizes or bonuses) or non-monetary incentives (e.g. prestige, publicity, or reputation for prize entrants.) Technology incentives are linked to the market value of the prize technologies and/or the benefits for the entrants of introducing the prize technologies for own use. These include, for example, potential revenues from commercialization of the technologies or cost savings obtained by the exploitation of the technologies in own performance improvement. This research considers that the prize announcement does not affect the market value that the prize technologies may have. The second assumption is that there is a group of entrants not generally involved with the development of the prize technologies and can be classified as *unconventional*. The opposite group, *conventional entrants*, comprises those individuals and organizations generally involved with the development of prize technologies. In this research, the attribute that defines such involvement is the industry experience that individuals and organizations have with the prize technologies. In the case studies examined by this research, groups of individuals with significant experience working for space industry/agencies are considered conventional entrants. The rest of the prize entrants are considered unconventional.

There are at least two main potential explanations for the relationship between types of incentives and type of entrants. In the first explanation, prize entrants factor out only the cash purse offered by the prize to decide their participation. This alternative—which resembles a simplified version of economic modeling—assumes that would-be entrants evaluate the prize money and the risks of prize participation, compare them with alternative strategies based on their private information, and only enter the competition if they foresee a profit. In the examination of how different incentives weigh in the decisions to compete, this alternative represents a null hypothesis as only one type of incentive is perceived and no variation would be measured. The second explanation—a richer elaboration that includes other insights from the literature—posits that would-be entrants have unique characteristics that affect their perception of both monetary and non-monetary incentives. For example, individuals not generally involved in technology development may perceive in prizes the opportunity to participate and learn, an opportunity that they would not otherwise have access to. Other individuals and organizations already involved in technology development may perceive in prizes the opportunity to create synergies with their ongoing activities and use their expertise to win the prize simultaneously with the development of valuable technologies for their own projects.

Hypothesis 1 (H1) adopts the perspective of the second explanation and posits that there exists a relationship between types of incentives and types of entrants. It anticipates that, for any given technological field and its general context, more significant prize incentives are more likely to attract unconventional entrants and more significant technology incentives are more likely to attract traditional entrants.

Hypothesis 1: *For any fixed technological field and its general context, more significant prize incentives (PIs) are more likely to induce the participation of unconventional entrants and more significant technology incentives (TIs) are more likely to induce the participation of conventional entrants.*

3.2 Prize R&D activities

In technology prizes, entrants have to perform some type of R&D activities to achieve the challenge before the prize expiration date. Our understanding of the organization of those activities is mostly intuitive and limited to very general—though still instructive—characteristics of R&D. Prizes are not only instances of competition but also cases of collaboration and communication. Awards in general—not only technology prizes—may serve the function of what economists call "communication," as they bring disparate players into informed contact with one another so that mutually beneficial transactions occur among them (English, 2005). Simultaneous competition and collaborations between problem solvers have been also found to be key for individual innovators to succeed in recently launched virtual online prize platforms (Bullinger et al., 2010; Hutter et al., 2011). This phenomenon of competition and formation of research communities to advance specific technologies and solve concrete technical problems has been also observed in recent competitions such as the DARPA Challenges and the Netflix Prize (DARPA, 2006, 2008; McKinsey & Company, 2009). These prize communities may benefit from the participation of unconventional entrants and small players that are less risk-averse and more likely to pursue technologically radical concepts than institutionalized competitors which generally compete for grants and contracts (Nalebuff & Stiglitz, 1983). The open environment provided by prizes for innovation may be also able to encourage unconventional partnerships between entrants and other entities and contribute new ways to organize R&D (Culver et al., 2007).

On the other hand, much was discussed about the ability of prizes to induce R&D effort and leverage investment. Theoretically, larger prize rewards may lead to more vigorous R&D races and shorter achievement times for technology development considering that performers start from similar position (Grishagin et al., 2001). Some argue that ex-ante fixed rewards, deadlines, and technology specifications have the potential to induce very focused R&D efforts (Newell & Wilson, 2005). The flip-side of the increasing activities is the potential duplication of R&D when prizes engage large numbers of participants because there tends to be only a finite number of innovative ideas for any given technology problem at a given time (Maurer & Scotchmer, 2004; Newell & Wilson, 2005). In the same vein, some maintain that free entry to competitions is not optimal and that entrants have to be taxed with an entry fee. Otherwise, the individual R&D effort of prize entrants would weaken when there is an increasing number of competitors as entrants perceive fewer chances to win the prize (Taylor, 1995; Fullerton & McAfee, 1999). There is also some empirical evidence of the ability of prizes to leverage funding. For example, Brunt et al. (2008) found that monetary rewards only offset one-third of the costs of technology development in RASE prizes. Schroeder (2004) estimates that the AXP induced an investment from entrants 40 times the size of the cash purse, and that the DARPA Challenges induced investments up to 50 times the size of the cash purse. Recent prize experiences such as the NGLLC may have also shown that prize entrants spend several times the cash purse to achieve the prize challenge (see for example Davidian, 2007).

The interest in the organization of R&D activities in prizes has been raised by the exceptional performance of entrants in recent prize competitions. These entrants have had significant technological achievements with low budgets and, sometimes, no previous experience in the field. For example, there is Armadillo Aerospace, from Mesquite, Texas. This team was created in 2000 by a small group of mostly IT professionals to enter the AXP to develop a suborbital spacecraft. The team also entered the NGLLC in 2006 to develop vertically take-off and landing rocket vehicles. The team spent at least $3.5 million in its R&D program—much less than similar space programs—and won two prizes for $850,000 (Armadillo Aerospace, 2008). In those competitions, the team introduced sophisticated computer controls for its vehicles and contributed to establish new standards of reusability, operation, speed of development and efficiency (NASA, 2009b).

To the author's knowledge, the unique characteristics of those prize R&D activities and the extent to which they differ from traditional industry practices have not been investigated. There are at least three basic characteristics of prizes that can be examined to gain insights into this topic. First and foremost, prizes generally do not provide up-front funding to perform R&D. That might create conditions that differ from R&D undertaken in procurement contracts, research grants, or even corporate new product development, which generally do have some (or all) funding up front to perform R&D. This should be particularly relevant for some technological challenges that require significant funding and access to expensive facilities or equipment for their achievement. Yet, on the other hand, prize entrants are likely to focus their effort on a single and discrete goal instead of having to pursue a continuous activity with multiple projects or customers and maintain a considerable industry-like infrastructure, which ultimately may allow implementing less costly R&D organizations.

Prizes also pose strict deadlines to come up with a technological solution. Deadlines and shorter lead times are not an exclusive feature of prizes since time is generally considered a key resource for R&D teams working in all competitive environments (Waller et al., 2001). However, deadlines may be interpreted in two different ways: as the available time to achieve a specific goal, or as part of the overall goal that team members must work toward to achieve (Locke & Latham, 1990; Karau & Kelly, 1992). In prizes, by definition, the deadline is part of the prize challenge and, thus, is defined by the sponsor at once for all entrants. In other words, to win the prize, entrants have to organize their activities to produce the technical solution within the given timeframe. In other contexts (e.g. commercial product development, procurement contracts) the R&D performer sets or negotiates deadlines and maybe even able to postpone based on its own strategies and/or available resources.

Last but not least, the often cited ability of prizes to induce R&D effort from unconventional entrants is also intriguing. These entrants comprise individuals and organizations that are generally not involved with the prize technologies and may bring unorthodox approaches and fresh ideas to the competition.

This research builds upon those basic features of prizes and literature insights to investigate the characteristics of prize R&D activities and their differences with traditional industry practices. New evidence on the nature of prize R&D activities can contribute significantly to better understand the ability of prizes to induce new, creative problem solving methods. Findings can also inform the process of implementation of prize competitions and, particularly, the process of calculation of rewards and definition of development lead times/expiration dates. For example, program managers may pose challenges that demand significant R&D effort yet, at the same time, allow longer development lead times to find more affordable solutions. Moreover, the understanding of how prize R&D is performed would shed light on what types of rules are the most adequate to induce, for example, certain technological outputs or approaches to produce them. Particularly interesting are the rules that regulate the use of public funding or allow hybrid approaches that include monetary rewards and seed funding to support entrants' R&D activities, both used in recent competitions (see, for example, DARPA, 2008).

Question 2: *What are the characteristics of prize R&D activities and how do they differ from traditional industry's R&D activities?*

The earlier discussion suggests that the lack of up-front funding—or, its counterpart, the R&D funding requirements—and the prize deadline may affect the peculiar characteristics of the prize R&D activities. While the deadline is inflexible and explicitly stated by the PC definition, the funding requirements are indirectly set by the PC and relate to the costs to provide a technical solution to the given problem. Therefore, both deadlines and funding requirements are parameters that sponsors may ultimately adjust when defining the PC to induce certain effects. Due to the lack of previous research, this research focuses intuitively on the impact that those parameters may have on three potentially unique characteristics of prize R&D activities: the designs introduced by entrants, the extent to which entrants draw upon existing technologies, and the overall organization of R&D collaborations. This focus is fairly generic to allow comparisons with other instances of R&D activity but also reasonably specific to allow operationalization and hypothesis probing.

Considerably short development lead times and the lack of up-front funding may become significant constraints in the competitive context of prize competitions. It is possible that entrants do not face such constraints and, therefore, these factors do not introduce significant differences between prize R&D and activities performed in other contexts such as corporate and government R&D. Yet, it is also plausible that these factors do affect prize R&D by different means. For example, the need for faster achievement times and the lack of funding may push entrants to introduce simpler technologies to be able to come up with solutions faster and at a lower cost. Furthermore, whenever is possible, entrants may shorten lead times and reduce costs by drawing upon/combining existing technologies rather than developing new technologies to achieve the prize challenge. If entrants cannot respond to time and funding constraints with alternative design criteria or using existing technologies, they may engage in increasing collaborative efforts that help in accomplishing the prize challenge.

Hypothesis 2 (H2) posits that there is that kind of relationship between time/funding requirements and the characteristics of prize R&D activities. It anticipates that shorter lead times and more significant funding requirements lead to simpler technological designs, more significant reliance upon existing technologies, and more collaborative R&D efforts. In this context, the definition of simplicity is associated with the number of parts and their interconnectedness in a technological system, i.e. simpler designs have fewer and less interconnected parts than complex designs. Existing technologies are those considered readily available, commercially or by other means. More collaborative efforts are those that involve an increasing number of actors (individuals and/or organizations) and relationships between them and the prize entrants.

Hypothesis 2: *For any fixed technological field, shorter lead times and more significant funding requirements posed by the prize lead to simpler technological designs, more significant reliance upon existing or standard technologies, and more collaborative R&D efforts.*

3.3 Prize technology outputs

Not much has been written about the quality of the Prize technology outputs (PTOs.) These are the technologies that entrants produce during the competition to achieve the PC. Entrants may start producing these outputs as soon as they enter the competition (or earlier if they have already ongoing projects) and in diverse forms such as designs, models, prototypes, and actual products or services. They may also use those technologies in their own projects or introduce them into new or existing markets. The winning entry is generally the most visible output of this type of prizes yet runner-ups and other participants may also contribute significant technological developments.

The advantages of prizes to advance technologies are also, in some cases, weaknesses of this type of instrument. Prizes may offer greater scope for unexpected solutions and for solutions arising from unexpected sources compared with conventional innovation policy instruments (Kalil, 2006). Some argue that that is the result of the participation of unconventional prize entrants which are more likely to introduce novel technologies and methods. Still, prizes may not be efficient to induce certain quality of technological outputs. That is, prizes cannot guarantee that entrants with the best ideas are motivated to participate or, if that happens, that the best idea is selected or implemented at the minimum cost. Moreover, strict technical specifications for the prize challenge may not tap all the creativity that is widely dispersed in the population (Scotchmer, 2005). In the same vein, there is the idea whereby prizes can be tailored to induce research effort but are often ineffective because it is difficult to anticipate in advance exactly what combination of ideas will be required to address a particular problem (Gans & Stern, 2010).

Prizes may also fail to produce technological results in certain circumstances. For example, strict technical specifications for the PC may prevent some significant—yet not up to the prize exact requirements—innovations to be rewarded, for which the sponsor may be still interested in paying, for example, a partial reward (Kremer, 1998; Masters & Delbecq, 2008). It may also occur that, in certain technological field, current-day capabilities, R&D costs, or both are not yet up to the requirements of the PC, in which case a prize may fail to find a winner (Macauley, 2005). On the other hand, given the sequential and cumulative nature of innovation, prizes may fail to induce subsequent superior inventions if the proper incentives are not offered (Gallini & Scotchmer, 2001). That relates with the ability of prizes to induce commercialization of technologies. Prizes may provide adequate incentives to make an invention occur, yet the invention may still never be applied or reach the market for commercialization if prize entrants only target the prize challenge and lack sufficient incentives to develop the invention commercially (Kieff, 2001; Wei, 2007).

The empirical evidence in this regard is also little. An early examination of prizes awarded by RASE in 1851 suggests that only two out of 170 awarded medals rewarded extraordinary novelty or utility (Sidney, 1862). A more recent study of prizes awarded by RASE between 1839 and 1939 found that prizes were correlated with patenting activity and had a large effect on the quality of the invention measured through patent renewal fees (Brunt et al., 2008). Case studies of prizes implemented during the 20th century show that competitions motivated inventors and stimulated innovations to achieve increasing performance goals in fields related with the prize technologies. Even when there was no immediate commercial gain, prizes were valuable to achieve the most efficient innovation outcome, improving designs that were not entirely new (Davis & Davis, 2004). Sponsors and commentators have also attributed positive effects of prizes on technology development. For example, the DARPA Grand Challenge 2005 for autonomous vehicles led to many technical accomplishments and remarkable improvement in several technologies related to the prize challenge (DARPA, 2006). The NGLLC has also induced the development of sophisticated instruments and the achievement of new standards of reusability, operation, speed of development and efficiency (NASA, 2009b).

This research investigates the characteristics of PTOs and their relationship with the characteristics of prize entrants and their R&D activities. A better understanding of this topic would help in understanding how innovation occurs in unconventional organizational settings—such as prizes—and as a response to diverse types of incentives. Moreover, concrete knowledge on the quality of the technological outputs induced by prizes, and the contribution of different types of entrants, would inform the process of prize design to implement competitions that are able to focus R&D processes to induce specific outputs or even commercialization. For example, program managers may target or restrict prize eligibility to specific research communities to induce specific outputs rather than having wide-open entry processes that motivates more entrants yet also increase the costs of operation of the prize program.

Question 3: *What are the characteristics of the prize technology outputs and how do they relate to the characteristics of prize entrants and their R&D activities?*

PTOs are technologies in different stages of development that result from the activity of prize entrants during the competition, ranging from ideas and concepts to successfully implemented devices or technological systems. A number of factors may affect the characteristics of the PTOs, including the attributes of the prize entrants and the resources available to them. The possibility of attracting unconventional entrants that may introduce fresh ideas and creative approaches to technology development makes the relationship between the quality of the PTOs and types of entrants relevant for this inquiry. This research maintains the assumption of the existence of a group of unconventional prize entrants to probe the contribution of individuals and organizations generally not involved with the development of the prize technologies.

To study the relationship between features of R&D activities and ultimate technological outputs, this research focuses on the design criteria and the relationship of the PTOs with current-day technologies. The degree of novelty and the actual implementation of the technologies are particularly interesting as both contribute to innovation. Innovation is defined as the creation and implementation of new or improved products, processes, or organizations (OECD/Eurostat, 1997). This research considers the degree of novelty to be relative to industry's current-day products, processes, and organizations, and it is measured in a scale that comprises current-day, derivative/improved, and breakthrough technologies. Using standard definitions, derivative/improved technologies are those more efficient or affordable versions of current-day technologies, while technological breakthroughs are those able to generate a paradigm shift in the science and technology and/or market structure of the industry sector (Garcia & Calantone, 2002). Implementation refers to commercialization of technologies—or services based on them—and use of the technology for own performance improvement (e.g. intent to win the prize.)

The concepts of novelty and technology implementation can be also linked to different Technology Readiness Levels (TRL) in engineering projects (Table 3.1). TRL levels are a systematic metric for technology maturity that allows the consistent comparison between different types of technologies (Mankins, 1995). Novel ideas and concepts are linked to research activities ("pure research") at low TRL levels; proof-of-concepts, tests, and capability demonstrations are linked to medium TRL levels; and the advancement of technologies for their actual deployment or commercialization are linked to higher TRL levels. Government agencies—including NASA—and major private companies use this measure to assess the maturity of evolving technologies such as materials, components, and devices prior to incorporating them into a system or subsystem (e.g. in space projects, TRL levels indicate the maturity of the technology in relation to being acceptable for launch or "mission-ready".) At the same time, TRL levels indicate the risk and/or uncertainty that the use of the technology involves (i.e. the lower the TRL, the greater the risk/uncertainty.) TRL levels do not correlate to any specific project management principle or guideline (Sauser et al., 2005). This research uses TRL levels as a reference to assess the contribution of PTOs to advances in the technological field.

Table 3.1: Technology Readiness Levels (TRL levels)

<table>
<tr><th>TRL Level</th><th>Definition</th><th>Phases</th><th>Activities to advance the technology</th></tr>
<tr><td>9</td><td>Actual system “flight proven” through successful mission operations (ground or space)</td><td rowspan="2">Production and deploy-ment</td><td rowspan="2">Implementa-tion</td></tr>
<tr><td>8</td><td>Actual system completed and “flight qualified” through test and demonstration (ground or space)</td></tr>
<tr><td>7</td><td>System prototype demonstration in a space environment (ground or space)</td><td rowspan="2">Systems de-velopment and demon-stration</td><td rowspan="4">Develop-ment</td></tr>
<tr><td>6</td><td>System/subsystem model or prototype demonstration in a relevant environment (ground or space)</td></tr>
<tr><td>5</td><td>Component and/or breadboard validation in relevant environment</td><td rowspan="2">Technology development</td></tr>
<tr><td>4</td><td>Component and/or breadboard validation in laboratory environment</td></tr>
<tr><td>3</td><td>Analytical and experimental critical function and/or characteristic proof-of-concept</td><td rowspan="3">Research and feasibility demonstra-tion</td><td rowspan="3">Research</td></tr>
<tr><td>2</td><td>Technology concept and/or application formulated</td></tr>
<tr><td>1</td><td>Basic principles observed and reported</td></tr>
</table>

Source: based on Mankins (1995)

In the consideration of the factors that may affect the degree of novelty and the actual implementation of the prize technologies, there is the appealing notion by which unconventional or new-to-industry entrants are more likely to introduce novel ideas and approaches as they draw upon knowledge, skills, and networks that are atypical for the prize technological field. Likewise, conventional entrants have access to knowledge, skills, and networks relevant to the prize technologies and may take advantage of those resources to improve technologies they are already familiar with and seek their implementation or commercialization through well developed industry networks. These potential explanations of the relationship between types of entrants and PTOs are only speculation as the literature does not provide further insights in this regard. A null relationship is also possible. For instance, unconventional entrants may come up with novel ideas yet also lack the skills or resources to further develop and introduce them. Moreover, those novel contributions may lack commercial merit if they are very unorthodox and represent a radical departure from traditional technology and business models. It is also possible that commercialization is not the main motivation of more conventional entrants to participate in prizes.

Hypothesis 3 (H3) explores that relationship between the characteristics of PTOs and the types of entrants. It anticipates that unconventional entrants are more likely to introduce more novel technologies and conventional entrants are more likely to advance more mature technologies for commercialization.

Hypothesis 3: *For any fixed prize challenge (PC) definition, unconventional entrants are more likely to introduce novel technologies and conventional entrants are more likely to advance more mature technologies for commercialization.*

3.4 The overall effect of prizes on innovation

There is much said about the virtues of prizes to induce multiple effects including technological innovation yet no significant empirical evidence has been contributed about their real effects. Most importantly, the literature is not precise on the nature of those effects and what their causal factors are.

In one of the earliest references of the academic literature to the potential of prizes to induce innovation, Michael Polanyi suggested that prizes may increase the amount of industrial research that is published (since industrial laboratories may become eager to claim potential rewards) and eventually contribute to some important technical innovation (Polanyi, 1944). It was only recently that scholars—and many commentators—started to elaborate on the potential of prizes to accelerate innovation or speed up development in certain technological fields (see, for example, Anastas & Zimmerman, 2007; Culver et al., 2007; Masters & Delbecq, 2008; McKinsey & Company, 2009). Today's mainstream discussion refers to the ability of prizes to mobilize participants, attract capital, induce focused R&D activities, raise industry and public awareness, and, remarkably, spur innovation. Others have suggested that prizes can also change the direction of the innovation pathway or "focus innovative efforts on problems for which solutions otherwise do not seem to be forthcoming" (Davis & Davis, 2004). Prizes may be also able to motivate the last effort to come up with a technical solution that was are already under development (Saar, 2006), be efficient instruments to induce technological breakthroughs (Mowery et al., 2010), and serve as an innovation catalyst by lowering entry barriers to markets and thus enabling the participation of a much more diverse range of players (Culver et al., 2007). The mere announcement of some historical prizes had induced considerable activity to find technical solutions to the prize challenge (see, for example, Sobel, 1996; Kessner, 2010).

Other sources maintain that the potential technology accomplishments induced by prizes may include new inventions, new applications, performance improvements, and technology diffusion (NAE, 1999). The effect of prizes may include both incremental and radical innovations. Some datasets of technology prizes suggest both improvements and technology breakthroughs in diverse technological fields, ranging from the creation of methods to preserve food in early prizes to the recent Ansari X Prize achievement linked to private commercial spaceflight, yet with more notable activity in the development of aviation/aircrafts (see, for example, Masters & Delbecq, 2008; McKinsey & Company, 2009). Based on its experience with prize organization, the XPF recommends that short-term prize competitions with relatively small rewards can be aimed at inducing incremental technological changes, and that medium- to long-term competitions with more significant cash purses can be aimed at inducing revolutionary changes and breakthroughs (Pomerantz, 2006).

The literature's discussion on the ability of prizes to spur innovation has developed much faster than the contribution of empirical evidence. Among the most notable empirical works is the work by Brunt et al. (2008) on the Royal Agricultural Society of England's prizes for the development of tools and implements for agriculture between 1839 and 1939. These authors found that those prizes influenced positively the direction of technological effort and its quality, as indicated by the increasing patenting activity for the prize technologies. Also Davis & Davis (Davis & Davis, 2004) found that prizes had an important role in the development of motorized flight, human-powered flight, and energy efficient refrigerators during the 20th century. Though in some cases prizes did not produce technologies with immediate commercial merit, they stimulated innovation in related technologies and contributed to the development of aviation-related industries. In his investigation of five case studies of 18th and 19th century prizes, Saar (2006) found that non-traditional, unexpected technical solutions were a common feature of those prizes and, in some cases, the winning entries were possibly under development when the prizes were announced. Interestingly, a very early account by Sidney (1862) points out that the Royal Agricultural Society's prizes studied by Brunt et al. (2008) did not have more effect than the traditional exhibitions and industry competitions and, generally speaking, prizes only misdirected the effort of people.

This research investigates the effect of prizes on technological innovation and seeks to understand how different causal factors weigh in such effect. This is the most relevant aspect of the study of prizes for at least two reasons. First, there has been much discussion about the virtues of prizes to advance technologies and spur innovation, yet there is almost no empirical evidence in this regard. Second, there is an increasing interest to make a more widespread use of this type of instruments to promote innovation and achieve other related goals. A better understanding of prizes and their technological effects based on empirical evidence and systematic examination can inform the decision to implement prizes in alternative circumstances and the design of more efficient prize competitions.

Question 4: *Do prizes spur innovation over and above what would have occurred anyway?*

While the use of counterfactuals has been generally criticized due to their alleged ambiguity, determinism, and problematic implementation, counterfactual conditionals contain causal implications and are always implicit or explicit components of the analysis of causality (Roese & Olson, 1995; Broda-Bahm, 1996). In practice, addressing a counterfactual question can yield a more enlightening debate and be effective to guide research inquiry aimed at uncovering the real potential of prizes to induce innovation. Undoubtedly, prizes do induce some type of R&D activity and may help in advancing technologies. The question is whether the same outcomes would be observed if the prize was not announced and only more traditional incentive mechanisms were used for technological development.

For analysts and commentators, the winning entry has traditionally been the demonstration of the ability of prize to induce innovation. This research maintains that the investigation of the effect of prizes on innovation has to examine not only the more visible outputs but also other developments of the competition, and consider them relative to their context. From this perspective, the winning entry in competitions speaks more about the winner's ability than about the real effect of prizes. Certainly, distinguishing what effects are truly induced by the prize or other contextual factors is an intricate task due to the specificity of each prize given by certain context or technological field, competition design, and prize participants. Our ability to gain a better understanding on the effect of prizes would be limited if no examination of both the dynamics of the competition and its context is performed.

This research anticipates that prizes do induce innovation over and above what would have occurred anyway. Though this may occur through diverse means, this research is interested in those effects that prize organizers are able to produce systematically by designing a prize competition with the expectation to produce certain outputs. In particular, this research focuses on two key parameters that sponsors are totally free to choose: the prize reward (or other prize incentives) and the definition of the prize challenge. The literature offers some insights that may explain a positive effect of those parameters on innovation. In principle, larger prize incentives are likely to attract more entrants and induce more intense competitions. Larger rewards also increase the chances of engaging unconventional individuals and organizations that introduce novel ideas if the definition of the prize challenge is sufficiently open-ended to allow alternative approaches to solve technological problems. Depending on the characteristics of the technological field, prize technologies may also be introduced in markets or used for alternative applications. On the other hand, though intuition suggests a role for those parameters, it may also be the case that there is no relationship between the prize incentives/challenge definition and innovation. For example, the incentive to innovate may be in the market value of the prize technologies and, therefore, prize participants enter the competitions to be able to realize such value, independently of the design of the competition.

Hypothesis 4 (H4) anticipates that prize innovation is the result of particular combinations of prize incentives and degrees of openness of prize challenge definitions.

This relationship is likely to vary between technological fields and conditions of the general context. This hypothetical relationship also assumes that the announcement of the prize does not have any effect on the market value of the prize technologies and, therefore, technology incentives remain constant.

> ***Hypothesis 4:*** *For any fixed technological field and its general context, more significant prize incentives and more open-ended challenge definitions are more likely to induce innovation.*

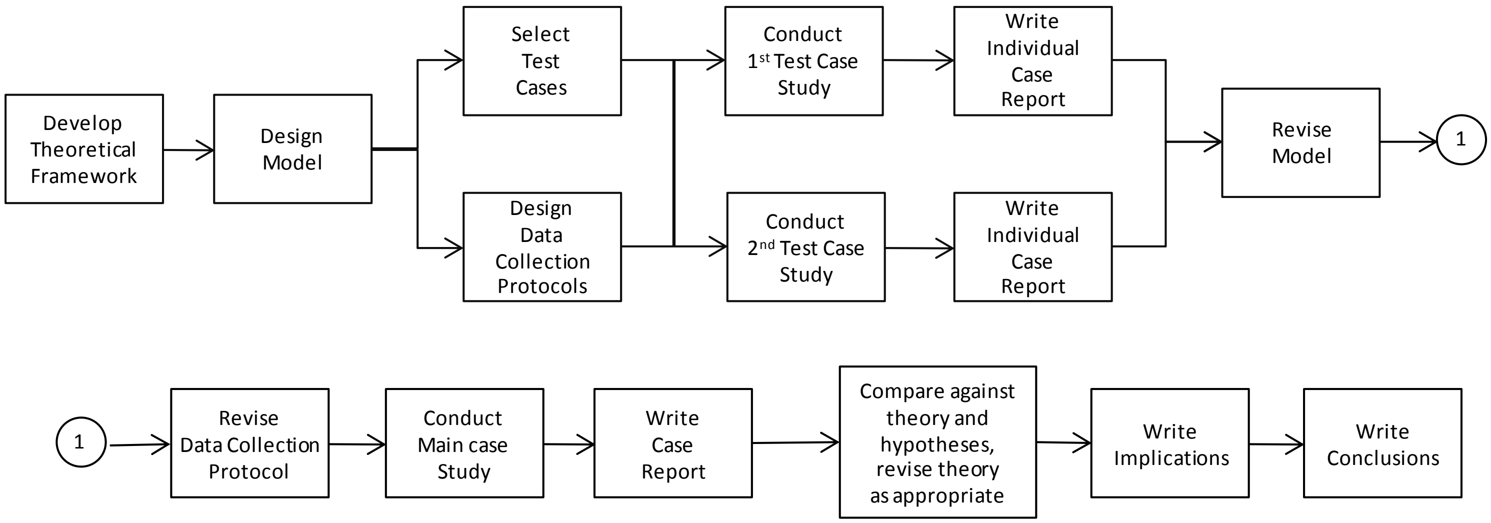
CHAPTER 4

METHODS AND DATA

4.1 Methodological approach

This research pursues a field-based, mixed methods case study strategy combined with an iterative process to build explanations about the phenomenon and generate grounded theory (Eisenhardt, 1989; Yin, 2003). This iterative process introduces an innovation model to investigate prizes, tests and revises the model with pilot case studies, analyzes the main case study, probes hypotheses and revises theory, and draw final conclusions (Figure 4.1). This research draws upon different methods of data gathering such as direct observation, on-site interviews, application of questionnaires, and document analysis. The analysis strategy is based on the triangulation of data sources during the interpretation of data with equal weighting for data gathered through different methods (Creswell & Plano Clark, 2007).

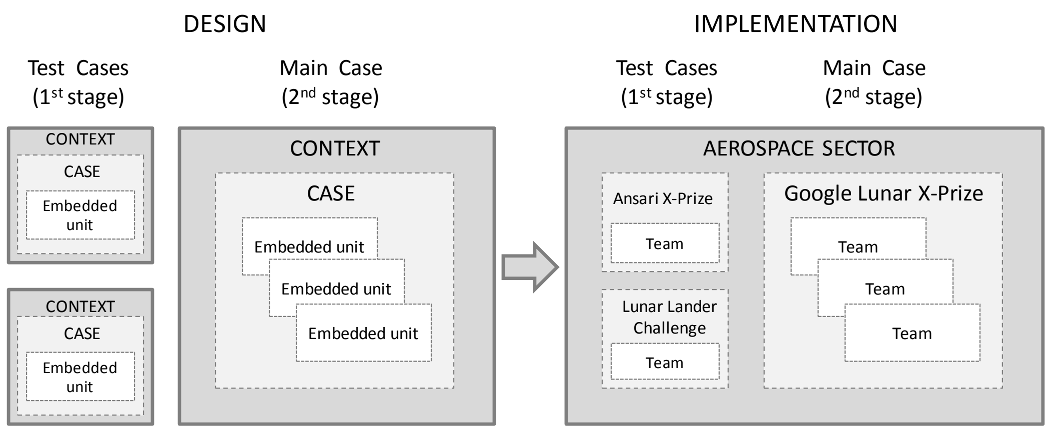
This research maintains that a better understanding of prizes can be only achieved by investigating not only the prize competition as the unit of analysis but also its entrants and broader technological context. Therefore, this approach seeks to a) learn about the prize by looking at how entrants respond to incentives, perform R&D activities, and advance technologies, and b) disentangle the effect of the prize competition from ongoing R&D activities and broader industry and technological trends. This highlights the importance of the historical research perspective when examining cases of finished prizes.



Source: own design based on Yin (2003).

Figure 4.1: Case study method and process

To organize the inquiry, this research follows an embedded multiple-case study design (Yin, 2003) combining multiple-units of analysis in two stages (Figure 4.2). There is a first stage with two mini-case studies to test the model and a second stage with a main case study with embedded units of analysis (prize entrants.) The first stage reduces the risk of focusing on a single case study and serves other purposes as well. It allows defining more precisely the constructs involved in the model, determining the plausibility of the hypotheses, testing data sources, improving data gathering instruments, and contributing insights for the main case study. Multiple embedded units of analysis in both stages provide richer data to analyze the prize cases.



Source: own design based on Yin (2003).

Figure 4.2: Case study design and implementation

The analysis of data follows an interactive approach involving data reduction, displaying, and conclusions (Miles & Huberman, 1994). This approach involved follow-ups, further data gathering, and re-coding when there were missing or ambiguous data. NVivo data coding and qualitative analysis software by QSR International was used in this analysis. Case study data include documents, responded questionnaires, transcribed interviews, and memos with observation data.

This research sets out to increase the external validity of the investigation of the main case study by considering the counter-factual “Would innovation occur anyway if the prize did not exist?” and the insights from the two pilot cases. Moreover, two additional aspects are considered: (a) the potential alternative strategies that prize entrants might have been pursued if there was no prize announcement or if prize entrants did not join the competition; and, (b) the industry sector/technological field developments that might have occurred if the prize was not announced. For example, prize entrants are asked about their goals and relationship between the prize and their previous projects to understand their potential alternative strategies if the prize was not announced. Experts are also asked to assess these aspects from the industry context analysis standpoint.

4.2 A model of innovation applied to prizes

4.2.1 Prior work

To the author’s knowledge, no framework or model has been offered by the academic literature for case study research on the effect of prizes on innovation. The academic literature has mostly contributed economic models in which a prize sponsor offers a unique monetary reward—the cash purse—to induce increasing R&D activity in a specific technological field or the production of a single innovation. These models have generally assumed that the innovation is ultimately placed in the public domain and thus the prize winner cannot reap the benefits of monopoly pricing.

The work by Wright (1983) is among the earliest applications of formal modeling techniques to compare incentive mechanisms, including prizes. Wright explores the optimal application of patents, prizes, and direct research contracting to induce innovative activity from the standpoint of a social welfare-maximizing administrator and with many researchers targeting the same innovation. In his work, the optimal choice between those mechanisms is based on terms of the probability of success of the research projects and the elasticity of supply of research.

Several other works have built upon Wright's research to compare the effectiveness of alternative incentive schemes. For example, de Laat (1997) investigates whether the results of Wright's model hold under less competitive R&D processes by looking at the case of one innovator which is a technological leader and focused on the comparison between prizes and patents. Shavell & Ypersele (1999) compare the patent system—in which the innovator's incentives are the monopoly profits—with a rewards system—in which the incentive to invest in research is a monetary reward. They use a model of a single potential innovator with private information about the demand for the innovation and government with knowledge about the probability distribution of demand curves. Newell & Wilson (2005) analyze the use of prizes to induce innovations for climate change mitigation and use a simplified model that assumes that prize entrants and the sponsor share information about each other's costs, benefits, and probability of success.

Formal economic modeling of prizes has been also applied to the examination of optimal designs. For example, Taylor (1995) introduces a model in which identical risk-neutral research firms, with no capital constraint and private information about the value of the innovations, decide whether to pay an entry fee to participate in a contest to produce an innovation of the highest value for the sponsor and win the prize money. Moldovanu & Sela (2001) use a model of multi-prize contests where risk-neutral players have private information about their abilities and the number and cost functions of the contestants affect the configuration and size of the prize values that maximize the expected sum of efforts.

The number of empirical works that investigate prizes is even smaller. A notable example is the study of Brunt et al. (2008) which looks at prizes awarded by the Royal Agricultural Society of England (RASE) between 1839 and 1939 to determine whether prizes induce innovation. For that analysis the authors used econometric models (negative binomial regressions) that look at the entry effect of prizes and correlated patent activity, using datasets with prize entrants, rewards, and patents data for the time period of 98 RASE exhibition shows. Interestingly, their models incorporate the type of reward (i.e. monetary and others) as an independent variable.

Davis & Davis (2004) follow a case study approach to investigate the role and incentive effects of prizes in three 20th century innovations—motorized flight, human-powered flight, and energy efficient refrigerators—where prizes were considered to play a significant role in technology development. These authors examine qualitative, historical evidence to determine how prize designs affected contest outcomes. Though there is not a formal model, their analysis is guided by five issues addressed by the literature: the size of the prize reward, duplication of R&D effort, spillovers and reputational gains, sequential innovations, and the co-existence of prizes with patents and the firm strategic choice.

Finally, Saar (2006)—also with a case study approach yet from a different perspective—investigates the reasons why prizes are rarely used as innovation mechanisms by addressing, among other aspects, the effect of prizes on technological innovation. He studied five prizes offered since the 18th century, including the Longitude Prize, the Alkali Prize, the Orteig Prize, Ansari X Prize, and the Windows-on-a-Mac prize. Saar's analysis is structured to answer ten questions that look at diverse aspects, namely: prize purpose, prize sponsor, prize financing, entry rules, type of prize, related markets, prize offer length, funding of R&D activities, characteristics of the winning solution, publicity of the prize, and co-existing prizes. Saar notes that among the most important limitations to pursue this type of case studies are the lack of reliable data, particularly for prizes offered long ago.

Those works suggest a number of considerations for further research. First of all, the number and importance of the conditions under which prizes demonstrate to be effective—at least theoretically—suggest that prizes can only complement—and not substitute—patents, contracts, grants, and other incentives to promote innovation and, thus, exclusive strategic choices such as patents or prizes need to be relaxed to examine the decision of prize participation under more real conditions. These real conditions have to consider the diversity of potential prize entrants, motivations, and perception of risks in the decision to enter innovation prizes. Moreover, this decision may be based on information on the costs, benefits, and probability of success of research projects that differs in quantity and quality between innovators and prize sponsors, or on assessments that consider incentives other than monetary rewards. Further research has to consider also factors that may be a) internal to the competition, such as the attributes of the innovators, or b) part of its context, such as the characteristics and dynamics of the technological field in which the competition is held. Finally, prize research has to consider the sequential and cumulative nature of innovation and examine ongoing industry R&D efforts and the "after-market" value of the innovations achieved in competitions.

On the other hand, from a methodological standpoint, the lack of systematic documentation of a number of aspects related with prize competitions—such as the perception of incentives by prize entrants, R&D activities, and/or technology achievements—demands research models that allow empirical investigation based on mixed data sources. In particular, further research requires introducing measures of the quality of prize outputs to be able to examine and compare different types of prize implementations.

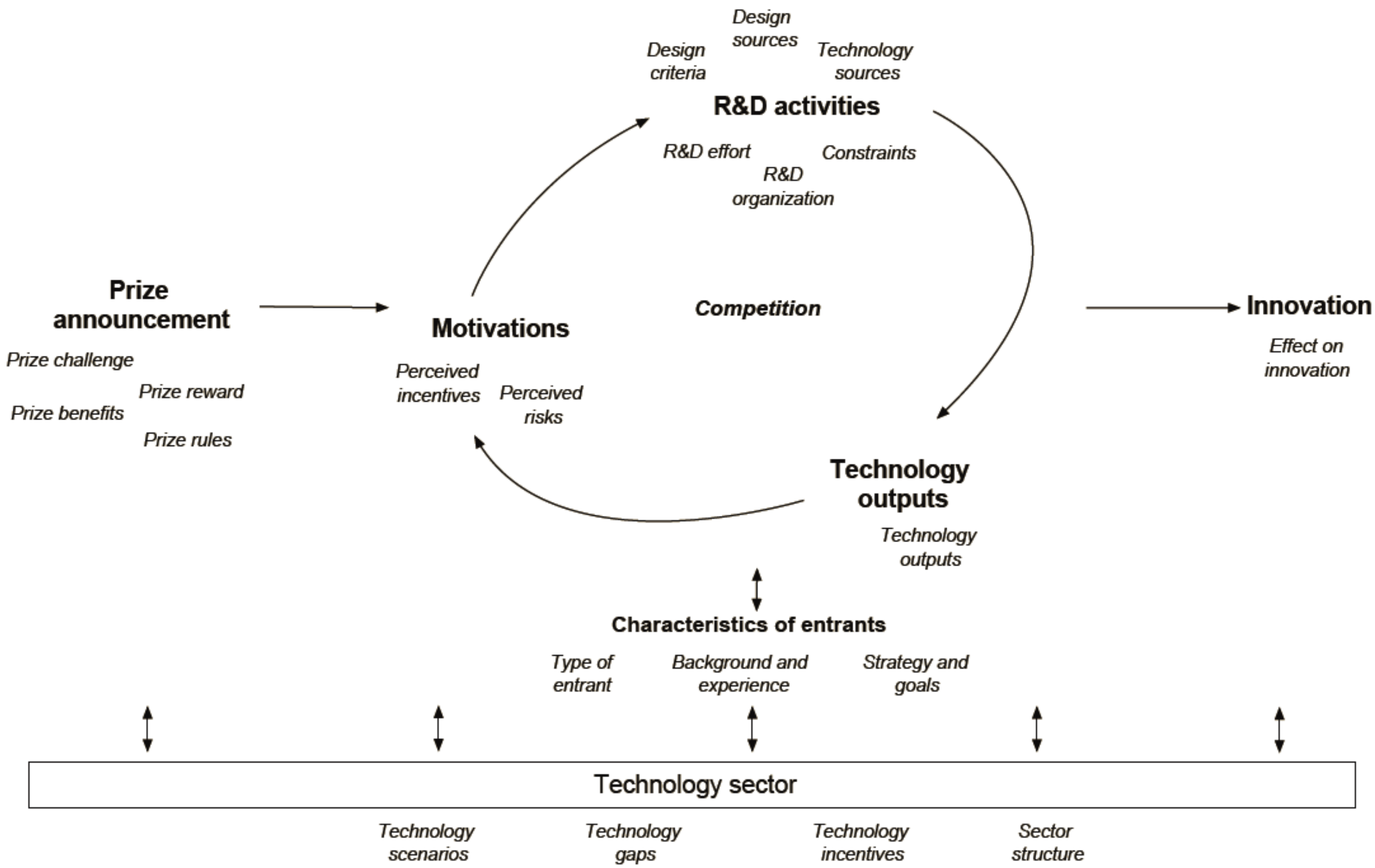
4.2.2 The model

This research proposes a model of innovation applied to prizes that considers the prize competition as the unit of analysis and includes factors that are either internal or external to the competition to better understand the phenomenon. This model draws primarily upon the prize literature and seeks to include all the factors that possibly determine the innovation effect of prizes. The model departs from the typical econometric approaches and aims at guiding and facilitating prize research following an approach to theory building based on case study research and multiple types of data sources (Eisenhardt, 1989). This model assumes that, at the core of the any prize competition, there is a pattern that encompasses motivations, R&D activities, and technology outputs and is influenced by the characteristics of the prize entrants and dynamics and structure of the prize context (Figure 4.3). In this model, it is this pattern that renders prizes as unique instances of innovation processes.

The process to create this model encompasses four major steps. First, there is the identification of dimensions of the study of prizes. For this, the author analyzed other scholarly works, accounts of historic prizes, and analyses and reports by prize advocates and commentators in addition to the literature cited in the previous section. In total, 40 different knowledge sources published between 1862 and 2009 were analyzed, including 13 scholarly journal publications and 14 working/conference papers.[8] Six dimensions of the study of prizes were identified to outline the model and group concepts and relationships. These dimensions are prize announcement, motivations of entrants, prize R&D activities, prize technology outputs, characteristics of entrants, and the context/technology sector. Second, there is the identification of themes and topics by literature coding. For this, the author applied a descriptive approach to data coding (Saldaña, 2009) to the selected literature. This research used Nvivo data coding and qualitative analysis software by QSR International for the task. Third, there is the re-contextualization of topics into categories. Coded topics were re-contextualized from their contiguity-based context into conceptual- or causal-based context based on both prize and more general innovation literature and preventing the creation of "analytic

[8] All references to this literature are cited in this section.

blinders" that may impede observing connecting relationships in the data (Maxwell & Miller, 2008). That yielded a number of categories that follow either a variable-oriented approach in which categories are concepts linked by relationships (e.g. entrant's characteristics that relate to decisions to enter the competition) or a process-oriented approach in which categories are events or conditions that lead to successive events or conditions in the context of one case (e.g. prize design's features that lead to certain technology outputs.) (Miles & Huberman, 1994) Fourth, there is the operationalization of research categories or variables. The categories were defined to be operationally specific (i.e. categories are defined in terms of its measurement) and present no measurement issues (i.e. be reliable when measuring the phenomenon using different data sources and collection methods.) (Bacharach, 1989) Table 4.1 shows the complete set of dimensions, relevant literature, categories, and operationalization.



Source: own development based on the literature cited in text.

Figure 4.3: Innovation model applied to the study of technology prizes

Table 4.1: Dimensions, identified topics, literature references, and proposed categories for a model to study prizes

Dimen-sions	Identified topics and literature references	Categories	Operationalization
Prize an-nouncem ent	•Definition of prize target (Shavell & van Ypersele, 1999; Kremer, 2000; Masters, 2003; Macauley, 2005; Newell & Wilson, 2005; Kalil, 2006; Mervis, 2006; Stallbaumer, 2006; NRC, 2007)	Prize challenge	Definition of prize challenge
	•Size of monetary reward (Shavell & van Ypersele, 1999; Abramowicz, 2003; Maurer & Scotchmer, 2004; Schroeder, 2004; Wei, 2007)	Prize reward	Reward (i.e. cash purse, bonuses, or others)
	•Other prize benefits (e.g. public exposure, prestige) (Brunt et al., 2008)	Prize benefits	Benefits associated with mere participation due to sponsor's or competition's characteristics (e.g. public exposure, prestige)
	•Validity of the invention (Sobel, 1996; Che & Gale, 2003)	Prize rules	Regulation, limits, or special requirements
Motiva-tions	•Prizes vs. other incentives (Wright, 1983; Shavell & van Ypersele, 1999; Scotchmer, 2005) •Non-monetary incentives (Davidian, 2007; Brunt et al., 2008) •Reputation and credibility (Maurer & Scotchmer, 2004; Kalil, 2006; Culver et al., 2007; Brunt et al., 2008) •Promotion, publicity (Maurer & Scotchmer, 2004; Schroeder, 2004; Brunt et al., 2008) •Market size/opportunities (Sidney, 1862; Diamandis, 2004; LeVine, 2008)	Perceived incentives	Incentives perceived by entrants, e.g., prize incentives (i.e. incentives that would not exist without the existence of the prize itself, such as reward or other prize benefits) or technology-related incentives (i.e. those that vary with the prize technology, like potential commercialization or exploitation in own processes or products)
	•Risk (Nalebuff & Stiglitz, 1983; Macauley, 2005)	Perceived risk	Perception of risk of prize participation by the team (e.g. risk resulting from: overall competition, technology development, or not being paid by the sponsor if the prize challenge is achieved)

Source: own analysis.

Table 4.1: Dimensions, identified topics, literature references, and proposed categories for a model to study prizes (Contd.)

Dimensions	Identified topics and literature references	Categories	Operationalization
R&D activities	•New/diverse R&D approaches (Byko, 2004; Kalil, 2006; Culver et al., 2007) •Unconventional partnerships (Culver et al., 2007)	Design criteria	Design criteria in prize technologies (e.g. project cost, novelty, simplicity, reliability, environmental impact, market value, standardization).
		Design sources	Sources of inspiration for prize designs (i.e., relation to industry developments)
		Technology sources	Technology sources in prize R&D (e.g., subcontracting, commercial off-the-shelf)
		R&D organization	Organizational arrangement of R&D activities: physical organization (e.g. decentralization); collaborations / interactions; processes / approaches (e.g. trial and error).
	•Strength of R&D activity (Grishagin et al., 2001), innovation effort (Davis & Davis, 2004)	R&D effort	Resources available to entrants and applied to R&D
		Constraints	Perception of constraints in competition (e.g. time or budget constraints)
Technology outputs	•Quality of invention, novelty (Scotchmer, 2005; Kalil, 2006) •Commercialization of invention (Kieff, 2001; Wei, 2007) •Sequential innovations (Davis & Davis, 2004)	Technology outputs	Technology outputs of entrants (concepts; designs; models; prototypes; crafts)
	•Technology development acceleration (Anastas & Zimmerman, 2007; Culver et al., 2007; Masters & Delbecq, 2008) •Redirection of innovation (Davis & Davis, 2004) •Incremental vs. breakthroughs (Pomerantz, 2006)	Effect on innovation	Emerging research finding and reference to the concept of innovation (OECD/Eurostat, 1997)

Source: own analysis.

Table 4.1: Dimensions, identified topics, literature references, and proposed categories for a model to study prizes (Contd.)

Dimensions	Identified topics and literature references	Categories	Operationalization
Characteristics of entrants	• Unconventional innovators (Schroeder, 2004)	Type of entrant	Classification of entrants into: conventional entrants and unconventional entrants
	• Experience/background (Byko, 2004) • Previous participation in prizes (McKinsey & Company, 2009)	Experience / Background	Entrant experience with prize technologies and professional background
		Strategy / goals	Explicit or implicit goals of the entrant and strategies to achieve them
Technology sector	• Stage of sector/technology development (Davis & Davis, 2004) • Type of technology (LeVine, 2008)	Technology scenarios	Forecast for prize technology sector in the next 3-5-10 years
		Technology gap	Gap between current-day technologies and technologies required to win the competition
	• Market size/opportunities (Sidney, 1862; Diamandis, 2004; LeVine, 2008)	Technology-related incentives	Perception of the value of the prize technologies
	• Regulatory framework (Culver et al., 2007)	Technology sector structure	Structure of prize technological field (e.g. actors, relationships, regulations)

Source: own analysis.

The final version of the model resulted from several iterations of topics-coding and display-building. The author sought to balance the number of research categories and the comprehensiveness and broader scope of the model. Connections between categories imply correlational or directional relationships that are subject to further probing. In this case, the connecting strategy was simply based on identifying key relationships suggested in the prize literature and more broadly discussed in the innovation literature. Subsets of categories can be linked to more abstract constructs (e.g. “motivation”) for analytic purposes. The research categories were tested with the study of pilot cases. When possible, the triangulation of data sources was used to test validity (i.e. appropriateness of operationalization) and reliability (i.e. measurement issues) in categories and to adjust their definitions. The application to pilot case studies was also aimed at probing the utility or descriptive power of the model. Purposely, the scope of the model allows addressing different specific research questions at different levels of analysis (Table 4.2).

Table 4.2: Selected research questions and dimensions in the study of prizes

Main research question	Specific research questions (examples)	Literature themes	Primary level of analysis
How do prizes induce innovation?	How do different prize designs lead to different technology outputs?	Prize design	Prize
	What is the motivation of prize entrants?	Motivation of entrants	Entrant
	How do prize R&D activities differ from R&D activities in other contexts?	Prize R&D activities	Prize/Entrant
	What are the characteristics of the prize’s technological outputs?	Technology outputs	Prize/Entrant
	How do the characteristics of entrants influence the technological outputs of the competition?	Characteristics of entrants	Prize/Entrant
	How do prize outputs and context interrelate?	Prize-context interplay	Context/Prize

Source: own analysis.

Further research may expand this research model to operationalize other concepts and relationships and address more specific questions.

4.3 Case studies

This research investigates three cases of recent technology prizes in the aerospace sector (Table 4.3). The main case study is the Google Lunar X Prize (GLXP) for robotic exploration of the Moon. The two pilot case studies are the Ansari X Prize (AXP) for suborbital manned flight and the Northrop Grumman Lunar Lander Challenge (NGLLC) for the development of vertical take-off/landing vehicles.

The GLXP[9] is a $30 million multi-year global competition organized by X Prize Foundation and sponsored by Google, Inc. It was announced on September 2007 and has not found a winner yet. The GLXP requires participants to land a robot on the Moon, among other secondary goals, by December 2015. Thirty-five international teams entered the competition and more than 40 countries have been involved. This research investigates the competition as unit of analysis, the space sector as its context, and 17 teams as embedded case studies. The author selected this main case study for four reasons. First, the GLXP is an ongoing competition, which allows gathering real-time data and observing R&D activities and other aspects of the participation of prize entrants. Second, this is the most documented prize competition in history. Diverse and multiple data sources are available. Third, the GLXP prize challenge involves technology development in strategic areas for the U.S. S&T and innovation policy. Fourth, the GLXP is a global competition, which allows observing more variation in embedded cases. The embedded units of analysis comprise those teams that responded a questionnaire applied to all GLXP teams. To perform a more in-depth examination of prize entrants, the author selected interview teams based on their willingness to share information about their prize

[9] Google Lunar X Prize's official website: http://www.googlelunarxprize.org/

activities; their availability for in-person or phone interviews; the authorization given to observe their activities and facilities; and, a more efficient use of the funding available for this research (e.g. travel proximity.) The author also sought to increase the diversity of respondents by including both U.S. and foreign teams and different types of entities and organizational forms.

The AXP[10] is a $10 million prize offered in 1996 to the first non-government organization to launch a reusable manned spacecraft into space twice within two weeks to a minimum altitude of 100 km. It engaged 26 teams from seven countries. The U.S. aircraft design company Scaled Composites won this prize in 2004. This prize was privately funded and inspired by the early 20th century Orteig Prize for the first nonstop transatlantic flight between New York and Paris. This was the first prize program administered by the X Prize Foundation, an educational, non-profit corporation established in 1994 to inspire private, entrepreneurial advancements in space travel.

The NGLLC[11] is a multi-year competition held between 2006 and 2009 as part of NASA's Centennial Challenges program, which comprises about a dozen different prizes. Twelve independent, small U.S. teams participated in four years of competition. The NGLLC offered a total of $2 million in cash prizes for the first and second best-performing teams. To win, the teams had to build and fly a vertical take-off and landing rocket-powered aircraft within minimum, pre-specified standards of efficiency, and under conditions that simulate the same flight on the moon. This program had two competition levels with different degrees of difficulty (I and II, II being the most difficult.) The prize money rolled over to the next year when no entries qualified. Masten Space Systems and Armadillo Aerospace, two aerospace startups, won different levels of this prize in 2008 and 2009 and shared the total prize money.

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[10] Ansari X Prize's official website: http://space.xprize.org/ansari-x-prize
[11] Northrop Grumman Lunar Lander Challenge's official website: http://space.xprize.org/lunar-lander-challenge

The criteria to select the AXP and the NGLLC and a number of their entrants were the availability of secondary data and the similitude of industry sector with the main case, which facilitates the observation of teams that participated in more than one prize, the simplification of the research by studying only one context without affecting the results of the project, and the elaboration of conclusions specific to the use of prizes in the strategic U.S. aerospace sector.

Table 4.3: Summary of information for prizes investigated in this research

	Ansari X Prize (1996-2004)	Northrop Grumman Lunar Lander Challenge (2006-2009)	Google Lunar X Prize (2007-present)
Prize challenge	First non-governmental organization to build and launch a reusable manned spacecraft into space twice within two weeks	Build and fly a reusable, rocket-powered vehicle simulating a flight on the moon within pre-specified timeframe and performance, and in a designated location	First to land a spacecraft on the Moon, traverse 500 meters, and send back high-definition video footage
Prize type	First-to-achieve, winner-takes-all, medium- or long-term competition	Best-in-class, multi-prize, multi-year competition with purse rollover	First-to-achieve, multi-prize, medium- or long-term competition
Prize purse	$10 million	**Level I:** $350,000 for first place, $150,000 for second place **Level II:** $1 million for first place, $500,000 for second place	Grand prize: $20 million 2^{nd} place prize: $5 million Bonus prizes: $5 million
Sponsor / manager	X Prize Foundation (sponsor and manager) with funding from the Ansari family	NASA and Northrop Grumman Corp. (sponsors) / X Prize Foundation (manager)	Google Inc. (sponsor) / X Prize Foundation (manager)
Prize entrants	26 teams from seven countries	12 U.S. teams	35 teams from 17 countries (6 already withdrawn)
Prize winners	Scaled Composites, from Mojave, California ($10 million)	**NGLLC 2006 and 2007:** No winners **NGLLC 2008:** Armadillo Aerospace from Rockwall, Texas: Level I (first place) for $350,000 Masten Space Systems from Mojave, California: Level I (second place) for $150,000 **NGLLC 2009:** Masten Space Systems from Mojave, California: Level II (first place) for $1 million (2009) Armadillo Aerospace from Rockwall, Texas: Level II (second place) for $500,000 (2009)	No winner yet

Source: diverse sources described in the following sections.

4.4 Data and data gathering

4.4.1 Pilot case studies

The investigation of the AXP and the NGLLC draws mainly upon the analysis of documentary sources (Table 4.4). Seven embedded cases (out of 26 prize entrants) are examined for the AXP and five embedded cases (out of 12 prize entrants) are examined for the NGLLC. Eighty-seven primary and secondary data sources (McDowell, 2002; Danto, 2008) have been codified to gather the case studies data, including research articles, books, web sites, and other online content. This research used Nvivo data coding and qualitative analysis software by QSR International for this task. Both competitions already ended and required the researcher to disentangle all the historical and special interest factors that may affect the objectivity of the documentary sources. Data sources were checked for external validity (i.e. authenticity) and internal reliability (i.e. credibility and biases) (Danto, 2008). Comparing and contrasting data sources were very important to tease out common components and attributes, interpret, and reconstruct the story of the prize competitions and the participation of teams. The triangulation of data sources also helps to increase the internal validity of the research. Primary data sources provide data directly from prize entrants in the form of team profiles, blog posts, forum comments, and other online content created by team members. Secondary data sources comprise all other sources, including but not limited to the prize sponsor's reports and media coverage. Both competitions were held in a time period that coincides with the widespread growth of the Internet, which contributed significantly to the publication of information about the competitions and participant teams. Online tools such as the Wayback Machine also allow gathering data from web pages that existed only when these competitions were in progress.[12] Moreover, prize sponsors have been interested in disseminating information and progress updates on these competitions to attract the attention of the general public, which increased the amount of available data.

Table 4.4: Data coding inventory for pilot case studies

Case study	Prize announcement	Motivations	R&D activities	Technology Outputs	Characteristics of teams	Technology sector
Ansari X Prize						
• Sources	3	20	28	19	23	7
• References	6	48	108	49	80	11
NGLLC						
• Sources	6	14	23	16	26	7
• References	9	19	40	29	61	9
Total						
• Sources	9	34	51	35	49	14
• References	15	67	148	78	141	20

Note: cells indicate number of sources and coded references.

Further data on the AXP and the NGLLC were gathered in unstructured, open-ended interviews with prize experts. Mr. Gregg Maryniak (Vice President of Aerospace Science, St. Louis Science Center and X Prize Foundation's Advisor) managed diverse aspects of the X Prize Foundation in the 1990s and was interviewed by phone to learn more about the AXP. Mr. Ken Davidian (Director of Research at the FAA Office of Commercial Space Transportation—AST) is former NASA's manager for the Centennial Challenges program and was interviewed in-person to learn more about the NGLLC. The knowledge and expertise of these interviewees also allowed learning more about other prize cases, including the GLXP.

[12] The Wayback Machine web site can be accessed at: http://www.archive.org/web/web.php

4.4.2 Main case study

The study of the GLXP draws upon data specifically collected at the team-, prize-, and context-levels (Table 4.5). Team-level data were gathered using questionnaires, interviews with team leaders and members, site visits, and documentary sources. The latter include team profiles published on the official GLXP website and team websites. Prize- and context-level data were gathered using interviews with prize and industry experts and documentary sources. In this case, documentary sources also include journal articles, industry reports, official GLXP press releases, and media articles.

To study the GLXP prize entrants, questionnaires were applied to leaders of 23 GLXP teams between February 2010 and September 2010.[13] A total of N = 17 teams responded the questionnaire within that time frame. This response rate allowed gathering data from both U.S. and foreign teams, in proportions similar to the overall participation of U.S. and foreign teams throughout the competition. One of the participating teams was already withdrawn when responding the questionnaire (a special version of the questionnaire was mailed with similar questions.) As of January 2011, i.e. after the data gathering process finished, three other participating teams withdrew the competition. The rest of the teams are still in competition.

Six teams that were active during the February 2010-to-September 2010 time frame either did not respond to the request to fill out the questionnaire or responded they were too busy to participate in the study. For these teams and those that entered the competition after that time period, the author was only able to gather data from documentary sources, which includes team websites, profiles on the official GLXP website, and other online media content.

[13] Only one team whose leaders had legal problems at that moment was not surveyed.

Table 4.5: Summary of data gathering to investigate the GLXP

Level	Data sources
Team	• Questionnaires to teams (N=17 teams) • Interview with team leaders and members (N=7 teams, including six team leaders and eight team members) • Site visits (N=5 teams visited; eight different facilities) • Documentary sources (e.g. team profiles posted on official GLXP website, team websites)
Prize	• Interview with GLXP prize manager • Documentary sources (e.g. official GLXP website, official press releases)
Context	• Interview with industry experts (N=3 experts) • Documentary sources (e.g. journal articles, industry reports, media articles)

The analysis of questionnaire data might suffer from nonresponse bias. Nonresponse bias results from individuals or organizations who respond to questionnaires being different from individuals or organizations who did not respond, in a way relevant to the study (Dillman, 2000). There may be different sources of nonresponse. Refusal and unlocated can be applied to this type of research (Daniel, 1975; Hawkins, 1975). Refusals to respond may depend on researcher-subject rapport, the quality of the questionnaire, and the nature of the inquiry (e.g. confidential or sensitive information.) Unlocated may occur when no contact data are available. To handle nonresponse, the questionnaire was pre-tested for question comprehension, ability to answer questions without error, selection of responses, and reactions to sensitive questions to improve the questionnaire's clarity and acceptability. This pre-test was performed with help of three anonymous colleagues and four graduate students from the Satellite Communication and Navigation Systems class of Fall 2007 at the Georgia Institute of Technology (these students were familiar with the GLXP as they produced class projects aimed at designing a spacecraft for the GLXP that was just announced.) To guarantee an appropriate delivery of questionnaires, the researcher had collaboration from the XPF to deliver envelopes with questionnaire/letter packages to team leaders at the 3rd annual GLXP Summit. The XPF also provided contact data of teams for follow-ups when team leaders authorized that. To increase the response rates, the researcher also used the personalization technique in follow-ups by e-mail, which involves giving the researcher's attention to individual team leaders (Dillman, 2000).

The questionnaire (included in the Appendix) was organized in five sections and asked team leaders about the motivation, R&D activities, technology outputs, and members of their teams (the questionnaire is included in the Appendix.) Most of the creativity and innovation literature draws upon self-reporting methods when studying team process variables (Hulsheger et al., 2009). However, innovation research based on self-report data, such as questionnaires, may suffer the problems of susceptibility of response biases and potential overestimation of effect sizes. The researcher has sought to overcome such potential problems in questionnaires with further data gathering from other sources and triangulation in the analysis.

The interviews with team leaders and other members addressed most of the topics of the questionnaire. They allowed discussing specific aspects more in-depth and obtaining clarification of responses given in questionnaires. These interviews were semi-structured and open-ended and conducted in-person at the team workplaces in most of the cases. Nine questions were used to guide these interviews (see Appendix.) N = 7 teams accepted interviews with their team leaders and, in some cases, with some of the team members. Only one interview was conducted by phone and another one by mailing questions and receiving responses by e-mail. When given the proper authorization, the researcher visited the workplaces of the teams to observe how the teams organize their activities. N=5 teams were visited including eight different facilities/workplaces.

The analysis of team-level data does not seek to compare teams based on their performance, yet to discover patterns that help to better understand how motivations, R&D efforts, and technology development occur in the context of prizes. Since the

GLXP is an ongoing competition, the data that may reveal competitive positions or strategies of teams were anonymized or deliberately excluded from this analysis. The perception of motivations and the self-assessment of the outputs of the teams and their innovativeness date to the moment in which each questionnaire was responded. The author sought to consider the external factors that may affect perceptions and assessments during the time period in which the questionnaires were responded.

To investigate the prize-level of the main case study, this research used an unstructured, open-ended interview, attended a GLXP summit, and analyzed documentary data sources. The researcher interviewed Mr. William Pomerantz, the XPF's Director for Space prizes, in-person. The researcher also attended the 4th annual GLXP Summit held in the Isle of Man (U.K.) in October 2010. At this event, representatives of 13 teams presented updates on their projects and discussed different aspects of organization of the competition with the organizers. This opportunity was used to observe the interaction between team members and between the teams and the prize sponsors, and to speak informally with some team members to gather general impressions about the Summit and the competition. This research also draws upon documentary sources that include the official website of the GLXP, the websites of the teams, and diverse content published online by the specialized media.

To investigate the GLXP context, this research includes insights from industry experts and literature analysis. The researcher conducted unstructured, open-ended interviews with three industry experts by phone (Table 4.6). These experts contributed opinions and points of view in relation to four main aspects of the context of the GLXP: expected sector scenarios, technology gaps to achieve prize targets, industry structure, and technology-related incentives linked to the GLXP. The contribution of the experts in each of these aspects varies. Interview questions were difficult to respond without further analysis on the experts' part, particularly the questions regarding the expected scenarios.

Still, these experts provided significant insights that allow a better understanding of the context in which the GLXP is held.

This research complied with the requirements of the Georgia Institute of Technology's Institutional Review Board (IRB) to apply questionnaires, conduct interviews, and visit workplaces.

Table 4.6: Industry experts participating in interviews

	Interviewed industry experts		
	Dennis Stone	**Jeff Greason**	**G. Thomas Marsh**
Sector	Space agency (NASA)	New space industry (XCOR)	Traditional space industry (Lockheed Martin)
Current position	Assistant Manager for Commercial Space Development in NASA's Commercial Crew & Cargo Program at the Johnson Space Center, part of Commercial Orbital Transportation Services (COTS) initiative.	Founder and President of XCOR Aerospace, founder of the Commercial Spaceflight Federation.	Retired from Lockheed Martin Space Systems Co. as Executive Vice President.
Experience	20 years in NASA's Space Station Program in a variety of positions, including Chief System Engineer of the Assured Crew Return Vehicle, Manager of Avionics Integration, and Co-chair of the ISS Commercialization Working Group. Prior to NASA, he worked for McDonnell Douglas, Ford Aerospace, and Rockwell.	Was team lead at Rotary Rocket (another new space company) for engine development, and previously worked at Intel. In May 2009, Greason was named a member of the Review of United States Human Space Flight Plans Committee, an independent review requested by the Office of Science and Technology Policy (OSTP).	From 1969 until 1995, worked at Martin Marietta Corporation, most recently as President, Manned Space Systems. After 1995, various positions within Lockheed Martin Corporation, including President and General Manager of the Missiles and Space Operations business unit from 2002. Appointed Executive Vice President of Lockheed Martin Space Systems in 2003.
Education	Bachelor degrees in Physics and Electrical Engineering from the University of Hawaii.	Graduated with honors from California Institute of Technology in Pasadena.	Bachelor's degree, electrical engineering, University of New Mexico. Master's degree, Business Administration, University of Colorado.

CHAPTER 5

A FIRST APPROACH: THE ANSARI X PRIZE AND THE NGLLC

5.1 The Ansari X Prize

5.1.1 The prize

The AXP was announced by the X Prize Foundation (XPF) in 1996. It offered a $10 million cash purse for the first non-governmental organization to build and launch a reusable manned spacecraft into space twice within two weeks, by January 1, 2005. This prize was privately funded and inspired by the early 20th century Orteig Prize for the first nonstop transatlantic flight between New York and Paris. Twenty-six teams from seven different countries entered this prize. The competition was won in 2004 by Scaled Composites, a U.S. aircraft design company. The winning flights are considered the first privately funded human spaceflights in history.

This was the first prize program administered by the XPF, an educational, non-profit corporation established in 1994 to inspire private, entrepreneurial advancements in space travel. Its purpose was to demonstrate the feasibility of private space flight, change existing public opinion about private industry's capabilities, and generate concrete business opportunities for commercial space tourism (Maryniak, 2010). To accomplish that, the XPF posed a challenge that involved building and flying a manned vehicle to a minimum altitude to be considered a space flight (100 km) and having mostly—90 percent or more—privately funded projects. Though the idea of space tourism was not new at that time, the AXP defined the private space flight problem in concrete terms. In particular, the rules required for the vehicle to be built: a) crew capability: be able to carry the pilot plus equivalent capacity for two passengers; b) re-flight: the same vehicle had to complete two flights within two weeks; and, c) reusability: no more than 10 percent of the vehicle's first-flight non-propellant mass could be replaced between the two flights. The teams were allowed to use any technology and approach to accomplish this feat (e.g. the rules mention tow vehicles, balloons, descent ballutes, among other examples.) The prize rules allowed teams to retain all the IP and commercial rights related to their technologies, vehicles, and services.

Otherwise indicated, the analysis and findings reported in this section are based on seven embedded cases or teams: Scaled Composites (U.S.,) Armadillo Aerospace (U.S.,) Advent Launch Services (U.S.,) ARCA (Romania,) Da Vinci Project (Canada,) PanAero (U.S.,) and Starchaser Industries (England.) Table 5.1 shows a data summary for these seven embedded cases and Appendix Table A.1 shows the complete list of entrants in this competition. Appendix Table A.2 shows a data gathering summary for the embedded cases.[14]

[14] The classification of prize entrants is based on their industry experience (i.e. space agency/industry experience.) Due to a lack of primary data on the experience of the team members, the pilot cases use a classification based on the author's assessment of the relationship between previous activities and the prize technologies.

Table 5.1: Summary of data for embedded cases in the Ansari X Prize

	Selected teams						
	Scaled Composites	**Armadillo Aerospace**	**Advent Launch Services**	**ARCA**	**Da Vinci Project**	**PanAero**	**Starchaser Industries**
Type of team	Aircraft design firm	Independent R&D team	Employee-owned corporation	Non-profit org. pursuing space activities	Independent R&D team	New aerospace engineering company	Space research fnd. later incorporated
Created	1982	2000	1996	1999	N/A	1997	1998
# members	135	6	12 (~100 volunteers)	8	14 (~500 volunteers)	9	35
Location	Mojave, CA, USA	Mesquite, TX, USA	Houston, TX, USA	Ramnicu Valcea, Romania	Toronto, Canada	Fairfax, VA, USA	Cheshire, England

Notes: N/A indicates data not available.

Source: own analysis based on data described in the text.

5.1.2 The context

Space tourism was not a new idea when the AXP was announced. Suborbital pleasure trips began to receive serious consideration in the mid-1980s, yet the main barrier was still the cost of space travel (Collins & Ashford, 1986). The potential size of this market was appreciated only 10 years ago. In 2001, Dennis Tito became the first paying space tourist when flying to the International Space Station for a $20 million price tag and demonstrating the possibilities for private space travel. A few other wealthy tourists have repeated such trips and many others have been willing to, at least to the suborbital space. In 2002, a study by Zogby International found that 19 percent of those surveyed in the U.S. were willing to pay $100,000 for a 15-minute trip into suborbital space (Byko, 2004).

There was no established provider of suborbital space flights as of 1996. Large companies in the aerospace and aviation business (e.g. Lockheed Martin and Boeing) demonstrated no interest in this competition when it was announced, something that the XPF sought purposely with its prize design (Diamandis, 2004; Maryniak, 2010). A few other small companies were also pursuing similar suborbital flight targets. For example, XCOR is a U.S. private rocket engine and spaceflight development company founded in 1999. Although the company had similar projects, it did not enter the competition because the prize was perceived to reward speed of development rather than the commercial merit of the spacecraft (Greason, 2010).

The competition received extensive media coverage due to its implications for space exploration (XPF, 2007). At the time it was won, this competition received more than five billion media impressions and was telecast and webcast to a global audience with the support of NASA, America Online, the Discovery Channel and other media outlets (Maryniak, 2005). As of 2010, commercial tourism space flights are not more frequent than those initial experiences ten years ago. Industry experts suggest this market may be sizable yet only more affordable and secure solutions are likely to have commercial merit (Marsh, 2011).

5.1.3 Prize entrants

The prize was open to any private team (including international teams) with the condition that its vehicle had to be privately financed and built. Ultimately, 26 official teams from seven countries participated, but the sponsors received many more inquiries from potential entrants interested in participating (Maryniak, 2010). The data suggests that at least 18 out of 26 prize entrants were unconventional to the space sector, including pre-existing companies that re-directed their activities, new startups, and independent R&D groups. They were referred to as "people that would never look at a government contract." (Diamandis, 2004) Scaled Composites, the winner, is a U.S. aviation company that builds innovative aircrafts since 1982 (Byko, 2004). Northrop Grumman Corp. had a 40 percent-stake in this company when it won the AXP. Most of the other teams were created after the year of the prize announcement. There were very small teams (i.e. about 10 people or fewer) and sometimes with significant volunteer efforts as well (e.g. Advent Launch Services and Da Vinci Project enrolled up to 100 and 500 volunteers, respectively.) Scaled Composites had about 50 full-time equivalent people working in the AXP project (XPF, 2008c). Some kind of engineering experience was a feature of all teams, and at least four teams recruited members with extensive experience from NASA or the private aerospace industry. For example, Advent Launch Services was founded by a group of NASA retirees.

Three out of seven teams analyzed here entered the competition in 1996/1997 and four entered after 2000. Scaled Composites entered the competition officially in 2001 when it partnered with Vulcan, Inc. (owned by Paul Allen, cofounder of Microsoft) to create Mojave Space Ventures and started the effective development of the winning entry

(Discovery Channel, 2005; Linehan, 2008). While the literature points out that this company had its own ongoing “secret space program” since 1993 (Byko, 2004; Linehan, 2008) experts contribute different opinions on whether the technologies under development were useful to win this prize (Greason, 2010; Maryniak, 2010; Marsh, 2011).

5.1.4 Motivations

The AXP offered a $10 million cash purse to accomplish a challenge aligned with a sizable potential market. Some teams considered the cash purse as potential funding to pursue related projects or start new companies. Though the XPF needed until 2002 to secure the money necessary to pay the reward, only one team commented about the risk of not being paid the reward if it achieved the prize challenge. The teams also perceived the opportunity to publicize their activities, accomplish organizational and personal goals, learn, and pursue a challenging goal. There is no evidence that these teams considered entering the competition as an additional risk to the risk implicit in technology development. This is interesting considering that there existed an important regulatory risk related with the fact that no permit had been ever given by the Federal Aviation Administration (FAA) for private human spaceflight before the winning attempts of 2004. Prize entrants retained the IP rights on their technologies and services and were not required to place their inventions in the public domain.

5.1.5 R&D activities

The teams focused on providing simple and low cost solutions to the prize challenge using existing technologies and, in some cases, novel conceptual designs. Most importantly, teams had to consider the re-usability requirement in their designs. Only a few teams had reliability as a design criterion. The designs of Scaled Composites were influenced by the X-15 rocket-powered aircraft project (a U.S. USAAF/NACA program) and sought to shorten development lead times (Discovery Channel, 2005). A few teams performed the major part of the R&D activity in this competition. Only two teams scheduled an attempt to win the prize (Scaled Composites and Da Vinci Project) and only three teams actually tested spacecrafts or scaled-down versions of them (Scaled Composites, Da Vinci Project, and Starchaser Industries) (Linehan, 2008). Scaled Composites exerted the greatest R&D effort, estimated at $30 million (Linehan, 2008). The effective development of the winning entry (final design and construction) started in 2001 (Discovery Channel, 2005). Other R&D efforts were more modest. For example, Armadillo Aerospace invested about $1 million and American Astronautics Corp. invested $2.5 million (Byko, 2004; Culver et al., 2007). Overall, all the 26 teams spent more than $100 million in their attempts to win the prize (XPF, 2004).

These seven teams manufactured, subcontracted, and procured commercial off-the-shelf technologies to different extent. They also applied diverse R&D approaches. For instance, Scaled Composites applied a fast prototyping approach in which an interchangeable group of engineers and technicians can rapidly define a technical or mathematical problem and apply their expertise quickly to solve it, even on the business side (Kemp, 2007). The activities of the teams presented different forms of organization that can be characterized as entrepreneurial, traditional corporate, volunteer, or joint venture partnership. Some teams drew upon knowledge and advice provided by consultants (e.g. Da Vinci Project) or even family and friends (e.g. Advent Launch Services.) In general, the main obstacle for the teams was the lack of funding, while only two teams (of those analyzed here) reported the lack of aerospace engineering experience and skills. Regulatory requirements were a barrier common to all teams. No team reported to face constraining prize rules.

5.1.6 Technology outputs

Though the AXP did not specify the characteristics of the technology to be developed, winning the prize required a creative approach to building and operating a space vehicle with a relatively low budget and contemplating minimum design criteria related with human transportation. Scaled Composites introduced significant innovations with its winning entry, comprising a hybrid spacecraft with a pivoting-wing system, a patented hybrid rocket motor configuration, and an air-launch system for piloted spaceflight (Boyle, 2004b). Other teams presented novel designs as well, yet only a handful of them moved into development and testing stages. Other innovations include, for example, sophisticated computer controls for rockets and a composite materials reusable rocket that Armadillo Aerospace and ARCA introduced, respectively. In spite of the direct connection between the prize challenge and the emerging space tourism market, only three teams (out of seven) revealed such market as their main target when entering the competition. Other three teams explicitly excluded commercialization of technologies as the purpose of their participation.

Figure 5.1 shows a picture of the White Knight turbojet aircraft with the SpaceShipOne spacecraft attached below, both built by Scaled Composites to win this competition. Figure 5.2 summarizes the analysis of the AXP in terms of different dimensions and categories.

Source: Scaled Composites.

Figure 5.1: Scaled Composites' White Knight turbojet aircraft with SpaceShipOne spacecraft attached underneath.

Ansari X Prize	**Motivations**	**R&D activities**	**Technology outputs**
• **Prize challenge**: be the first non-gov. org. to launch a reusable manned spacecraft into suborbital space twice within two weeks. • **Monetary reward**: $10 million. • **Prize benefits**: global exposure due to extensive media coverage. • **Prize rules**: open-ended and conducive set of technical specifications; targeted space tourism; focus on requirement of private funding.	• **Perceived incentives**: very diverse motivations; prize money is secondary. The competition offered significant exposure and publicity to teams. Sizable market opportunities were perceived yet directly targeted by only a few teams. • **Risk**: prize participation did not imply additional risk for teams. In general, teams interested in prize money only entered the competition when sponsor guaranteed prize money.	• **Design criteria**: simplicity and low cost were main criteria; re-usability was required by prize rules; reliability and safety were criteria as well. • **Design sources**: teams drew upon existing technologies and new conceptual designs. • **Technology sources**: in-house manufacturing, subcontracting, and off-the-shelf procurement. • **R&D effort**: more than $100 million invested in R&D, external funding attracted. Volunteer effort. • **R&D organization**: diverse R&D approaches; only a more dynamic and entrepreneurial approach succeeded; only a few teams reached stage of development. • **Constraints**: Lack of funding.	• **Technology outputs**: winning entry was a hybrid spacecraft design with innovative configuration, use of new materials. Other innovative concepts were introduced by all teams. Scaled tests introduced new features and materials as well. Hardware outputs concentrated in a few most active teams. • **Commercialization**: potential commercialization was a key driver in design and development and was implicit in prize rules. • **Effect on innovation**: accelerated ongoing R&D activity, attracted new innovative players, and induced conceptual and operational innovations as well.
Characteristics of teams	• **Type of teams**: mostly unconventional teams, incl. pre-existing companies that redirected activities or new startups. Multiple types of partnerships emerged to raise funding. Significant volunteer effort in some cases.	• **Experience / Skills**: all teams attracted individuals with aerospace experience which influenced designs. Overall engineering experience was present in all cases. No team had experience in past competitions or suborbital space flight.	• **Strategy/goals**: comm. of tech. and opportunity to enter the new space tourism market was the initial goal of a few teams. Some independent teams sought to accomplish personal and other organizational goals.
Suborbital manned space flight sector	• **Technology scenario**: technologies likely to have demand if they are affordable and safe. First space tourism experience not seen until 2001, after prize announcement.	• **Technology-related incentives**: sizable market opportunities in space tourism market through suborbital flights. • **Technology gap**: though tech. already existed, significant breakthrough was needed to make spaceflights more affordable and safe.	• **Sector structure**: sector that emerged along with the competition; comprises new players, mostly small companies that re-directed activities or were just created. Regulatory framework required modifications to allow flights.

Source: own analysis based on secondary data described in the text and model introduced in previous sections.

Figure 5.2: Summary of analysis of the Ansari X Prize

5.2 The Northrop Grumman Lunar Lander Challenge

5.2.1 The prize

The NGLLC was a multi-year competition held between 2006 and 2009 as part of NASA's Centennial Challenges program, which comprises about a dozen different prize competitors. Twelve independent, small U.S. teams participated in four years of competition and up to 45 would-be entrants demonstrated interest in this competition in 2006 (Pomerantz, 2006). The NGLLC offered a total of $2 million in cash prizes for the first and second best-performing teams. To win, teams had to build and fly a vertical take-off and landing (VTOL) rocket-powered vehicle within minimum, pre-specified standards of efficiency, and under conditions that simulate the same flight on the moon. The goal of the NGLLC was to accelerate commercial technological developments that would have direct application to NASA's space exploration goals (including the development of a new generation of Lunar Landers) and the commercial launch procurement market (XPF, 2008a). NASA, Northrop Grumman Corp., and the XPF partnered to offer this prize. The XPF managed the competitions at no cost to NASA. NASA contributed the cash purse and Northrop Grumman Corp. funded part of the costs of operation of the program.

This program had two competition levels with different degrees of difficulty, I and II, being the latter the most difficult. The prize money rolled over to the next year when no entries qualified. In 2006 and 2007, the prize-winning attempts of all the teams took place at a sponsor-organized public event. The same format was used in 2008 but the event was not open to the public. In 2009, the teams were allowed to designate their preferred site and date to attempt their flights. Masten Space Systems and Armadillo Aerospace, two aerospace startups, shared the prize money for Level I in 2008 and Level II in 2009. In 2008, Armadillo Aerospace won the 1st place ($350,000) and Masten Space

Systems won the 2nd place ($150,000.) In 2009, Masten Space Systems won the 1st place ($1 million) and Armadillo Aerospace won the 2nd place ($500,000.)

Otherwise indicated, the analysis and findings presented in this section are based on five embedded cases or teams: Armadillo Aerospace, Masten Space Systems, BonNova, High Expectations Rocketry, and Unreasonable Rocket. Table 5.2 shows a data summary for these five embedded cases. Table A.3 and Table A.4 in the Appendix show the complete list of entrants and a data gathering summary for the embedded cases, respectively.

Table 5.2: Summary of data for embedded cases in the NGLLC

	Selected teams				
	Armadillo Aerospace	**Masten Space Systems**	**BonNova**	**High Expectations Rocketry**	**Unreasonable Rocket**
Type of team	Independent R&D team	Small startup, rocketry and propulsion company	Small aerospace company	Small engineering research group	Father and son amateur team
Created	2000	2004	N/A	N/A	2007
Years of participa-tion in NGLLC	2006, 2007, 2008 (1st place Level I), 2009 (2nd place Level II)	2006, 2007, 2008 (2nd place Level I), 2009 (1st place Level II)	2007, 2008, 2009 (withdrawn)	2008	2007, 2008, 2009
# members	8	5	6	4	4
Location	Mesquite, TX	Mojave, CA	Tarzana, CA	Moscow, ID	Solana Beach, CA

Notes: N/A indicates data not available.

Source: own analysis based on data described in the text.

5.2.2 The context

The first R&D activities specifically aimed at building lunar landers were performed in the 1960s when NASA procured technologies that were ultimately used in the Apollo missions. This technology sector has been primarily driven by programs of NASA and other U.S. and foreign government agencies. Large corporations have dominated most of the private space technology market until the recent emergence of new aerospace development startups in the 1990s. For instance, Northrop Grumman is a $30 billion global defense and technology corporation that has been NASA's prime contractor in the development of several technologies linked to lunar programs since the 1960s when it designed and produced the Apollo lunar modules. The company has also sought to support NASA on the development of Altair, a lunar lander that is expected to place four astronauts on the Moon by 2020 (Northrop Grumman, 2007; XPF, 2009a).

No significant technological developments were made in this field until some years before the prize announcement. The $60 million program to develop the Delta Clipper experimental vehicle in the 1990s (first led by the U.S. Department of Defense and then by NASA, with participation of McDonnell Douglas Corp.) was a recent antecedent in the development of VTOL vehicles (Pomerantz, 2007). Interestingly, Scaled Composites, the winner of the AXP, contributed technologies to such program.

5.2.3 Prize entrants

Only U.S. teams were eligible to enter this competition. U.S. government organizations, organizations principally or substantially funded by the federal government were eligible, and government employees were not eligible. The NGLLC ultimately enrolled 12 unique teams, but several of them participated more than once in the four years of competition. The number of participating teams by year was: four in

2006, eight in 2007, nine in 2008, and three in 2009. Most of the prize entrants were ultimately unconventional teams organized as independent R&D groups that were born to compete in this or previous prizes. For instance, Armadillo Aerospace entered the AXP a few years earlier and consolidated as an aerospace startup by the time it entered the NGLLC. This team did not have paid employees when entered this competition and worked only two days a week on the project (Pomerantz, 2006). BonNova's team leader participated in the development of the winning entry of the AXP as well. Masten Space Systems was organized as a small startup, rocketry and propulsion company with six full time employees in 2006. Experts suggest that both Armadillo Aerospace and Masten Space Systems were considered favorite teams at that time (Greason, 2010).

In general, they were very small (between five and nine people) self-funded teams with some kind of (and diverse) engineering experience, including some team members with amateur or professional rocketry experience. Three of the teams analyzed here were based in California.

5.2.4 Motivations

The NGLLC was offered by potential technology customers (NASA and Northrop Grumman) yet it did not represent any commitment to acquire technologies. A narrowly defined technology target and detailed technical specifications resembled standard procurement requirements and the idea of potential contracts to procure technologies could not be discarded. Prize entrants retained the IP rights for their technologies, yet they were required to negotiate in good faith to provide non-exclusive licenses if NASA is eventually interested in that. The cash purse was very small compared to the cost of similar technology development programs. The competition attracted NASA's and other corporate officials in addition to the general public (XPF, 2007). Some of the teams (three out of five analyzed here) sought to build a good reputation and gain the respect of those observers and declared primary interest in the prize money. A similar number of teams were driven by the challenging goal and the opportunity to accomplish personal goals as well. The teams referred to the risk of participation in different terms, including the probability of not being paid the cash purse, destruction of profitable equipment, or excessive personal commitment.

5.2.5 R&D activities

These five teams focused on delivering simple and low cost solutions in addition to introducing other unconventional design criteria such as modularization and programmability. The teams drew upon existing designs, own know-how, competitors' experience, or even science fiction design ideas. The teams sought to develop and manufacture most of their technologies in-house. They also contributed knowledge and approaches to R&D from industries such as software. Terms such as "fast prototyping", "learning-by-testing", or "incremental test production" had been used by the two winning teams to describe their approaches. Overall, an estimate of $20 million and about 100,000 person-hours were invested in R&D in four years of competition by all teams (Courtland, 2009). Masten Space Systems spent about $2.5 million to win the $1 million prize (Morring, 2009) and Armadillo Aerospace spent at least $3.5 million in its whole development program (Armadillo Aerospace, 2008). Within this group of five teams, only Armadillo Aerospace was successful in raising money from corporate sponsors. The short development time frames required by the competition represented a constraint in some cases (e.g teams had only 168 days to build their spacecrafts between the prize announcement and the competition day in 2006.) (Pomerantz, 2006) The process to obtain experimental permits from the U.S. Federal Aviation Administration was a constraint for all teams. An interesting feature of the prize R&D activities was the degree of openness of the teams with each other and with the public (Davidian, 2010). The teams used extensively online tools to share their experiences and advances and, most interestingly, may have relied on each other to analyze technical problems and suggest solutions (Pomerantz, 2010b). For example, the team Unreasonable Rocket shared its experimental flight permit application with the team TrueZer0, which also made its own permit application publicly available (along with many technology details in the same document.) (TrueZer0, 2008)

5.2.6 Technology outputs

Some prize assessments consider that the NGLLC induced several innovations in the form of new components, subsystems, and new standards of reusability, operation, speed of development and efficiency (Pomerantz, 2007; NASA, 2009b). There is more concrete evidence. For example, Armadillo Aerospace introduced sophisticated computer controls for its vehicles and BonNova developed new patent-pending rocket engine components. According to experts, technology development occurred at medium-to-high TRL levels (i.e. TRL 6 or higher) (Davidian, 2010). The 12 participating teams developed and tested some technology in these four years of competition. Seven teams participated more than once in the NGLLC. Five teams participated at least three times (including the two winners) and introduced incremental innovations that improved the precision of their flight tests. Throughout the four years of competition, the technical solutions contributed by the teams may have converged to similar designs (Pomerantz, 2010a), possibly as the result of mutual learning and imitation. Still, program managers suggest that there was no significant duplication of R&D efforts as teams tested different solutions to specific problems (Davidian, 2010). Some teams had a commercial orientation that was incorporated into their designs (e.g. using modularity as a design criterion) and resulted in patent applications. Other teams considered commercialization possible yet not a priority.

Figure 5.3 shows a picture of the MOD vehicle built by Armadillo Aerospace to participate in the NGLLC 2007. Figure 5.4 summarizes the analysis of the NGLLC prize in terms of different dimensions and categories.

Source: Armadillo Aerospace.

Figure 5.3: Team Armadillo Aerospace and its MOD vehicle at the NGLLC 2007

NGLLC	**Motivations**	**R&D activities**	**Technology outputs**
• **Prize challenge**: build and fly VTOL vehicle that simulates the flight of a vehicle on the Moon. • **Monetary reward**: $2 million divided into two levels and 1st and 2nd place. • **Prize benefits**: exposure to lots of general public and NASA and corporate officials at competition site. • **Prize rules**: narrowly defined technology target; detailed technical specifications, gov. funding not allowed.	• **Perceived incentives**: prize money, potential reputation (which may lead to commercialization,) and self-fulfillment are drivers of engagement and R&D effort. • **Risk**: teams internalize risk of participation and balance with risk of technology development since prizes are a mean to accomplish their goals.	• **Design criteria**: simplicity and low cost were main criteria; diverse set of approaches led to unconventional criteria as well (e.g. modularity.) • **Design sources**: teams contributed non-space knowledge and approaches to R&D. • **Technology sources**: in-house manufacturing predominated. • **R&D effort**: teams invested $20 million and 100,000 person-hours in pursuit of the prize purse. • **R&D organization**: very small, flexible teams with informal yet novel approaches to organize R&D and learn during the process. • **Constraints**: short development time frames.	• **Technology outputs**: new components and subsystems, new standards of reusability, speed of development, and efficiency. • **Commercialization**: in some cases, technology outputs had commercial orientation since design stage. • **Effect on innovation**: triggered new R&D activity in a narrowly defined technology sector with no active developments.
Characteristics of teams	• **Type of teams**: mostly unconventional teams created as independent, volunteer R&D teams to join the competition. A number of them participated in several instances of the competition ("prize teams")	• **Experience / Skills**: in general, diverse engineering experience, aerospace experience only in a handful of cases. Importance of learning-by-doing during the competition. Participation in past competitions had influence.	• **Strategy/goals**: pursuit of a challenging goal related to personal interests in most of the teams. A few teams used the competition to promote activities and, eventually, commercialize technologies.
Space exploration research and procurement sector, VTOL vehicles	• **Technology scenario**: opportunities to produce and comm. affordable and productive Moon exploration and suborbital flight technology in the medium- or long-term. • **Technology gap**: existing yet not efficient/affordable tech.; dev. of more precise, effective, and affordable vehicles.	• **Technology-related incentives**: Moon exploration is a target of space agencies; subcontracting by them (e.g. NASA) or large corporations (e.g. Northrop Grumman) are a direct comm. opportunity; other scientific and corporate applications exist for related services and tech.	• **Sector structure**: space agencies, few large corporate players, and large contracts have traditionally dominated this sector (e.g. Northrop Grumman, which has been linked to lunar programs since the 1960s.)

Source: own analysis based on data described in the text and model introduced in previous sections.

Figure 5.4: Summary of analysis of the Northrop Grumman Lunar Lander Challenge

5.3 Discussion

The data show that the motivation of teams goes beyond the monetary cost-benefit analysis suggested by most of the literature. Moreover, the relationship between types of incentives and types of entrants is not straightforward and needs more in-depth research. Prize incentives had been more likely to attract unconventional teams. Technology incentives were not the primary driver of conventional entrants. Two alternative explanations exist for the latter: a) technology incentives may have not been as significant or certainly signaled by the competitions as it was described and, therefore, no traditional industry players were interested in engaging in these challenges; or, b) other factors, such as risk of participation or the structure of the technology sector, may have played a role. In relation to a), the fact that technological targets were defined for a relatively early point along the commercialization timeline may have reduced the attractiveness of both competitions for conventional entrants (suggested in part by Kieff, 2001). In relation to b), there may be other sources of risk not considered a priori by this research, such as the risk of ruining one's business reputation if, for example, an experienced company is outperformed by unconventional teams (something suggested by, for example, LeVine, 2008). More generally, the fact that no conventional entrants engaged in spite of potential markets for the prize technologies suggests that unconventional entrants may be more optimistic in their forecasts or less risk-averse than established industry players (as suggested by Nalebuff & Stiglitz, 1983). On the other hand, the participation of conventional entrants may ultimately depend on the structure of the technology sector. This explanation fits particularly well in the AXP, which was linked to an emerging market with no established, specialized companies. In the case of the NGLLC, there existed large corporations or specialized firms, yet only 12 mostly unconventional teams were engaged in this four-year competition, which also suggests significant high-risk perceptions or entry barriers such as lack of knowledge, skills, or funding.

The data also show that teams of both competitions performed diverse R&D activities and faced a number of constraints. These findings suggest that the investigation of the effect of time/budget constraints also requires more in-depth investigation and richer data. The effect of each constraint should be explored in more detail to discover prize-specific relationships. For example, simplicity and low cost designs are likely to relate to lack of upfront funding. The use of existing technologies is likely to correspond with shorter development timeframes. In-house manufacturing may be the response to the need to control technology development and prevent unexpected events. Novel R&D approaches may result primarily from engaging unconventional entrants. It should be noted in that regard that, though the diversity of R&D approaches can be linked to the heterogeneity of professional backgrounds and industry experience in team members, the aerospace industry has always been characterized as multidisciplinary since its emergence. Still, these competitions allow the full deployment of capabilities due to the lack of restrictions compared to, for example, instances of conventional technology procurement and interactions between NASA and pre-existing industry players (Bromberg, 2000). For example, the rules of the AXP were characterized as open-ended and conducive to develop the prize technologies (Linehan, 2008). In the case of the NGLLC, for instance, Armadillo Aerospace was observed to bring “the dynamism of software development to aerospace projects” as its members had mostly IT industry background (SpaceRef.com, 2008).

These prizes leveraged significant R&D investment and induced the development of new technologies. Some outputs considered innovations would have not occurred by the prize deadlines if these competitions did not exist. The caveat is that prizes were linked to significant technology incentives and, fundamentally, ongoing R&D processes. Experts and scholars also consider that these prizes “provided a focus for efforts that people already had under way" (Greason, 2010) or simply motivated the last effort to come up with the final solution (Saar, 2006). Certainly, while a significant achievement or feasibility demonstration was observed in the AXP, the winning entry may have been already under development before the prize announcement. This is not a negative assessment of the potential of prizes, yet suggests that prizes may be more efficient in some circumstances. Moreover, it was less likely for the rest of the AXP teams to produce a similar prize outcome by 2004 as there was only another team—Da Vinci Project—with a scheduled attempt to win the competition.

Nevertheless, a handful of other unconventional teams (such as Da Vinci Project and ARCA) also had achievements that, in principle, would not have existed at that point without this prize (since those teams were created to compete for this prize or the competition was among their most important goals.) In the case of the NGLLC, Masten Space Systems and Armadillo Aerospace had pursued related R&D before the prize announcement, yet their specific innovations responded to the definition of the prize target. The rest of the teams were mostly new-to-industry, volunteer teams performing new R&D activities. In the end, the main contribution of these competitions may have been the introduction of a concrete definition of the characteristics of the innovations to be achieved and, hence, the focus of R&D efforts.

Most of the cited innovations were achieved in progress toward the prize target and commercialization was achieved after the prize deadlines. For example, in 2004, an agreement between Scaled Composites and Virgin Galactic resulted in a $250 million contract to deliver a fleet of 7 spacecrafts to offer suborbital travel services (Linehan, 2008). Moreover, both Armadillo Aerospace and Masten Space Systems were awarded $475,000 to perform test flights of their experimental vehicles under NASA's Commercial Reusable Suborbital Research Program (CRuSR) (NASA, 2010e). These contracts demonstrate how significant the potential technology incentives linked to prizes may be, and suggest that prize winners are the most likely to realize those commercial opportunities to full extent. Patent-pending developments by other teams, for example, also suggest other potential future commercialization activities.

5.4 Lessons for next steps

These case studies contribute some evidence for a better understanding of how prizes induce innovation and highlight several factors to be considered in further research. First, prize entrants do perceive varied types of incentives. Some of these incentives can be “adjusted” with different prize designs and others relate to the prize technologies. PIs (those that would not exist without the competition) have a significant effect on unconventional entrants, i.e. individuals or organizations typically not involved with the prize technologies. TIs may not have an effect on conventional entrants (including traditional industry players) if the market value of the prize technologies is uncertain, if entrants are more risk averse, and/or the structure of the technology sector has certain features (e.g. a few players dominate the sector.) Second, there are a number of possible constraints faced by prize entrants such as time, funding requirements, and sector regulations. The real effect of these constraints on the organization of R&D activities can be only understood with further research. Still, novel R&D approaches can be associated with the presence of unconventional entrants. Third, these prizes induced innovations over and above would have occurred anyway, with the caveat that these prizes were linked to significant technology incentives and, more importantly, ongoing R&D processes. The main contribution of these competitions may have been the definition of the characteristics of the innovations to be achieved and, hence, the focus of R&D efforts.

The findings also suggest other methodological considerations. First, the classification of prize entrants based on their industry experience (i.e. space agency/industry experience) is appropriate for the study of prizes (a proxy was used in these pilot cases; entrants were classified based on the author's assessment of the relationship between previous activities and the prize technologies.) Further research may uncover other factors that define even better the motivations, R&D activities, and technology outputs of prize entrants. Second, the characterization of technological outputs requires more accuracy as data sources refer to them inconsistently. Third, these case studies support the idea that the investigation of prizes requires a better understanding of the characteristics of both prize entrants and technology sector. The investigation of the context and team levels is important and enhances our understanding of the phenomenon. In particular, further research has to examine whether there are ongoing technological developments when the prize is announced and what the significance of the TIs is. Fourth, the operationalization of categories is appropriate for the analysis of the main case. Categories might need re-definitions if more in-depth studies suggest that. Fifth, triangulation of documentary and other data sources is very important, particularly to investigate past prizes. More in depth analysis is required to better understand specific aspects of prizes, which also requires drawing upon primary data sources using methods such as questionnaires or interviews. Sixth, the examination of the overall effect of prizes on innovation might require consideration of additional factors. PIs, TIs, technology gaps, and challenge definitions do not act as simple "yes/no" determinants of innovation. These factors are more likely to blend together to influence the nature of the prize technology outputs in a continuum that goes from use of current-day technologies to technological breakthroughs, passing through incremental and other less significant innovations.

CHAPTER 6

A CLOSER LOOK: THE GOOGLE LUNAR X PRIZE

6.1 The GLXP prize

The GLXP is a $30 million competition that started in September 13, 2007. It is organized by the XPF and sponsored by Google Inc. The competition requires prize entrants to land a robot on the surface of the Moon, among other secondary goals, by December 31, 2015. According to the XPF, this is the largest prize competition in terms of cash purse and it is designed to “accelerate technology developments supporting the commercial creation of multiple systems capable of reaching the lunar surface and performing operations over an extended period of time.” More broadly, the purpose of the competition is: educate the global public about the benefits of opening up space and exploring the Moon; inspire and excite the world about science, technology, math, and engineering; enable and qualify a new generation of engineers and entrepreneurial companies able to design, build, deliver, and operate space hardware; and, open the space frontier to new ideas and new participants by lowering costs by a factor of thirty. The XPF has sought to design a competition that has multiple back-end business markets that can be supported by the technologies developed in pursuit of the prize (Pomerantz, 2010a). The XPF also expects this competition to have a sociological impact since half of today's world population was not alive at the moment the last NASA Apollo mission visited the Moon. The advancements made by the GLXP teams would allow NASA and other space agencies to save money and expand the capabilities of future robotic and human missions to the Moon (XPF, 2008d).

There was not a specific strategy to launch this competition and the XPF announced the prize as soon as its design was ready. The GLXP was announced at the annual Wired Magazine’s NextFest event of 2007. The XPF considered that that event would make the GLXP visible to the "right kind of people" or "nontraditional competitors," which includes, for example, "dot com billionaires, open source people, and a million different other kind of people who might see this as interesting enough to get involved." The XPF has also had the ability to reach out the "classical aerospace community," as they were in contact with industry players to organize other competitions and attend the same type of meetings (e.g. conferences.) (Pomerantz, 2010a) The announcement of the GLXP almost coincided with the launch of Kaguya, a Japanese lunar orbiter by the Japan Aerospace Exploration Agency (JAXA.)

6.1.1 The challenge

The challenge posed by this prize requires launching a spacecraft from Earth to Moon, landing on the Moon, deploying a rover (or equivalent unit) to traverse 500 meters, and collecting and sending back to the Earth high-definition video footage. The competition requires prize entrants to accomplish such mission by December 31, 2015 to be able to claim the cash purse.

The cash purse is divided into a Grand Prize, Second Place Prize, and other Bonus Prizes. The Grand Prize is valued at $20 million (if a government-funded mission launched after January 1, 2010 performs similar mission, the Gran Prize is reduced to $15 million.) The second place prize is valued at $5 million. The Bonus Prizes are valued at $4 million. The Grand Prize will be awarded to the first team to complete all of the mission requirements. The Second Place Prize will be awarded to the second team to complete the mission requirements. At sole discretion of the XPF, this prize may be also awarded (as a "consolation prize") to a team that accomplishes most of the requirements to win the Grand Prize but, due to unforeseen reasons such as mechanical difficulties, ultimately fails to meet all the mission requirements (in which case the Grand Prize would be still available.) The Second Place Prize may not be won by the Grand Prize winner. The Bonus Prizes will be awarded to the team or teams that successfully complete the bonus requirements and the Grand Prize or Second Place Prize mission requirements.

The following GLXP mission requirements have to be met to be able to claim the Grand Prize:

1. LANDING: the team must land its craft on the surface of the Moon.

2. MOBILITY: the craft or a single secondary vehicle carried by the craft must move a distance of at least 500 meters along the surface of the Moon in a deliberate manner (on, above, or below the lunar surface, yet with straight line displacement capability for that distance.)

3. MOONCAST TRANSMISSION: the craft or a secondary vehicle must transmit from the surface of the Moon two “Mooncasts:” an “Arrival Mooncast” and a “Mission Complete Mooncast” (eight minutes of High-Definition video each; both exclusively produced for the XPF or its partners.)

4. DATA UPLINK: the team must transmit to the craft or secondary vehicle while on the surface of the Moon as much as 100 kilobytes of data provided by the XPF for later transmission back to Earth.

5. PAYLOAD: the craft or secondary vehicle must carry a XPF’s payload of about one percent of the craft or secondary vehicle's dry mass, with a minimum mass of 100 grams and maximum mass of 500 grams.

The GLXP’s Bonus Prizes are: the Apollo Heritage Bonus Prize ($4 million) to the first team that takes a mooncast that includes imagery and video of an Apollo site including footage of a historical artifact associated with the Apollo mission; the Heritage Bonus Prize ($1 million) to the first team that takes a mooncast that includes imagery and video of a historical site of interest including footage of an artifact associated with a previous mission to the Moon other than the Apollo missions; the Range Bonus Prize ($2 million) to the first team that moves its craft or a secondary vehicle along the surface of the Moon for no less than five kilometers; the Survival Bonus Prize ($2 million) to the first team that successfully operates its craft or a secondary vehicle on two separate lunar days (second day with mission requirements;) and the Water Detection Bonus Prize ($4 million) to the first team that provides scientifically conclusive proof of the presence of water. The actual amount paid for each Bonus Prizes will depend on whether other Bonus Prizes were already paid (the total will be $4 million.) The GLXP also offers a Diversity Award ($1 million) to the team that, in the opinion of a panel of experts, has made the greatest attempts to promote diversity in the fields of science, technology, engineering, and mathematics (there is no need to claim other prizes to receive this award.)

The GLXP's rules include some considerations regarding the use of public funding and other resources. The government funding of the team may not exceed ten percent of the funds used to compete (including support received as cash and the cash-equivalency of in-kind support.) Teams are not allowed to purchase preexisting hardware from sources such as museums, space agencies, or defunct companies, unless equivalent or superior replacement products are commercially available. Teams are allowed to use governmental facilities, personnel, hardware, or information previously developed by a government organization, if access is available to other teams as well. Government personnel are allowed to work for a team so long as they are working outside of the scope of their government employment. Teams are permitted to use other government resources yet those resources will be considered public funding and will count against the maximum ten percent for public financing.

There are two types of documents containing the prize rules. There is a document that contains the prize guidelines which focus more on the technical requirements and are more informally written to be understood by regular people, specifically engineers and entrepreneurs. Another document is the Master Team Agreement (MTA) that contains the guidelines and legal provisions to regulate different aspects of the competition. The MTA is a binding contract that every team has to sign to participate in the GLXP. The initial MTA 1.0 was made public during the first year of competition to have feedback from the teams and the public. The version 2.0 (August 2010) and the final version 3.0 (January 2011) were produced with inputs from the GLXP teams. During this process, also the original deadline of the GLXP changed (it was December 31, 2012.) The XPF extended such deadline because the process of finalizing the prize rules took longer than expected and the economic conditions had not helped the participating teams to raise funding for their projects.

To be able to enter the GLXP, teams had to register between September 2007 and December 2010 and submit an application package with diverse information about the team and its members, finances, and mission plan. From the time the XPF opened the registration through the end of the calendar year 2008, there was a registration fee of $10,000. For calendar years 2009 and 2010, the fee was raised to $30,000 and $50,000, respectively. Teams could obtain a temporary extension of the $10,000 and $30,000 rates by filing a Letter of Intent to Compete, but no such extensions were possible at the end of 2010.

In the GLXP, the teams own all the intellectual property associated with the design, manufacture, and operation of the spacecrafts, secondary vehicles, and subsystems.

6.1.2 History

The original idea of a competition for lunar exploration emerged from NASA (Pomerantz, 2010a). In 2006, NASA requested Paragon Space Development Corporation and the XPF a study on the impact of an incentive prize for robotic lunar exploration. Paragon's study was a parametric analysis of the cost of the cheapest possible lunar surface mission which would suggest how big a prize purse would need to be to incentivize someone to actually go out and pursue that mission. XPF’s study approached the topic from an opposite angle. The approach was to find out what is the most the agency can get out of the part of the community that might pursue it. Although the results of both studies were not alike, both suggested a prize purse of about $20 million for that kind of challenge but restricted only to a minimum of U.S. teams and to land on the lunar surface and take pictures, but not move. In 2006, the Constellation program for returning humans to the Moon was still a priority for NASA, and a prize like the GLXP would contribute significant data for that program. In spite of that interest, it was difficult for NASA to organize this competition, particularly considering the amount of the cash purse (which requires the proper authorization) and the fact that the competition would have been restricted by law to U.S. teams only. Further conversations between the XPF and experts were followed by Google's interest to support this type of competition. However, this time, incentivizing some kind of surface mobility was important as well and was expected to be the enabling technology that really makes a big difference. Half a kilometer was considered enough as it would demonstrate control and ability to move in any direction.

6.1.3 Organizer, sponsors, and partners

The organizer of the GLXP is the X Prize Foundation. This foundation is an educational, non-profit corporation established in 1994 to inspire private, entrepreneurial advancements in space travel. This is the largest single international prize ever offered by the Foundation but not the only one. The XPF also organized the AXP and NGLLC and has several other prizes in concept development process in areas such Energy and Environment, Life Sciences, and Education and Global Development (XPF, 2011b). Google, Inc. is the sponsor of the GLXP. This company seeks “to organize the world's information and make it universally accessible and useful.” Google has been a long time supporter of the XPF and the “approach of using competition to stimulate the private sector to achieve important goals more quickly and affordably than previously possible.” This competition is not related to Google’s core business yet the company expects to contribute to start what they call “Moon 2.0” or a new era of lunar exploration that will be more participatory and more sustainable than the first Moon race that ultimately led to the Apollo missions (XPF, 2008b).

The XPF has also partnered with other organizations that sponsor this competition and offer products and services to participant teams. They are considered “preferred” partners and relate to different technology aspects of a moon exploration mission. For example, Space Exploration Technologies (launch), will return 10 percent of the launch costs for all launches on their Falcon 1, Falcon 1e, and Falcon 9 rocket vehicles; the SETI Institute (communications,) offers free use of the Allen Telescope Array for receiving data from the surface of the Moon for the first seven Earth days of operations on the lunar surface; the Universal Space Network (communications,) offers a 50 percent discount on communication services for the spacecraft while in transit to the Moon and for 30 Earth days of operations on the lunar surface; Space Florida (launch site,) an Independent Special District of the State of Florida charged by the Florida Legislature with promoting and developing Florida's aerospace industry, offers a Bonus Prize of $2 million to the winner of the competition if they launch from Florida; and AGI (software) provides one license of its STK package for complex mission planning from launch to landing, valued at $150,000 each, to all registered GLXP teams free of charge.

NASA has not officially endorsed or supported the GLXP yet congratulated the initiative of the XPF, particularly with regard to the efforts of the Foundation to engage the youth and inspire students to pursue careers in science, engineering, and other fields related to space exploration (Griffin, 2007). Also JAXA, the Japanese Aerospace Exploration Agency, congratulated the XPF for the GLXP (Tachikawa, 2007).

6.2 The context of the competition[15]

6.2.1 Planetary robotic exploration

The proximity of the Moon has made it an obvious target for planetary exploration and a possible intermediate point to reach farther destinations. The natural resources of the Moon and their potential for the development of economic and scientific activities offer many possibilities (Schrunk et al., 2008). Robotic exploration will allow setting the initial stepping-stone for the exploitation of those resources or the development of future human settlements. Though for limited time and surface range, that robotic exploration started about five decades ago. In 1966, the Luna 9 unmanned spacecraft, part of the Soviet Union's Luna program, become the first spacecraft to achieve a soft landing on the Moon (and on any planetary body other than Earth) and send photographic data back to Earth. Several unmanned missions were conducted since then, by the Soviet Union and the U.S. The last successful U.S. lunar lander was Surveyor 7, the fifth and final spacecraft of the Surveyor series sent to perform a lunar soft landing in 1968. The last spacecraft to land on the Moon was the Soviet Luna 24, in 1976. Since the first robotic exploration of the Moon in 1966, agencies from the Soviet

[15] This section looks at the context of the GLXP and focuses on the technology-related factors that are more directly interrelated with the prize, as discussed in the description of the model to study prizes. Certainly, the accomplishment of missions with goals similar to the GLXP may have non-technological implications that are not analyzed here, such as those related to geopolitical matters.

Union, U.S., European, and Japanese governments have accomplished more than 50 missions to the lunar surface or its orbit, most of them considered successful (Schrunk et al., 2008).

To gain a better understanding of the technical implications of a GLXP-like mission, it is instructive the examination of past space missions and some of their basic statistics. Table 6.1 shows a data summary for selected NASA's Moon and Mars robotic programs. Despite their different planetary target, they have represented similar means to carry on planetary exploration (except for the Ranger missions that used hard landings.) The goals of these programs included both exploration and scientific components. The scientific component was generally related with measuring and analyzing surface and environmental features and included capturing video and images of the visited bodies. The exploration goals of most recent missions were related with landing in certain areas of interest and inspect the surface using rovers to search for targets of scientific interest (e.g. rocks.) Though this means of exploration is considered limited, in most of the cases implies several kilometers of surface traverse.

These programs had budgets between $170 million and $850 million if the costs to build, launch, land, and operate the spacecrafts are considered (rovers may operate longer than originally planned and then generate further operational costs.) Programs such as Mars Pathfinder had capped costs. In other cases, costs had grown significantly. For example, the Mars Exploration Rovers (MER) were developed in exceptionally short periods, yet at the cost of significant budget increments (Dornheim, 2003). Development lead times have approximately been between 32 and 60 months. Robotic planetary missions have had development times shorter than typical Earth-orbiting missions due to constrained launch windows, yet they have failed twice as often (Bitten, 2008).

Over the coming decade, several countries or space agencies are planning lunar landings, including the European Space Agency (ESA,) the Russian Federal Space Agency (Roscosmos,) and the Indian Space Research Organization (ISRO.) For example, ISRO and Roscosmos have partnered for the mission Chandrayaan-2, which includes landing a spacecraft and deploying a rover by 2013 (ISRO, 2010). Two additional missions from China and Japan follow in 2013 and 2015 (Brown, 2010). NASA also considers a GLXP-like mission which comprises landing on the Moon with a robot that can be tele-operated from Earth and can transmit near-live video. Robotic precursor missions of that kind would have life-cycle costs of less than $800 million (NASA, 2010b).

Table 6.1: Selected robotic planetary exploration programs

Program	Mission	Year[a]	Description	Mission duration[b]	Mass (Kg.)[c]	Traverse distance[d]	Program go-ahead to launch period	Development lead times	Budget (current US$)	Scientific component
Ranger (NASA)	Ranger 7-9	1964-1965	Hard landers	Impact	N/A	-	1959-1965 (three blocks of dev.)	(1961 first test launch)	$170 million (9 spacecrafts)	First close-up photos of the lunar surface
Surveyor (NASA)	Survey-or 1-7	1966-1968	First soft lunar landers (Hughes Aircraft contractor to NASA)	30-210 days	N/A	-	1961-1966	60 months	$469 million (7 spacecrafts)	Very little scientific instrumentation; over 100 sensors for surface/ environ. measurements
Luna (USSR)	Luna 17	1970	Lander and Lunokhod 1 wheeled rover	90 days	900	11 km (speed 1-2 km/hr)	N/A	N/A	N/A	TV cameras and other scientific instruments to explore the surface and return pictures
	Luna 21	1973	Lander and Lunokhod 2 wheeled rover	56 days	840	37 km (speed 1-2 km/hr)	N/A	N/A	N/A	
Mars Pathfinder (NASA)	Mars Path-finder	1997	Lander and lightweight wheeled robotic rover named Sojourner.	120 days	11	100 m (speed 0.036 km/hr)	Oct 1993-Dec 1996	38 months	Capped $150M project implementation plus $22M rover	N/A
Mars Exploration Rovers (NASA)	Spirit	2003-today	Mars rover to search for and characterize a wide range of rocks and soils	Jan 3, 2004-today	185	7.7 km (got mired in deep sand)	July 2000-June 2003	32 months; 4 years shorter than historical for this type of development.	Initial cost to build, launch, land, and operate rovers was $299M (each); grew to $420M; "open check book" mission	Panoramic camera and several scientific instruments
	Oppor-tunity	2003-today	Mars rover to search for and characterize a wide range of rocks and soils	Jan 24, 2004-today	185	20+ km	N/A	33 months; 4 years shorter than historical for this type of development.		

Note: a. Program years; b. Duration of planetary exploration; c. Spacecraft mass (including lander and rover); d. Distance traversed in Moon/Mars

Source: diverse journal articles, reports, and specialized media (Spear, 1995; NASA, 1997; CBO, 2004; Zakrajsek et al., 2005; MSNBC.com, 2007; NASA, 2010g, 2010f)

6.2.2 Sector structure

Historically, government-led efforts have driven global R&D in space technologies through government agencies' programs, with emphasis in the U.S., the Soviet Union/Russia, Europe, and Japan. Lately, other countries such as China and India have expanded their space activities and gained a share of the space market.

In the U.S., agencies such as NASA and the Department of Defense have been the main drivers for civil and military space development, respectively. As of today, the U.S. government is still the largest single customer for technologies and services such as launch vehicles. Large corporations such as Northrop Grumman, McDonnell Douglas, and Boeing have been involved since the early days of spaceflight as agencies' prime contractors. NASA has also involved other companies and universities through grants, contracts, and cooperative agreements.

Since their creation in the 1950s and 1960s, government space agencies have generally grown in size and budget and become centralized, bureaucratic, and less productive organizations with substantial fixed-costs. Years of experience have allowed both agencies and large contractors to build strong in-house capabilities, extensive control systems to manage large and multiple projects, and complex hierarchical structures with division of labor between multiple R&D centers (McCurdy, 1994; Bromberg, 2000; Cucit et al., 2004; Petroni et al., 2009). Moreover, corporate structures and practices have been significantly influenced through subcontracting and supervision policies of government agencies (Bromberg, 2000).

Over time, the space industry has consolidated into a few large players and new entrepreneurial companies have entered the space sector offering more affordable solutions for commercial space development (Gump, 1990; Cucit et al., 2004). Three factors explain the emergence of those new aerospace companies. First, a global, constant need to advance technology in diverse areas linked to aerospace has pulled an increasing number of new small companies that can provide technological capabilities the marketplace demands. For example, software programs and algorithms have become major elements in aerospace over time. Other relevant technologies include microbiology, energy, and power systems. This, however, more than a new trend, is the very advancement of technology as the industry moves forward and generates needs for different capabilities that new companies can fill in (Marsh, 2011).

Second, particularly in the U.S., there has been a great deal of new companies started by executives from non-aerospace businesses over the last 10 or 15 years. The origin of this is in, for example, feasibility demonstration projects such as Delta Clipper DC-X,[16] which in the 1990s led many people to revise what the conventional wisdom said about what and what is not possible in aerospace development (Greason, 2010). Since then, new ways of doing business, new ways of managing companies, and new ways of structuring programs have been brought into the aerospace industry from outside. Recently launched, startup-like companies such as Blue Origin, XCOR, Armadillo Aerospace, Masten Space Systems, and SpaceX are examples of that.

Third, there may also be a generational factor for the case of the U.S. The executives of those new companies tend to cluster in a fairly small range of ages and they were either very young or not born yet when the Apollo program finished. These executives may have had a common sense that the potential and promise shown in the last days of the NASA space race had been unfulfilled and potentially unrealized. Therefore, in spite having careers in different industries, these executives had never lost interest in space and, at some point, they had realized that they can contribute to fulfill such promise and potential (Greason, 2010)

New U.S. policies and regulations with more commercial and entrepreneurial orientation to space activities have also contributed to the emerging new space sector and

[16] This is a technology demonstration project to develop vertical take-off and landing vehicles in the 1990s, first led by the U.S. Department of Defense and then by NASA, with participation of McDonnell Douglas Corp.

new forms of organization of R&D (Culver et al., 2007). For example, NASA's programs have contributed significantly to develop this emerging commercial space sector by supporting companies such as SpaceX since 2002. During its first six years—which the company used to develop its first commercial launch rocket from scratch—this company has been backed almost entirely by NASA and its founder's own money (Homans, 2010). This research has discussed some examples too. For example, Armadillo Aerospace, winner of the NGLLC, was awarded $475,000 to perform test flights of its experimental vehicles under the NASA's Commercial Reusable Suborbital Research Program (CRuSR) (NASA, 2010e).

The space sector is also marked by the particular characteristics of space developments. In general, these developments have been characterized by their technological complexity and excessive cost to the point that no one organization or company can afford to tackle space exploration projects alone (Bugos & Boyd, 2008). Large scale, long duration, and one-of-a-kind space projects integrate diverse technologies, multi-disciplinary and multi-team structures, and multi-organization efforts. Market pressures have led large companies to involve suppliers and other partners in the development effort to source specialized competencies, technologies, and knowledge. Yet, generally, those companies have maintained the design authority, administered the development effort, and assembled, tested and marketed the products (see, for example, Baird et al., 2000; O'Sullivan, 2003).

Delays or cost over-runs are common in space programs. For example, in past robotic science missions, NASA had cost and schedule growths of 20 percent or more due to the inadequate definition of technical and management aspects, program funding instability (i.e. funding must be approved annually and priorities change,) program re-designs, technical complexity, and budget constraints (Bitten, 2008). In general, there has been a trade-off between cost, schedule, and performance, with costs as a dependent variable (CBO, 2004). The relationship between cost and schedule is dictated by excessive overhead costs, which results in very expensive technologies when there are long development cycles. For example, the preliminary planning for the Mars Sample Return (MSR) NASA/ESA program—aimed at collecting samples from Mars and returning them to Earth—has began in 2008 yet launch is expected by 2018-2022. The total expected cost of its multi-element, more complex mission is around $6-7 billion (iMARS, 2008; NASA, 2010c). When systems are finally built for this kind of long-term missions, other cheaper commercial solutions are likely to be readily available.

Space flight and exploration systems have increased their performance over time, yet they also have become more complex or "tightly coupled." This has significant impact on project risks. Simpler designs decrease the probability of facing technical problems because there are fewer parts and components and less complex interrelations between them, and the probability of detecting a problem before significant damages is much higher. The complexity of systems leads also to high task interdependency between development teams. Consequently, project management and communications have become critical factors to project success and led to more complex and bureaucratic R&D organizational forms. Also accidents in space projects have led agencies and companies to focus on risk management procedures, which in turn led to increasing bureaucracy and control to prevent failures (Kranz, 2000).

Lately, new approaches to project management have been introduced along with smaller missions. Small spacecraft missions can reduce costs significantly, speed up turnarounds, and allow many more actors to enter the sector, including companies, universities, and countries not traditionally involved with aerospace development. These missions generally use combinations of the latest technology with commercial off-the-shelf (COTS) technologies (Table 6.2). The general miniaturization of COTS components has allowed increasing capabilities in smaller spacecrafts. The lower cost of COTS technologies has also allowed engineers to compensate for their lack of space heritage by engaging in much more rigorous testing at a much earlier stage in program development.

While spacecrafts have traditionally been based on older, heritage parts that are expensive and have long development lead times, new smaller missions are associated with aggressive and early prototyping and testing, rapid development schedules, and focused objectives which leads to faster turnarounds and cheaper missions (Marshall et al., 2007; Bonin, 2009).

The small mission concept has been increasingly adopted. Since the 1990s, NASA has introduced a series of small, fast-track implementation Discovery class missions at low (and sometimes capped) cost. The NEAR Near Earth Asteroid mission and the Mars Pathfinder mission are examples of that kind of approach. Large companies such as Hughes Communications, Inc. and Rockwell International had also worked on small landers development during the 1990s for Mars exploration programs (Spear, 1995; Vorder Bruegge, 1995). There is also an entire small satellite industry based on this approach to space exploration (Bonin, 2009). Small missions have also been the mainstream concept for the new space sector since the first private, commercial, and student-oriented initiatives of the 1990s (Ridenoure & Polk, 1999).

Table 6.2: Main differences between traditional space programs and small missions

	Traditional programs	**Small missions**
Cost	Expensive	Low cost
Development lead times	Long cycles (10+ years)	Fast-track (12-36 months)
Technologies	Low TRL levels, development, and latest technologies	Latest technologies combined with COTS (or other mature technologies) whenever possible, higher TRL levels
Launching	Conventional launchers	Next generation launch vehicles
Size/mass capabilities	Larger spacecrafts and payloads	Size and mass constraints
Risk	Reliability yet higher programmatic risk	More frequent, smaller, higher-risk missions, overall programmatic risk smaller

Sources: Marshall et al. (2007) and own analysis.

Recent examples illustrate the small mission concept very well. For instance, STRaND-1 is a small satellite containing a smartphone payload that will be launched into Earth orbit later 2011. This satellite is being developed by researchers at the University of Surrey and Surrey Satellite Technology Limited (SSTL) to demonstrate the advanced capabilities of a satellite built quickly using advanced COTS components (SSTL, 2011). There are also organizations such as Copenhagen Suborbitals, an open source, non-profit initiative with the goal of launching a human being into space. Based entirely on sponsors, private donors, and part time volunteer efforts (about 20 people,) this organization has performed more than 30 engine tests and is expecting to accomplish its first space flight by mid-2011 with a budget of less than $100,000 (Copenhagen Suborbitals, 2011).

Finally, certain regulations also define technological development activities in the space sector. In particular, U.S. citizens and organizations that develop certain aerospace and defense technologies are required to abide by the U.S. International Traffic in Arms Regulations (ITAR.) This regulation impedes U.S. companies to export technology that may be considered inherently military in nature or has "double-use," which has forced some foreign agencies and companies to introduce "ITAR-free" designs in their spacecrafts (Hudson, 2008). Considering the GLXP, this regulation has two effects. First, ITAR impedes foreign teams to obtain some key technologies for their projects from U.S. companies, including propulsion, communications, and navigation and control systems. Teams without access to certain technologies must depend upon in-house capabilities or buy from alternative sources (when available.) Second, this regulation compromises the business plans of U.S. teams that seek to commercialize their technologies abroad. Multi-national teams are also affected by ITAR, particularly those that are open-source and seek to engage both U.S. and international members. On the other hand, there are sensitive technologies that are only available to U.S. government-funded projects and are not available to any GLXP team (as the GLXP mission must be privately funded.) There are also other aspects related with intellectual property protection that may eventually affect teams that successfully launch their missions and seek to commercialize services. Some maintain that "common terrestrial legal practices" such as licensing terms may not be suitable for outer space operations (Hudgins, 2002; Kleiman, 2010).

6.2.3 Technological capabilities/gaps

The GLXP challenge has a very open-ended definition in terms of certain soft-landing, mobility, and communication capabilities. Moreover, there is no specification of the technologies or means to be used. In 2006, the XPF conducted an industry survey of CEO level individuals from industry, academia, and government to assess the feasibility of a GLXP-like mission (Pomerantz, 2006). Based on a hypothetic $20 million cash purse, 70 percent of the respondents assumed that a mission including a rover and video of an Apollo landing site was feasible without support from NASA. The mission achievement lead time since prize announcement was estimated at about 4 years in that survey.

When the GLXP was just announced, the XPF anticipated a series of challenges that teams would face (Table 6.3). Past government missions faced and sought to work out the same challenges, with exception of fundraising. Certainly, fundraising is a key component of the GLXP mission. Teams not only have to demonstrate their technical ability but also the commercial merits of their technologies if they are not backed by own funding or other sources. The fundraising effort may divert the development effort to win the prize. Thus, project management is very important as it requires a mix of technical and business skills that some teams may not have.

The key requirements of the GLXP mission comprise Earth-to-Moon launch, Moon landing, surface mobility, and Moon video broadcasting. Each of these broadly defined phases of the GLXP mission involves systems and technologies with diverse levels of maturity and needs of further development. For reference only, Table 6.4 shows some examples of technologies/systems for robotic exploration and their maturity level based on assessments of NASA's projects.

Table 6.3: Challenges faced by GLXP teams according to the X Prize Foundation

Challenge	Description
Power on the Moon	Vehicles/bots will likely be solar powered, taking advantage of the Lunar day, which is 14 Earth-Days long. Higher power requirements will require more mass for solar panels.
Surviving Lunar Night	The Lunar night lasts 14 Earth-Days and temperatures fall to -387 degrees Fahrenheit (-233 Celsius) from a high of 253 F (123 C) during the day. These massive temperature swings cause thermal expansion and contraction that can destroy hardware.
Bandwidth (Earth-Moon-Earth)	Bandwidth to and from the Moon is very limited by virtue of power limitations, aperture size, and access to Earth-bound deep-space networks (e.g. 1 Gbits may take 24 hours to be sent back to the Earth)
Time-delay (2.5 second round trip)	Traveling at the speed of light, information –whether that is commands for a rover or video for the public—takes 2.5 seconds to make a one way journey between the Earth and the Moon (no team would use autonomous solutions, they are likely to drive the vehicles from Earth via RC).
Landing Mass	The bigger the mass of the rover/bot and the landing system, the bigger and more expensive the launch service.
Landing Accuracy	Cheap and lightweight systems for landing on the Moon (e.g. airbags) have fairly poor accuracy. More accurate positions are possible with more expensive and heavier systems.
Fundraising	Allowing teams to generate revenue

Source: XPF (2008c).

Earth-to-Moon launch requires having capabilities to reach the Earth's orbit and then transfer the spacecraft to the Moon. Teams may build their own launch vehicles—and even try unorthodox methods such as balloons or spaceplanes—or buy already proven commercially available solutions. SpaceX, partner of the XPF to offer discounted launch vehicles to the GLXP teams, is one of the top players in this market. Commercial launch services are expensive and range, for example, between $10 million to $50 million in the case of the SpaceX's Falcon 1e and Falcon 9 rockets, respectively (the more mass the spacecraft has, the more expensive the launch rocket.) Launch vehicles with similar capabilities and relatively similar costs exist since at least the 1990s (Poniatowski & Osmolovsky, 1995). Teams may be able to launch their spacecrafts as secondary payload to share costs with other spacecrafts. Companies that accept secondary payloads, however, may be unwilling to accept the additional risk of carrying payloads that have their own propulsion systems, something needed to transfer the spacecraft from Earth's orbit to the Moon (Werner, 2010).

Interestingly, some of the GLXP team members attending the 4th annual GLXP Summit suggested sharing the launcher and its costs between teams. Furthermore, the XPF also considered offering a smaller cash purse and providing a launch vehicle for the first few teams to be launch-ready, yet the idea was discarded to, among other reasons, allow a more open-ended definition of the challenge and, eventually, produce more innovations (in this case, innovation in mission approaches to launch the spacecrafts) (XPF, 2011a).

Moon landing is probably the most challenging part of the mission from the technical viewpoint. Since the Moon has no atmosphere, common atmospheric descent methods are not suitable (e.g. supersonic parachutes) and completely propulsive methods are needed. Moreover, this is the only part of the mission that cannot be tested prior to launch, because, on Earth, for example, it is not possible to neutralize the gravity and recreate the vacuum-effect that affects the performance of thrusters and engines that are used for the lander's descent. Industry experts point out that soft landing on the Moon was already achieved by the robotic missions mentioned earlier and even by humans with the NASA Apollo missions, and that is a very important precedent (Greason, 2010; Marsh, 2011). Most sophisticated technologies for lander descent have a medium level of maturity.

Surface mobility to traverse 500 meters is the next important requirement after lunar landing. For reference only, the Mars Exploration Rovers were designed to drive up to 40 meters per Earth-day, yet that goal was notably exceeded (NASA, 2009a). With that minimum daily driving, a GLXP rover might be able to cover the 500 meter distance during a lunar day (about 15 Earth-days long) without requiring more complex equipment for lunar night hibernation. Moreover, while the initial GLXP's MTA versions referred to wheeled rover-like capabilities, the final MTA 3.0 version allows using any type of system to traverse that distance. Mobility technologies have been available since the 1970s with different levels of maturity. About a dozen missions to the surface of the Moon and Mars have used mobile robots and most of them used wheels as their mobility element for locomotion. Most of those mobility designs are spin-offs from terrestrial applications. Others are purely for space application such as hoppers and legged systems and their state of the art is generally low-to-medium TRL. Wheel-enabled systems are already in TRL levels 8-9, yet current systems for space missions are still quite mechanically complex (Seeni et al., 2010). Certain technical complexities are associated with extreme Moon surface conditions such as temperature and the presence of lunar dust. Low/high temperature mechanisms such as motors and robotic arms still need further development (Balint et al., 2008). More complex technological capabilities such as robot-robot interactions are not required by the GLXP, yet teams that use main and secondary crafts may need, for example, rover-to-lander communications capabilities.

Table 6.4: Maturity of planetary robotic exploration technologies, selected examples

Technology maturity		**Selected technologies/systems for robotic exploration**						
		New mobility tech. (e.g. hoppers, leg-enabled systems)	**Wheel-enabled systems**	**Propulsion Advanced Development (warm gas)**	**Lunar Dust Mitigation**	**Energy Storage**	**Autonomous Landing and Hazard Avoidance Technology**	**Mars Sample Return**
		Technology application						
		Rover's mobility		Lander's descent main engine	Bearings, seals, lubricants	Primary fuel cells and regenerative fuel cells	3D Imaging Flash LIDAR	Diff. tech. under NASA's SBIR program[a]
Mission use	TRL 9		**X**					
	TRL 8		**X**					
	TRL 7							
Maturation and demonstration of capability	TRL 6							**X**
	TRL 5			**X**			**X**	**X**
Prove feasibility of novel, early-stage idea	TRL 4	**X**		**X**	**X**	**X**	**X**	**X**
	TRL 3	**X**		**X**	**X**	**X**	**X**	**X**
Early stage innovation	TRL 2							**X**
	TRL 1							

Note: a. These technologies include, for example, Ablative Thermal Protection Systems, Sample Encapsulation Devices, Low Cost Igniters for Ascent Vehicles (Parabolic Arc, 2010).

Source: diverse scholarly articles and reports (Zakrajsek et al., 2005; NRC, 2008; Braun, 2010; Seeni et al., 2010).

The GLXP challenge does not pose complex scientific goals as those seen in past robotic missions, yet it does include the requirement of broadcasting high-definition video. This requires the implementation of high-definition cameras according to specifications of the prize rules and a data-link for image/video data transmission. The prize rules do not specify the characteristics of this subsystem yet requires certain capabilities such as being able to capture full 360º views of the landing site. This kind of requirements may involve more complex technical solutions. For example, cameras have to include more mechanisms (such as motors) to be able to capture images and video from multiple views. Moreover, while high-definition video capabilities are well developed for Earth applications, this would be the first time that high-definition video is transmitted from the Moon.

At last, but not least important, experts suggest that pursuing an Apollo-like landing or similar type of projects under very different conditions may represent actually a significantly different problem if the commercial viability of the technologies is sought. An industry expert explains: *"Cost matters. If what you are trying to do is develop a capability that might be commercially viable, figuring out how to do it 40 years later, a similar job, but for 1/100th of the prize, that's a difference in price that's so so large as to make the quantitative and qualitative difference in the problem."* (Greason, 2010)

Although more pressing cost/schedule conditions may actually pose a new problem if the commercial merit of the technologies has to be considered, there are no significant technology gaps to be closed to accomplish the GLXP mission. The most significant development efforts may be in fundraising and not in R&D. *"A very large share of the cost of winning the prize is going to be a check that you write to a launch vehicle provider. And clearly there is no technology involved in that,"* explains the same expert (Greason, 2010) Another expert also suggests that the conditions set by the GLXP challenge points to areas of potential innovation, which is more likely to occur in technologies used beyond the Earth low orbit. He explains that *"the ride is going to be on* *existing technology"* yet there may be new or advanced technologies in payloads, for example (Marsh, 2011).

Certainly, many technologies needed to accomplish the GLXP are commercially readily available, including both space rated and less expensive non-space components. These technologies might require engineering effort to reduce the cost of achievement, which is an independent variable in this context. Significant knowledge from past experiences is also available. For example, NASA's Technical Reports Server (NTRS) is a rich, publicly available source of technical documentation (e.g. a quick search of the keyword "lander" matches 9,362 documents.)[17] On the downside, some technologies that allow higher performance and have been used in agencies' planetary missions are not likely to be available to teams as they require special government authorization. This is the case of, for example, energy subsystems such as Radioisotope Heater Units to maintain sensitive electronic equipment at normal operation temperature in deep space or other planetary environments. This technology was used in, for example, the Soviet Lunokhod moon rovers to hibernate through many nights, keeping the craft's interior sealed and warm.

6.2.4 Technology scenarios

This research maintains that the assessment of the expected technology scenarios or forecasts is necessary to better understand the potential effect of prizes on innovation. To better understand the impact of the GLXP on technological innovation, this research should be able to identify a) capabilities required by the project that may require technology advancement over current-day technologies (i.e. the notion of prizes to accelerate technological development,) and/or b) breakthroughs or unexpected GLXP technology outputs from the point of view of capabilities anticipated in technology

[17] NASA's Technical Reports Server (NTRS) is available at: http://ntrs.nasa.gov/search.jsp

forecasts (i.e. the notion of prizes to induce the development of technologies that otherwise do not seem to be forthcoming.) It is not the purpose of this research to forecast when or how technology breakthroughs will ultimately occur.

Some technological fields deserve special considerations. The GLXP is embedded in a space agency-led sector and, therefore, the technological development pathway is highly dependent on priorities given to different areas of space development or space programs. Agencies such as NASA prepare technology roadmaps that can be used as proxies of technology scenarios. These roadmaps do not determine what technologies will be ultimately developed yet put forward priorities that shall be addressed by agencies to accomplish programmed missions. The literature also provides some insights on the expected technological developments in this area.

Space technology scenarios can be developed at, at least, the programmatic and subsystem levels. The expected evolution of mission approaches can be assessed at the programmatic-level. Table 6.5 shows how robotic planetary exploration approaches will differ from past missions in the long-term. Improvements in technologies for robotic planetary exploration are expected in a number of aspects. New mission approaches are expected to provide higher scientific returns by deploying multiple units per mission and increasing the reliability of the programs. While the program costs may not decrease, the use of multiple agents reduces the costs and risks involved in catastrophic damage of single units. Mobility capabilities of robots are expected to expand due to the introduction of new mobility systems and more intelligent coordination and exploration of multiple sites per mission. It is also expected for future missions to reach beyond the limits of current-day missions to accomplish longer surface exploration distances in autonomous mode. Science capabilities are also expected to increase as new, on-site assistance for decision-making is added to the current-day features of scientific instruments. Overall, these expected capabilities for mobility and science operations will make possible significantly longer missions.

The subsystem-level assessment of future technological scenarios provides further insights on how individual mission components are expected to evolve in the medium- or long-term. Table 6.6 shows selected examples of key subsystems relevant to a GLXP-like mission and their expected development by 2020 according to NASA's technology roadmaps. The purpose of this research is not the technical assessment of the state of the art of these subsystems, yet offer insights on the potential contribution of the GLXP to space developments. The general examination of these examples shows that the state of the art in some of these technologies refers to the capabilities seen in the Mars Exploration Rovers launched in 2003. This suggests development cycles of 10 years or more considering that no other mission deployed more advanced technologies lately. Moreover, these technologies—with a few exceptions in propulsion systems—are in low and medium TRL levels. NASA seeks to develop/test these technologies internally or through programs such as the Small Business Innovation Research (SBIR) program.

Table 6.5: Comparison of past and future robotic planetary exploration capabilities

	Past robotic planetary exploration	**Future robotic planetary exploration**
Approach	• Deployment of single-surface-based, spatially constrained agent (e.g. lander or rover) • Expensive (low-cost missions more likely to fail)	• High reliability, high science return, low-cost missions • Hierarchical "tier-scalable" autonomy; orbital-, airborne- and surface-based units (e.g. orbiters, balloons,a rovers) • Multiple low-cost and expendable deployed agents in surface
Mobility	• Dependency on remote Earth-based human control • Surface-based agents with limited viewing range • Spatially constrained; locally optimal paths for exploration through limited areas • Short-distance mobility: e.g. MER distance between interventions = 40 meters • Terrain capabilities: gentle slopes, sparse obstacles, dense rocks • Mechanism: wheeled, surface-based agents	• Autonomous reconnaissance missions with manual override at all levels • Regional optimal paths for exploration • Multiple exploration sites • Long-distance mobility: 1+ km between uplinks • Terrain capabilities: hazardous and inaccessible locations; craters, steep slopes, dense obstacles; tethered exploration of cliffs • Mechanisms: legged or hopping systems
Science opera-tions	• Single scientific targets • Multiple, expensive instruments in single agents	• Multiple targets with agents assistance to decision about features that are worthy of scientific investigation • Scientific instruments distributed between multiple agents
Risks	• No redundancy; high risk of losing mission if an agent is damaged or destroyed	• Redundancy; mission reliability and safety
Duration	• Weeks, months	• Months, years

Notes: a. balloons are restricted to exploration of bodies with atmosphere (e.g. Mars)

Source: based on literature (Pedersen et al., 2002; Fink et al., 2005; Seeni et al., 2010) and NASA's websites for past missions.

Table 6.6: Technology state of the art and NASA's roadmap for GLXP-related technologies (selected examples)

Mission component	Subsystem	Technologies relevant to GLXP-like missions (selected examples)	
		State of the art	**Roadmap (~2020)**
Earth-to-Moon transfer	Propulsion	Ion thrusters at TRL6 require flight demonstration or mission application	Higher thrust, longer life, more efficient ion motors
Landing	Avionics and navigation	Lander horizontal velocity estimation (Mars Exploration Rovers)	3-D Imaging Flash Lidar for safe landing / hazard detection and avoidance
	Chemical propulsion	Cold gas systems are TRL 9; warm gas are TRL5/6	Warm gas thrusters development
Mobility	Hazard avoidance	Local map-based obstacle avoidance, limited onboard autonomy enables hazard avoidance while driving (Mars Exploration Rovers)	Quickly assessment of subtle terrain geometric and non-geometric properties (e.g. visually estimating the properties of soft soil;) "autonomous systems" that resolve choices on their own, with target geometry unknown
	Mechanisms	Predominant wheeled systems with specific problems related with extreme environments.	High performance in traversing extreme terrain; new mobility mechanisms (e.g. motors that work under extreme conditions)
Communications	Downlink rates	2 Mbps	200 Mbps

Source: based on NASA's technology roadmaps (NASA, 2011).

6.2.5 Technology related incentives

To better understand technology development trends in the space sector and assess the impact of the GLXP, this research examined the perceptions regarding the value of the technologies involved in this prize. Insights from experts and other sources also allowed a better understanding of the future drivers of these technology markets. The peculiar characteristics of the space sector have significant influence in the structure of the space technology markets. In particular, space agencies have significant influence through their space programs and programs aimed at promoting entrepreneurship and commercialization.

The GLXP—and other competitions launched by the XPF—are designed to have multiple backend business markets that can be supported by the technologies developed in pursuit of the prize (Pomerantz, 2010a). Ideally, prize entrants should be able to continue working on the commercial development of the prize technologies after the end of the competition and be able to differentiate their strategies through different business models. The XPF has expected the immediate near term market to be NASA and other foreign space agencies and GLXP teams to be able to provide data, heritage for new hardware, and, at the broad extent, risk management for government funded space missions. For example, the recent NASA's Innovative Lunar Demonstrations Data (ILDD) program has awarded six GLXP teams with contracts to purchase $30 million worth of data from commercial lunar missions. Moreover, the XPF expects that "many contenders might eventually go into business, flying lunar robotic missions for $50 million or $60 million." (Hsu, 2010)

There is a consensus about the main drivers of technology development in this sector, yet there is uncertainty on the size of the potential markets for the prize technologies and the time horizon for their realization (Table 6.7). Experts and other sources (and even GLXP team leaders, as describer later) consider NASA and other space agencies as the most important customers. Private customers might increase their share of demand only in the mid- or long-term. Only reports by Futron Corporation—a technology management consulting firm—have provided some concrete estimates of the market value of technologies for lunar exploration and related services. On the other hand, experts explain that it is very difficult to know whether there is a market for commercial lunar surface activity of one kind or another and, therefore, the value of those potential markets is uncertain. Moreover, experts suggest that this market depends greatly on the reactivation of NASA's programs aimed at lunar exploration such as Constellation. Finally, experts have also pointed out that the broader economic context has not been favorable for space projects lately.

A more detailed estimate of the size of the lunar market has been available to the GLXP teams. This estimate was developed by Futron Corporation and presented at the 4th annual GLXP Summit (Table 6.8). Considering all segments for commercial lunar activity, this market may be worth up to $1.6 billion in the next 10 years. The study by Futron remarks the problems to assess the size of individual markets due to the lack of successful track record in them and the lack of comparisons with other markets. This study also considers the government sector as the most important driver through the purchase of hardware and services. The private sector market for space hardware and other revenue streams may be also available to emerging companies in the sector. For example, GLXP teams may provide services of payload transportation, sell mission data, or even provide some communication or entertainment services to private customers.

Table 6.7: Perceived technology incentives and expected scenarios related to the GLXP technologies

	Experts	**Other sources**
Perceived technology-related incentives *(incentives that the introduction or commercialization of technologies have for R&D performers)*	• Uncertainty on whether there is a market for commercial lunar surface activity of one kind or another • Government interest in planetary landers and Moon exploration still exists • NASA's plans to return to the Moon would be a significant incentive, if "reactivates something like Constellation"	• Lunar Market estimate 2011-2019: \$1.0 to \$1.6 billion (Futron Corporation, 2010b) • NASA as a customer may pay between \$4.5 and \$7 million per kg. for lunar transportation (optimistic and pessimistic scenarios, respectively) (Futron Corporation, 2010a). • NASA's 2011 budget proposal includes funding for lunar expeditions to test remote control of robots (Hsu, 2010).
Future drivers *(for the next 3-5-10-20 years)*	• **3-5 years**: economic slowdown affects the sector; programs may be cut or scaled down (both public and private); NASA's support for commercial resupply linked to space station; NASA's investment in commercial companies that can serve its needs continues • **5-10 years**: government agencies continue to be driving force; NASA has fixed demand for commercial services • **20+ years:** agencies drive human exploration of the Moon	• **5-10 years:** NASA and other agencies are main driver (Futron Corporation, 2010a); uncertainty about NASA's programs (ASAP, 2011) • **10+ years:** NASA continues to be the driver; other foreign agencies are potential customers too; commercial demand increases (Futron Corporation, 2010a); NASA's budget for lunar exploration expected to grow (CBO, 2004)

Note: experts contributed to these estimates to different extent, according to their area of specialization and present knowledge (they did not conduct any pervious analysis to contribute these estimates.)

Source: experts' assessment is based on interviews with industry experts cited in previous sections; other sources are cited in table and text.

Table 6.8: Lunar market size estimate, by segment

Market segment	Size estimate (2011-2019)
Hardware sales for government sector	$700M
Services for governments	$200-400M
Products for commercial sector	$30-160M
Entertainment	$10-100M
Sponsorship	$50-100M
Technology sales and licensing	$10-100M
Total	**$1,000-1,560M**

Source: Futron Corporation. (2010). Emerging Commercial Lunar Activities: Assessing Market Size and Development, Presentation to the Google Lunar X Prize Summit. Isle of Man, UK.

The market segments presented by that study represent different business and revenue models. No much data are available to assess opportunities for each case. For the case of payload services, another recent study by Futron Corporation about commercial Lunar Transportation suggests that *"…the majority of investors view lunar transportation as a new, unproven industry without proven business models that provide multiple revenue streams."* (Futron Corporation, 2010a) For that reason, the study continues, venture capital investors expect returns on investment of 40-50 percent for space-related ventures. Private equity seeks 30 percent or more. In addition, to become interested in space ventures in the short-term, investors request strong commitments of NASA-funded programs, several “beta-successful” companies, and multiple revenue streams, among others (Futron Corporation, 2010a).

It should be noted that commercial lunar exploration is not a new idea. This research was able to identify at least two private initiatives addressing such market. The first is BlastOff!, a company that was founded in 1999 to develop entertainment space missions financed through the sales of advertising, media content, merchandising, and payload delivery. Peter Diamandis, founder of the XPF, has been CEO of this company. The planned $50 million missions included soft-landing, rovers for long distance travel (10-20 km,) and high-definition video/image broadcasting (the company planned to use consumer-grade cameras.) (Diamandis, 2008) The planned costs for the first and second missions were $50 million and $20 million, respectively, and the expected revenues were at $250 million. The company was able to raise about $15 million in private funding, yet ceased operations after the dot-com stock market crisis of 2001 (Pomerantz, 2006).

The second private initiative is LunaCorp. The case of this startup is similar to that of BlastOff! and is very interesting due to its connections with the GLXP. LunaCorp was co-founded in 1989 by today's GLXP Team Astrobotic president. Table 6.9 offers detailed data on this space venture and shows that the total mission cost is among the most significant differences between the both initiatives ($250 million then, $100 million now.) LunaCorp startup planned to land a rover on the Moon and offer a number of services associated with the mission, including tele-presence experiences and payload delivery. Team Astrobotic is pursuing similar market opportunities with the GLXP and have already received contracts from NASA for hardware demonstration and mission data. This team also offers payload delivery to private customers. Both enterprises are notably similar. LunaCorp could not raise enough interest from sponsors and went out of business in 2003 (Reichhardt, 2008). Team Astrobotic has been among the first teams to announce its participation in the GLXP and has contributed significant technology outputs, as described later in this section. This team has also been the first team to publicly announce the signature of a launch contract for its mission with SpaceX.

Table 6.9: LunaCorp private initiative in the 1990s and Team Astrobotic, a GLXP business case example

LunaCorp	Astrobotic
• Business executives, scientists, and former NASA officials founded LunaCorp in 1989; Mr. Gump is the company's President. • Dr. William "Red" Whittaker of Carnegie Mellon University joins LunaCorp in 1993 to develop lunar rovers. • NASA supports CMU's lunar robotics effort with $1.25 million a year. • Placing two rovers on the Moon would have cost $250 million in 1996 dollars ($75 million to launch both primary and back-up rover missions, $12 million in insurance to pay for a third mission, $80 million to develop rovers, $38 million for technical and management oversight, and $45 million for contingency.) The cost announced in 1999 ranges between $80 million and $200 million. • Expected revenues $365 million: theme parks or telepresence ($80 million,) corporate sponsors ($76 million,) science ($74 million,) TV networks ($65 million,) ancillary sales merchandising ($55 million,) Internet ($15 million.) • Rovers with 20-50 kg. payload capacity at $1.2 million per kg. • New reusable Roton vehicle by Rotary Rocket, or Boeing's Delta II	• Spin-off of Carnegie Mellon university created in 2007; Mr. Gump is Astrobotic's President. • Core team led by Dr. William "Red" Whittaker, also participated in DARPA Challenges in 2005 and 2007 (won the latter) • Seeks to win $24 million in prizes with GLXP mission in 2013 • GLXP mission will cost $90 million, may generate up to $175 million in revenues • Plans to send a robot to the moon every year after accomplishing the GLXP mission • Planned future activities on the Moon: mining (e.g. iron, aluminum), establish first Moon outpost • Awarded NASA's $10 million contract for ILDD (Nov 2010); NASA's $600K, two-year contract to develop lunar mining technology; NASA's $500K purchase order (from a $10 million total) for hardware demonstration (Dec. 2010) • Other planned revenue sources: remote experiences, communications via rover, training, music and art sponsorships • Private investor contributed funding • Spacecraft contains a 175-pound rover and up to 230 pounds (103 kg.) of payload for customers; they would pay $2 million per kg. of payload • Astrobotic signed contract with SpaceX to use Falcon 9 to launch the 900-pound spacecraft (Feb. 2011)

Note: these data do not represent a systematic comparison and are shown as a reference only.

Source: LunaCorp (1996), Cronin, M. (2011), Bloomberg Businessweek (2011), and Astrobotic's website.

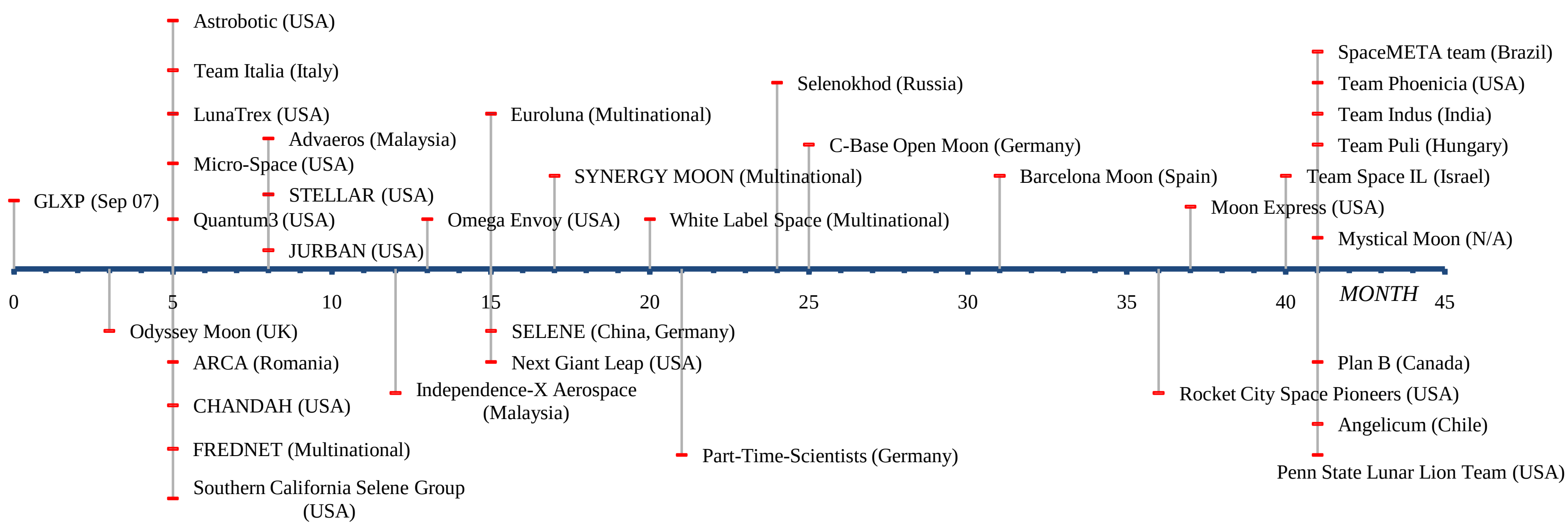
6.2.6 Other prizes

There is no other ongoing prize competition equivalent to the GLXP. Similar prizes implemented simultaneously might dilute the incentive power of this competition. Prizes only related to some extent to the GLXP include NASA's National Lunar Robotics Competition. In October 2009, three teams claimed a total of $750,000 in prizes at this competition. Competitors were required to use mobile, robotic digging machines capable of excavating at least 330 pounds of simulated moon dirt, known as regolith, and depositing it into a container in 30 minutes or less. The rules required the remotely controlled vehicles to carry their own power sources and weigh no more than 176 pounds (California Space Education and Workforce Institute, 2009).

Moreover, the incentives offered by the GLXP may change if there is an equivalent government mission to the Moon (i.e. if there is a "government landing" the Grand Prize would be reduced to $15 million.) Space agencies from countries like India and China have ongoing programs that may include Moon surface exploration. There are also new NASA initiatives with the goal of sending robotic spacecrafts to the Moon. The NASA's 2011 budget proposal considers lunar expeditions that would test the ability to control robots remotely from Earth or the International Space Station and transmit near-live video (Hsu, 2010; NASA, 2010b; Werner, 2010).

6.3 The prize entrants

Thirty-five teams from 17 countries entered the GLXP between September 2007 and February 2011 (Figure 6.1). Six teams have withdrawn/merged and 29 remain in competition to the date this research was finished. Those 35 teams that entered officially include 17 U.S. teams and 18 foreign or multi-national teams (Figure 6.2). For example, the team Synergy Moon reports having members from at least 15 different countries, including Bosnia, Serbia, Slovenia, Ireland, Sri Lanka, France, Australia, New Zealand, and USA, among others (GLXP, 2010b). Notably, several countries with teams in the GLXP have not had any significant space program before. The actual number of teams and participant countries exceeds the initial target of the XPF, which was about a dozen teams from a few countries (Pomerantz, 2010a). To enter the competition, the XPF have required entrants to be some type of legal entity that it is not an individual (e.g. company, foundation) and sign a *Letter of Intent to Compete* first and then have 90 days to formalize its participation, or loss the registration fee. Not all teams that submitted a letter of intent ultimately entered the competition (Appendix Figure B.1).



Note: The timeline indicates months since prize announcement; the deadline for registration to enter the competition closed in month 39.
Source: based on official press releases by the XPF.

Figure 6.1: Timeline with official entry period of GLXP teams

Note: entries as of Feb. 2011.
Source: X Prize Foundation.

Figure 6.2: Countries of GLXP team headquarters and member locations

There are diverse reasons why teams enter the competition months or even years after the prize announcement. The XPF suggests among the factors that may have prevented earlier entries are the economic slowdown that started in 2007 and the secrecy preference of some teams that might prefer to wait until their technologies are more mature before announcing its participation. From the late entrants' viewpoint, such economic slowdown may have played a positive role, as it may have prevented the teams that started earlier from getting as much of a head start as they might have (Pomerantz, 2011b).

Many more potential entrants have demonstrated interest in this competition. Between the prize announcement and the summer of 2009, the XPF received more than 2,500 inquiries from individuals, companies, and universities from 96 different countries (Pomerantz, 2011a). The XPF had required interested teams to submit an application package with diverse information about the team and its members, finances, and mission plan. Only those applications deemed serious were accepted. Non-serious potential entries comprise those applicants that are “completely unaware of what they are getting into,” are only seeking access to the “brand” of the competition or its sponsors and partners, or are critically reliant on demonstrably impossible methods. Applications were not rejected in any case, yet a few interested would-be entrants were asked to revise their proposals. During the 2007-2010 registration period, between five and 10 applicants were invited to re-submit revised versions of their applications. In this regard, the registration fees acted as an “external validator.” Fees are considerably lower compared with the expected cost of a GLXP mission. If would-be entrants are not able to raise funding to cover the entry fees based on a credible project proposal—assumes the XPF—then either their intentions are not serious or their mission designs have significant flaws. The most significant difference between the GLXP teams and those that ultimately did not enter the competition might be the level of seriousness of the applications. Inquiries that did not turn into formal entries seemed to be more “spur of the moment” (Pomerantz, 2011a).

Otherwise indicated, the rest of this research focuses on the analysis of 17 teams that participated by responding questionnaires, accepting interviews, and/or allowing site visits. This research gathered team-level data until December 2010. To that moment, only 26 teams had been officially announced as competitors and 23 of them were still active. A few other teams had signed letters of intent to compete as described in the previous paragraphs.

The GLXP teams adopt diverse legal forms. Seventeen teams reported their type of entity in questionnaires. Eight teams (47 percent) are for-profit organizations (e.g. company,) five teams (29 percent) are non-profit organizations (e.g. foundation,) three teams (18 percent) are independent, informally organized teams (e.g. group of colleagues,) and only one team is part of a larger organization (e.g. part of a university, company, or similar; in this case, part of a company.) Further investigation based on documentary sources and interviews indicates that the type of organization teams adopt may be correlated with the origin of the team. For example, a European team explains, it is easier to incorporate the team as a non-profit but, in turn, it is more difficult to receive donations. Also, some multi-national teams include groups that adopt different organizational form in each country for related reasons. In questionnaires, five out of eight for-profit teams (i.e. companies) reported to be based in the U.S. and four out of five non-profit teams reported to be based abroad.

Most of the prize entrants are “GLXP prize teams” yet there are also some pre-existing teams. Eleven out of 17 GLXP teams (65 percent) were created exclusively to enter this competition. The six teams created before the GLXP have a working experience as a group that ranges from three to 20 years.

This research classifies the individuals working with teams into members and collaborators. Members are those individuals permanently with the team. Members are classified into full- and part-time according to the time they spend working on the GLXP. These members are considered to form the core team. Full-time members are those that spend 80 percent or more of their time working on the GLXP project. Part-time members are those that are permanently with the team, but share time with other job or activity. Collaborators or *volunteers* are the people that work with the team sporadically, only when it is necessary (maybe even remotely.) The total number of people engaged at any time in the GLXP project of a team is the sum of full- and part-time members and active volunteers.

The size and composition of teams varies significantly among teams and over time. New people join the teams and some people step down. There are also sporadic collaborators and volunteers. The teams that participated in this study had between one and 40 full- or part-time members when responding a questionnaire. The small size of some teams is generally explained by either the recent entry date or their early stage of project development. In average, these teams had four full-time and 11 part-time members. All but three teams enrolled an average of 14 volunteers each, with a maximum of 80 volunteers for a team. Considering both members and volunteers, the author’s estimate is that the 17 teams that responded a questionnaire engaged at least 438 people in 2010 (this is about two years and a half after the GLXP announcement.)

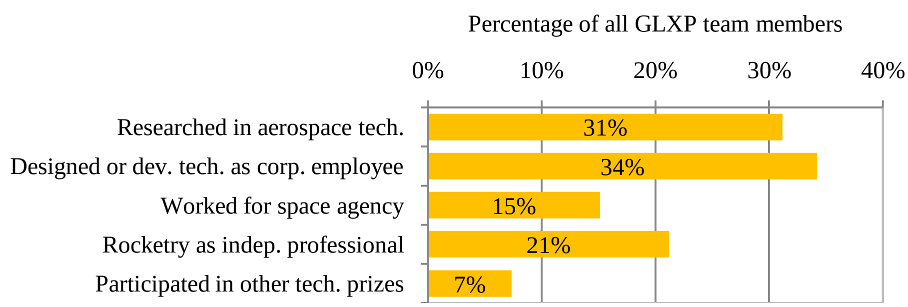
That estimate based on questionnaires may be misguiding when thinking of the total number of people engaged in the GLXP. Team FredNet is a special case and an example of that. This team is pursuing an open-source approach to the GLXP project and has enrolled more than 500 volunteers from about 30 different countries. These volunteers are between eight and 80 years old and contribute remotely to the project. In spite of its non-profit/open-source quality, the team has members dedicated to business development and has goals beyond the prize (Evadot, 2009). There is another open-source team in the competition yet its number of members is considerably smaller.

Based on the responses of 15 teams, the primary background of the GLXP team members is engineering with diverse complementary backgrounds. In average, at the moment of responding the questionnaire, 58 percent of the team members (full- or part-time) had an engineering background, 19 percent have a physics/chemistry/mathematics background, 14 percent have a computer science/IT background, and 23 percent have other backgrounds.[18] The data also show a significant proportion of team members with graduate education among the GLXP entrants. Five teams have 90 percent or more members with graduate education level. Moreover, in average, 15 percent of the team members have reached the Ph.D. education level; 42 percent reached the Masters level; 30 percent the College/Bachelor level; and nine percent reached only a High School level. In total, about 100 Masters-level and 40 Ph.D.-level team members have been engaged during 2010. Other 80 team members with College/Bachelor degrees were engaged as well.

The professional experience of team members varies but is still linked to aerospace technology research and development (Figure 6.3). Overall, minor proportions

[18] The total adds up to more than 100 percent because the questionnaire allowed respondents to indicate more than one type of educational background for each team member.

of the (full- or part-time) team members have working experience at either aerospace industry (34 percent) or space agencies (15 percent.) Moreover, almost 31 percent of the team members have undertaken academic research in aerospace-related topics and almost 21 percent have some type of rocketry experience as an independent professional. A few GLXP teams and about seven percent of all team members have already participated in other technology competitions. For example, Team Micro-Space has participated in both the GLXP and the N-Prize until recently. Team ARCA participated in the AXP. Rocket City Space Pioneers' leader was part of Scaled Composites, the team that won the AXP. Team Phoenicia also participated in the NGLLC. Some members of Team Astrobotic participated in the DARPA Challenges (and won the 2007 edition of the competition.) Finally, a handful of team leaders have some entrepreneurship experience prior to this competition.



Note: N=17 cases.
Source: questionnaire to GLXP teams.

Figure 6.3: GLXP teams' professional experience

This research uses the team members' work experience data to classify GLXP teams into unconventional and conventional entrants (Table 6.10). Teams with significant space agency/industry experience (i.e. 50 percent of team members or more) have been classified as *aerospace-experience* or *conventional teams*. The rest of the teams have been considered *unconventional teams*. Data gathered from 17 teams yield a classification into nine unconventional teams and eight conventional teams. When the analysis required the classification of teams that did not participate in the study (for example, to assess technology outputs) the researcher assessed the information publicly available about the team and type of entity (i.e. for-profit, non-profit, or independent.) Nine teams that entered before December 2010 did not participate in this study. Five of those nine teams are companies or groups thereof and have significant aerospace experience. These five teams are considered to be conventional. There are also three non-profit organizations or independent groups and one team organized as a group of companies and NGOs with uncertain space agency or industry experience. These four teams are considered unconventional.

That classification allows a more systematic analysis of the motivations, R&D activities, and technology outputs of prize entrants. This is a required assumption to continue this research yet, considering the diversity observed in teams, a word of caution is necessary. The competition has a moving target and teams evolve over time and therefore their perceptions and organization may change. Moreover, teams also change as both the competition and themselves gain visibility. Teams may gather new resources including more experienced or skilled new members. Teams may also evolve and adapt their form of organization to be able to raise funding or gather other resources and continue participating in the competition. This does not necessarily happen in other short-term prizes with less challenging goals.

Teams have grown significantly since they entered the competition. The membership of the teams that responded a questionnaire grew an average 170 percent between the moment of their creation and their participation in this study. The most significant average growth was found in the number of full-time members (about 190 percent,) followed by the average growth of part-time members (about 140 percent,) and then number of volunteers (about 90 percent.) At the moment of its creation, the largest team enrolled 15 members (full- and part-time) and the smallest team was just volunteers collaborating sporadically. The volunteer effort has grown significantly as well. Only two teams started with significant number of volunteers (60 and 15, respectively) when formally created. FredNet is the team that has grown the most. The team enrolled about 20 people within the first week of participation in the GLXP and then grew to about 100 people in a few months. Currently, this team has about 500 members and volunteers from about 40 different countries (Evadot, 2009). Other teams have successfully recruited new members thanks to their participation at conferences and industry events. For example, team Part Time Scientists grew from 40 people in April 2010 to about 70 in October 2010 by using those means. In interviews, the author learned that having an online presence helps teams significantly in the process of recruiting new members and volunteers. That presence not only comprises a team website, but also extensive use of social networks such as Facebook. Another method used by teams is presentation at conferences and talks at university classrooms, which has allowed a few teams to engage students (T11, 2010) and, sometimes, meet new partners (T20, 2010). A few teams such as White Label Space and Team Italia have presented papers describing their GLXP missions at academic conferences.

Table 6.10: Main characteristics of GLXP teams that participated in this study

	Unconventional teams									Aerospace-experience or conventional teams							
	T4	**T6**	**T7**	**T11**	**T13**	**T16**	**T18**	**T19**	**T23**	**T3**	**T14**	**T20**	**T21**	**T22**	**T24**	**T25**	**T26**
Created exclusively for GLXP?	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No
Type of entity	Profit	Non-profit	Indep.	Profit	Non-profit	Non-profit	Part other.	Non-profit	Indep.	Profit	Indep.	Non-profit	Profit	Profit	Profit	Profit	Profit
Origin	USA	Foreign	Foreign	Foreign	Foreign	USA	Foreign	Foreign	USA	USA	USA	Foreign	Foreign	Foreign	USA	Foreign	USA
Members	20	10	20	40	38	11	15	6	1	21	12	1	12	7	11	4	2
Volunteers	8	5	50	10	80	n/a	0	25	3	0	2	15	2	6	0	n/a	1
Space agency - industry experience (% of members)	5% - 10%	10% - 0%	0% - 5%	10% - 20%	0% - 16%	0% - 0%	13% - 33%	0% - 0%	0% - 0%	24% - 71%	0% - 100%	100% - 100%	17% - 100%	57% - 86%	36% - 55%	0% - 100%	50% - 50%
Students (% of members)	71%	0%	0%	25%	18%	100%	27%	67%	100%	24%	8%	0%	0%	29%	9%	n/a	0%
Predominant background (% members)	Eng. (45%)	Other (67%)	Eng. (80%)	Comp. Sci./IT (31%)	Eng. (53%)	Eng. (100%)	Eng. (67%)	Eng. (67%)	Eng. (50%)	Eng. (71%)	Eng. (67%)	Eng. (100%)	Eng. (58%)	Eng. (57%)	Eng. (64%)	Eng. (50%)	Eng. (100%)

Note: data corresponds to the date of completing the questionnaire; classification of teams into "unconventional" and "aerospace-experience" is based on significant proportion of members with experience in space industry or agency; the researcher confirmed the type of team with other data sources whenever these were available.

Source: questionnaire applied to GLXP teams.

Prize advocates emphasize the advantage of prizes to engage students and other individuals not typically involved in R&D. This research examined this aspect of prizes by asking teams about the number of student and/or female members. In average, 15 teams reported that 27 percent of (full- or part-time) members are students and 24 percent are women. In total, about 50 women and 66 students were engaged as team members at the moment these teams responded a questionnaire. After discussing the participation of students with teams in interviews, the researcher discovered that the real number of students engaged is higher, yet with a volunteer role. The number of students involved with teams also fluctuates considerably depending on the month of the year (e.g. when students return to class at the beginning of a semester.) For example, a team leader estimates that up to 200 students may have participated in a 20-people, university-based team during the first three years of competition (T4, 2010).

The assessment of the potential contribution of students to the prize developments varies, however. For example, a team leader explains that "*the problem with students is that you have to put a lot of energy into supervision of them*," and that that may offset the benefits of having them in the team in some cases (T20, 2010). On the contrary, a GLXP team's engineering student explains students' contribution with these words:

> *"Us as students, we're extremely passionate. We're right in the heart of our careers. We are learning a lot we know everything off of the top of our heads, and we have fresh thinking. We don't have any traditional designs that would influence the way we work. We can kind of come up with new approaches and new ideas and just run with it, and not have to worry too much about what we've done in the past because we haven't done much in the past. […] We have all of our time to dedicate to these things, we don't have to focus on other projects that we are getting paid to do and put this*

aside. We can continue working on it. So, things are getting done pretty fast." (T16, 2010)

Interestingly, GLXP teams have very diverse goals including some beyond the prize achievement (Table 6.11). The achievement of some of these goals requires winning the competition or, at least, having a good performance (e.g. demonstration of technological leadership.) Yet, other goals may be achieved with the mere participation in the competition. For example, some teams have entered the GLXP to inspire other people or get hands-on experience. Moreover, there are teams that *"are mainly in it for fun or for other things learned along the way"* and honestly know that they do not have high chances of winning the prize (Pomerantz, 2010a). This has been also observed in other competitions such as the NGLLC (Davidian, 2010). In addition, a number of teams are primarily in the pursuit of more sustainable commercial opportunities and not necessarily focused on winning the competition. The XPF's Director for Space Prizes explain:

> *"We have a number of teams that view their ultimate line of business primarily as a support business, so where they are going to develop the best mission control for a robotic lunar mission, and even if they don't get all the way to the moon, they're going to develop that step, and they're going to sell it to other teams, and they're going to sell it to Boeing, Lockheed Martin, and NASA, and aren't really anticipating getting to the further step unless something in the market changes or something in the company changes in a way that they don't foresee."* (Pomerantz, 2010a)

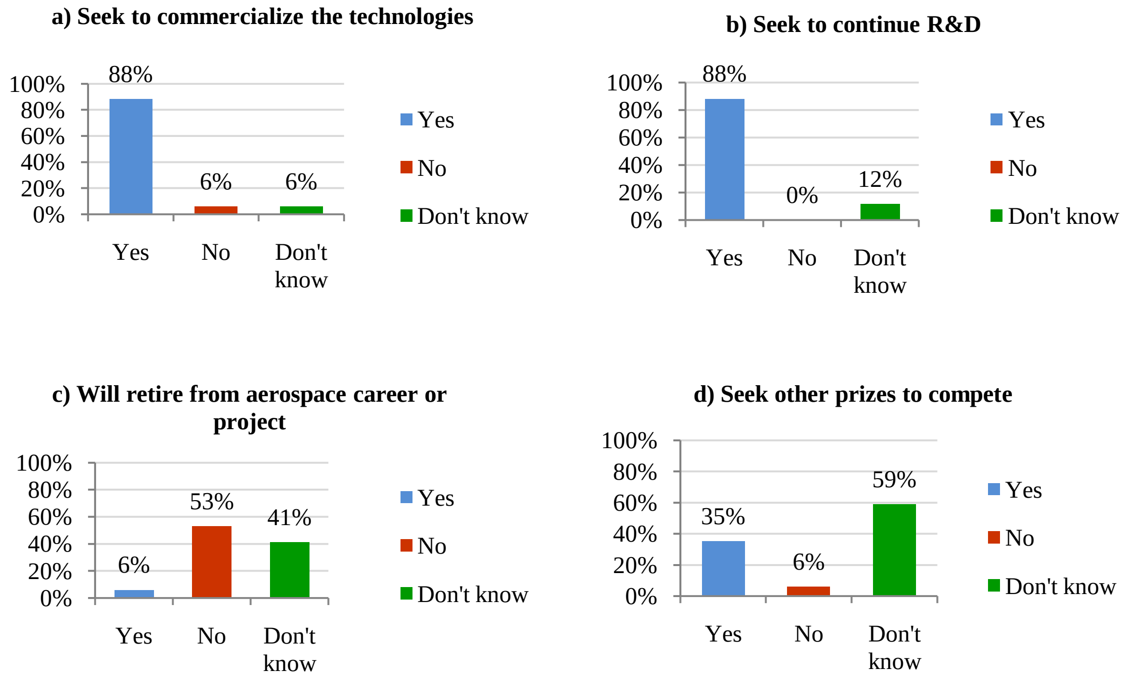
The GLXP team members seek to continue working in space development and commercialize the technologies they develop for the competition, according to the assessment of the team leaders about the future plans of the team members (Figure 6.4). Fifteen out of 17 teams (88 percent) have members that will seek opportunities to commercialize prize technologies; a similar share of teams has members that will seek opportunities to continue research in aerospace/aviation/satellite communications; only one team reported that its members will retire from the aerospace/aviation/satellite communications career or projects; and, six teams (35 percent) have members that will seek other prizes to compete. Ten out of 16 respondents also indicated having at least one team member dedicated exclusively to commercialization of prize technologies. Open-source teams also have members dedicated to business development.

Table 6.11: Types of team goals in the GLXP (selected examples)

Team goals (selected examples)	Quotations from interviews (selected examples)
Demonstrate technological leadership	*"When you lead a team, the world expects you to win"* (T4, 2010)
Create commercial space enterprise	*"trying to develop technologies to eventually start a company up in the future that can provide these services."* (T16, 2010)
Increase professional reputation, publicity, networking	*"we can gradually build up the ideas and promote ourselves."* (T20, 2010)
Other organizational goals	*"to increase the level of aerospace activities in our country and the desire to promote innovative research projects"* (T13, 2010)
Inspire other people	*"Most of the people in the team are like me, what I want to do is create education and inspire students"* (T11, 2010)
Learn	*"If you get to bend metal, test out equipment, do more hands on work, it's a lot more interesting."* (T16, 2010)

Note: N=7 cases.

Source: interview to GLXP teams.



Note: N=17 cases.

Source: questionnaire applied to GLXP teams.

Figure 6.4: Future activities of members of GLXP teams

6.4 Motivations of prize entrants

To investigate the incentives perceived by the GLXP teams and their motivations to enter the competition, this research gathered data with questionnaires and interviews. In questionnaires, team leaders were asked about the importance of a set of nine alternative reasons to participate in the GLXP prize. The questionnaire asked to classify them as Very Important/Important/Somewhat important/Not important at all. In addition, the questionnaire provided space for respondents to mention and classify up to two other reasons to participate if they have reasons that were not included in the questionnaire. Interviews produced richer data because interviewees were given the opportunity to express themselves freely. The researcher assessed these responses based on the emphasis that interviewees put into their statements and classified them according to their importance.

Table 6.12 summarizes the overall importance of motivations to participate in the GLXP based on both questionnaires and interviews. In questionnaires, the GLXP teams mentioned that the three most important reasons (i.e. "very important") to enter this competition are the benefits that technology development may bring for society (mentioned by 10 teams or 59 percent,) the commercialization of technologies developed for the prize (nine teams or 53 percent,) and the recognition from NASA or other government agencies for potential future contracts (eight teams or 47 percent) (Appendix Figure B.2 shows data from questionnaires only.) Participation in a real technical and intellectual challenge is the next motivation in order of importance. Seven teams (41 percent) consider it very important, and other seven teams consider it important, making participation in a real technical challenge the option most cited as either very important or important. The prize money is very important to only four teams (24 percent) and important to only two teams. Similar importance was given to the recognition from family, friends, or colleagues that may result from participating in the prize.

The questionnaires also anticipated the diverse motivations to enter the competition that were later confirmed in interviews. Six questionnaire respondents used the extra space provided to indicate other reasons to participate (Appendix Table A.6 shows a detail at the team-level.) In total, they indicated 11 other reasons to participate in this competition and classified them as either very important or important. Those reasons included three types of prize incentives and two types of other incentives that were not initially considered by this research. Three of those teams mentioned the "entertainment value" the GLXP offers and "having fun" as very important reasons. Interestingly, another team indicated a very important religious reason to participate in the GLXP.

Interview data highlight two facts (Appendix Table A.7 shows a detail at the team-level.) First, motivations vary significantly among teams. At least eight new types of prize incentives with varied degree of importance emerged from interviews with seven teams. For example, the GLXP helps to publicize R&D efforts, contributes to build reputation, and allows demonstrating technological leadership. When asked about why not pursuing the same kind of project on their own (i.e. without entering the GLXP,) two engineers explain that thanks to the prize their project "*get a lot more publicity*" and *"a lot more people know about it so you can talk about it."* (T16, 2010) A team leader who entered early in the competition illustrates the opportunity to demonstrate leadership with the following words: *"When you lead a team, the world expects you to win"* and "*…teams that are slow respond later. So, that when Google announces the prize, or the foundation announces a prize, they think it is a story about themselves and the prize. But if you are quick, it is a world story about your team.*" (T4, 2010)

The GLXP project also helps in accomplishing other goals of the teams and their members and focuses their efforts. Engineers explain that the GLXP *"…gives you something to compete against; so, it makes you work faster*" and "*sets a time line*" (T16, 2010) and *"we are constantly stimulated by competition, which leads us to push our limits."* (T13, 2010) This suggests that there are teams that use the GLXP challenge as a point of reference for other organizational goals and not as a goal in itself. Other motivations include the opportunity to gather resources to pursue other projects, the opportunity to gather resources to pursue this project thanks to the sponsorship value/credibility created by Google, and the opportunity to demonstrate a technological concept. The three most important motivations are still the opportunity to participate in a challenging project, the opportunity to compete, and intrinsic motivations related to the personal traits of the team members. Prize money is considered not important at all by most of the team members.

The second fact highlighted by interviews is that, at the individual-level, motivations of team members vary significantly within each team, i.e. while the main goals of the team seem to be shared by all members, certain members emphasize other motivations to participate in the prize. Most notably, the author perceived such differences in the perception of the relevance of the cash purse and the pursuit of commercial opportunities. A team leader refers to these differences with these words:

> *"...everyone got a different motivation [...] for some people there is a motivation like to say I just want to do this specific part [...] we have people that just want to build the rover or a certain part of the rover [...] we have people who say "I want to put this rover on the moon" [...] So, yes we have people who believe in the entire mission and we have people who believe in their single part of the mission."* (T11, 2010)

The competition also offers the opportunity to gain hands-on experience not only for students but for engineers in general. A team member with industry experience explain that participation in this prize allows students to "*work on something, which is really close to the edge of what is possible*" and, to all team members, to work in "*an exciting environment*" and "*work in complete things*" and not only in components or subsystems for a larger mission project. Moreover, a team mate continues, when working for a space agency "*…you're put in a box. You're a structure specialist, which was my role, you're thermal or electronics, whatever it is, and that was a bit frustrating because people want to be a bit more general.*" (T20, 2010)

The team member-level of analysis has to be expanded in further research to uncover other factors that explain prize participation. Intrinsic motivation appears to be a very important factor. Teams engage people that are very proactive, hard working, and are very attracted to challenging projects. For example, an engineer defines himself using these words: "*I'm not a 9 to 5 person. I'm a 9 to 2 AM person.*" (T16, 2010) Another engineer with space agency experience explains that space agencies do not have clearly defined competitors and therefore there are no real measures of success. He continues: "*But, a competition with a clearly defined objective, which is achievable, but difficult, I* *think, is a perfect measure of success and a measure of one's ability.*" (T20, 2010) Interviews also allowed grasping the richness of the team members' personal stories which shows how different their perceptions about prize participation may be compared to family, friends, or other individuals. For example, a young engineer explained that part of his family did not believe that the prize was worth the effort and that felt like he was questioned with *"Eh, you're still doing that?"* (T11, 2010) However—he continues—the quality and seriousness of his team's presentation at an international aerospace exhibition ultimately convinced his family about the value of the pursuit.

Table 6.12: Motivations of GLXP teams

Motivations related to prize incentives (options given in questionnaires)	**Data sources, assessment of importance**			**Selected statements** (from questionnaires or interviews, when available)
	Quest.[a]	***Quest. (add'l)***[b]	***Intv.***[c]	
Knowledge and skills acquired from practice and competition	◑	●	◑	*"…for me it was mostly learning everything."*
Recognition from family, friends, or colleagues	◔			
Participation in a real technical and intellectual challenge	◑		●	*"…like doing something that is really difficult to do."*
Business, professional, or personal reputation	◔		●	*"…want to be recognized as a competitor, that's already very valuable to me."*
Recognition from NASA or other gov. agencies for potential future contracts	●			
Cash purse	◔		○	*"…we are not driven by the prize"*

Table continues in next page.

References: ○ **Not important at all** ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: a. assessment of motivations indicated in pre-defined options in questionnaire (N=17); b. assessment of additional motivations indicated by respondents in questionnaire (N=6); c. assessment of motivations mentioned in interviews (N=7); when needed, the examples omit part of the text to maintain the anonymity of teams.

Source: assessment of the author based on evidence presented in previous sections.

Table 6.12: Motivations of GLXP teams (Contd.)

Motivations related to prize incentives (added by entrants in questionnaires or interviews)	**Data sources, assessment of importance**			**Selected statements** (from questionnaires or interviews, when available)
	Quest. [a]	***Quest. (add'l)*** [b]	***Intv.*** [c]	
Opportunity to gather resources to pursue *other* projects		●		*"Help raising money from non space related companies for space projects"*
Opportunity to gather resources to pursue *this* project			◑	*"…only in the competition we can do this. If we do this in our spare time without the competition, for the companies has no value or it doesn't make sense for to spend money or energy or components."*
Demonstrate technological concept		●	◑	*"…looked at the Google Lunar X Prize as a perfect way to demonstrate the […] concept"*
Opportunity to engage in aerospace development, hands-on experience		◑	●	*"…wanted to be a part of something real and be able to make something different."*
Opportunity to demonstrate technological leadership			●	*"we are the only team that is with the experience of winning a prize."*
Opportunity to participate as an additional incentive to accomplish organizational goals			●	*"[The GLXP] fits with our own goals."*
Networking			◑	*"The benefits that I have is that I'm getting in contact with a lot of interesting people."*
Competition			◑	*"We are constantly stimulated by competition, which leads us to push our limits."*

Table continues in next page.

References: ○ **Not important at all** ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: a. assessment of motivations indicated in pre-defined options in questionnaire (N=17); b. assessment of additional motivations indicated by respondents in questionnaire (N=6); c. assessment of motivations mentioned in interviews (N=7); when needed, the examples omit part of the text to maintain the anonymity of teams.

Source: assessment of the author based on evidence presented in previous sections.

Table 6.12: Motivations of GLXP teams (Contd.)

Motivations (shaded cells indicate options given in questionnaires)	**Data sources, assessment of importance**			**Selected statements** (from questionnaires or interviews, when available)
	Quest.[a]	***Quest. (add'l)***[b]	***Intv.***[c]	
Related to technology incentives				
Commercialization of technologies developed for the prize	●		◑	*"We have great hopes though that we could grow customers on the commercial side…"*
Development of technologies for other activities of the team or its members	◑			
Related to other incentives				
Benefits that technology development may bring for society	●	●		*"Help spreading/raising interest within youth in science & technology"*
Religious		●		*"Opportunity to Showcase and Testify to the Lord Jesus Christ's Blessings, Provision and Assistance for His Followers who are involved in Innovative Technology!"*
Entertainment		●		*"To have fun as a team"*
Intrinsic motivation			◑	*"the team itself is a really proactive people. [...] …people that are always doing something... [...] …people that in anyway would do something."*

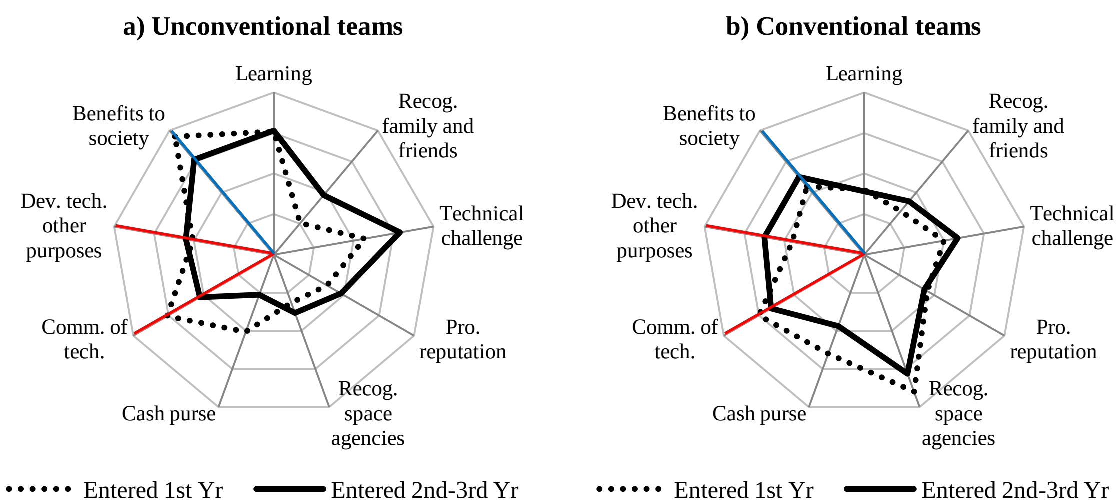
References: ○ **Not important at all** ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: a. assessment of motivations indicated in pre-defined options in questionnaire (N=17); b. assessment of additional motivations indicated by respondents in questionnaire (N=6); c. assessment of motivations mentioned in interviews (N=7); when needed, the examples omit part of the text to maintain the anonymity of teams.

Source: assessment of the author based on evidence presented in previous sections.

The analysis of motivations by type of team and entry period shows that different types of prize entrants/cohorts have different motivations and that would-be entrants' perceptions of the benefits of participation might vary over time (Figure 6.5). The latter seems reasonable—in principle—considering the evolution of the economic context of the competition. The GLXP was announced in September 2007 when the economic context was generally still favorable or neutral for industry. About a year later, the rumors of an important economic slowdown become more widely spread and markets plummeted (the Dow Jones index went down about 25 percent in the week after September 22, 2008.) According to the official entry date, seven teams of those that participated in this study entered the GLXP in that first year of competition (three unconventional, four conventional,) and 10 teams entered after that (six unconventional, four conventional.) Considering all the teams that have ever officially participated in the GLXP, 14 teams entered during the first year, eight teams during the second year, three teams during the third year, and 10 teams entered after three years and before the registration period closed.

Unconventional teams are generally driven by PIs, i.e. those created by the announcement of the competition, and TIs in some cases (Figure 6.5a). Other motivations are also important for early entries. The benefits that this type of project may bring to society are the most important motivation for the unconventional teams that entered during the first year of competition, followed by learning and commercialization of prize technologies. The teams that entered during the 2nd and 3rd year of competition have emphasized the importance of participation in a real technical challenge, learning, and benefits to society as well, yet to lesser extent in this case. Developing technologies for other purposes is the next most important motivation (more important than commercialization of technologies.) The importance of the cash purse is notably lower for unconventional teams that entered more recently. Conventional teams are primarily driven by PIs, particularly by the opportunity to get recognition from NASA and other space agencies (Figure 6.5b). The potential value of the prize technologies is a strong incentive in both time periods. Conventional teams that entered the GLXP in the 2nd and 3rd year of competition have similar motivations, yet they consider the development of technologies for other purposes and the participation in a real technical challenge more important. Benefits that technology development brings to society are also important for conventional entrants. Not surprisingly, learning is not a motivation for them (by definition, this group has space agency/industry experience.) The decreasing importance of the cash purse in all cases may indicate the perception of fewer chances to win the prize as the number of competitors increase, or the higher relative importance of other incentives such as those linked to the commercialization of prize technologies.



Note: N=17 cases; radar charts show importance given to each type of incentive, by type of team and prize period; lines in red indicate technology incentives and lines in blue indicate other incentives; number of teams first year=7 (3 unconventional, 4 conventional;) number of teams 2nd and 3rd years=10 (6 unconventional, 4 conventional.)

Source: questionnaire applied to GLXP teams.

Figure 6.5: Motivations of GLXP teams, by type of entrant and period of entry to the prize.

Teams, however, may not change their motivations and goals during the competition. When asked about that, team leaders explain, for example: *"My motivations* *haven't changed. My expectation of what's possible didn't change a lot, but I learned a few things along the way"* (T20, 2010) and *"Maybe not changed, but I think we learn as we go."* (T11, 2010)

The analysis of the context of the GLXP has exposed the potential sizable market value of the technologies involved in this competition. Recent contracts with agencies downgrade the value of the cash purse. For example, the NASA's Innovative Lunar Demonstrations and Data (ILDD) program already awarded six GLXP teams with up to $30 million in contracts for the next few years. NASA also awarded $500,000 to Team Astrobotic for hardware demonstration. Commercialization of services has even higher price tags. Astrobotic's customers would pay about $2 million per kg. of payload sent to the Moon. Teams perceive that value and seek the recognition from space agencies for potential contracts, commercialization of the prize technologies, or implementation of the technologies for other space projects (including the provision of services.) In interviews, teams explained how important are these technology incentives compared to the cash purse and assessed the prospects for potential commercialization. In words of a team leader, "*…the point is if one of the teams land on the Moon, it will get much more that the $20,000,000. […] If you have really a working technology, a reproducible working technology, those $20,000,000 are not the point anymore.*" (T6, 2010) However, with venture capital investors expecting returns on investment of 40-50 percent for space ventures and private equity expecting 30 percent or more, a business case based on revenues from government customers may not be sustainable. A team leader explains:

> "*Government space agencies…they don't let you take away huge profits in general. You're typically limited to a certain percentage of your contract value, which is your profit, 5% or 8%, and of course, if you're clever, you can stretch that out a little bit by saving costs on your projects. But you're*

not going to have that sort of exponential growth that you have, you know, venture capital investment." (T20, 2010)

The payback period is as important as the return on investment in this type of projects. Some team leaders consider that the realization of sustainable profits may be only possible in the distant future. In words of GLXP team leaders:

"…this is all kind of an initial phase to something maybe 20 years down the road…" (T16, 2010)

"In the distant future, maybe 10, 20, 30 [years], there will be private customers paying to send payloads to moon. But in the foreseeable future, which is sort of the timescale where you need to a see a financial return on an investment, it's really government who will be your customers." (T20, 2010)

The scenarios that are considered by teams (as suggested by these and other team leaders) can be summarized as follows. In the short- and medium-terms (3-10 years,) governments are the space market. U.S. teams will have NASA as the single biggest customer. The first Moon mining missions are likely to occur in this period and commercial demand is likely to grow as well. In the long-term (10-20 years,) private customers will pay to send payloads to the Moon and there will be deployment of robotic units to land on other surfaces beyond the Moon, such as Mars and asteroids ("*is going to be a hot topic*") (T16, 2010). In the distant future (20+ years,) the first Moon outpost will be a reality and lunar/planetary excavation technologies will be on demand.

It should be noted that the GLXP also offers a monetary reward that is not linked to the accomplishment of the lunar mission. The Diversity Award for $1 million is for to team that, in the opinion of a panel of experts, makes the greatest attempts to promote diversity in the fields of science, technology, engineering, and mathematics. Although this amount of money is considerably lower than the grand prize, it may be still a significant reward for some teams that are already engaged in the promotion of diversity. For example, Team JURBAN (from Baltimore, Maryland) is a non-profit team focused on motivating underrepresented students to enter fields of study in science, technology, engineering, and math (STEM) as it applies to space entrepreneurship. This and a few other similar teams may have entered the competition considering that specific award for diversity.

The perception of risks from participation is another important aspect related to the motivations to enter the prize. In general, there are more GLXP teams that indicate no concern with potential risks than those that do indicate so (Appendix Figure B.3 shows responses for all teams.) For example, most of the teams do not worry at all about investing time and resources but losing the competition anyway, or embarking on a technological approach that is not the most adequate for the competition. Moreover, whether the sponsor ultimately pays the cash purse if they achieve the prize challenge is not a concern for most of the teams. The two most significant risks perceived by the teams is assuming excessive financial risk and compromising other activities of the team members. Embarking on a technological approach that is not the most adequate for the competition, and investing time and resources yet losing the competition are significant concerns for only a few teams. Not being paid by the prize sponsor in spite of being the first to achieve the prize target is a great concern for one team only.

These data suggest that unconventional teams are less risk averse than other teams (Table 6.13). Unconventional teams generally report that those risks of participation are not a concern for them. With regard to the financial risks, a risk perceived by most of the entrants, unconventional teams are also less concerned than the rest of the teams. On the other hand, some conventional teams are particularly concerned with compromising other activities of the team members or invest time and resources and lose the competition despite those efforts.

In interviews, team members pointed out that there are no significant risks resulting from being involved in the competition. Only one of the team leaders mentioned a concern with deviating efforts from more important, non-prize goals that the team has (T13, 2010). Four interviewees mentioned possible technical risks in testing or launching phases, but promptly clarified that those risks also apply for technology development in a non-prize environment. In this regard, two team leaders explained that their teams apply risk management procedures, and one of them described those procedures as "pretty similar to the one that NASA has." (T16, 2010; T20, 2010) Three team leaders also explained that there may be some financial, business, or legal risks resulting from sponsorships or partnerships, and that those risks affect them to different extent depending on their organization (T11, 2010; T16, 2010; T20, 2010). For example, that risk would be mostly with the partners for a team that expects to develop partnerships to commercialize prize technologies (T20, 2010). For teams that use partners to source technologies in exchange for IP rights, percentage of revenues or other benefits, such relationships imply either a risk that has to be mitigated by reducing the team's commitments or an opportunity to actually decrease the risks by pursuing a much more collaborative effort (T4, 2010; T11, 2010). A team leader explains that *"...partners are very important. Every partner that you can get that has that subject area expertise is crucial to reduce your risk and to get you flying in a shorter period of time."* (T4, 2010) Two team leaders emphasized that, personally, *"...there is not much you can lose, except your time"* (T20, 2010) (these teams are in early and very early stages of project development.) Other interviewees also suggested that their GLXP projects are very time consuming.

Table 6.13: Risks perceived from participation in the GLXP, by type of entrant

Potential risks of participation	Percentage of teams with each level of concern with potential risks					
	Unconventional teams			Conventional teams		
	A lot	A little	None	A lot	A little	None
Assume excessive financial risk	22%	33%	44%	43%	57%	0%
Not being paid by the prize sponsor in spite of first achieving the prize target	0%	33%	67%	14%	43%	43%
Embark on a technological approach that is not the most adequate for the competition	11%	22%	67%	14%	29%	57%
Compromise other personal or professional activities of the team members	0%	22%	78%	43%	57%	0%
Invest time and resources but lose the competition anyway	0%	22%	78%	29%	29%	43%

Note: N=16 cases.

Source: questionnaire applied to GLXP teams.

Technical risks are not trivial in space projects. A mission with a catastrophic loss has no revenue and therefore it would imply a very significant economic loss for a GLXP team that has reached the point of a launch. Risks include those of any research and development activity and the programmatic risks. Research and development risks are inherent to any R&D process and are related with the cost, schedule, and technical performance of the technology. The advancement of technologies with different level of maturity is linked to different levels of risk as well. TRLs 1-2 represent situations of relatively high risk, TRLs 3-5 represent moderate risks, and TRLs of 6-9 represent lower risks. The programmatic or mission risks are with the uncertainty about whether the mission using that technology will actually fly, which can be considered in this case the "market risk" of space technologies (Shishko et al., 2004). The programmatic risk has been also related with technology development with below-average lead times. Historically, mission development times for planetary missions of less than 36 months are correlated with a significantly increased chance of failure (Bearden, 2003; Bitten et al., 2006).

The opposite side of motivations to enter the prize is the reasons to withdraw the competition. In general, difficulties to raise funding, find new members, or obtain other in-kind support might explain the inactivity and drop outs in GLXP teams, as discussed in the following sections. However, there have been other special circumstances as well. Team Micro-space's leader, Mr. Richard Speck, has recently passed away and his team withdrew the competition (he kindly collaborated with this research before that.) Two other teams were involved in legal issues that forced them to withdraw (those issues were at the team- and personal-levels, not related with the competition.) Another team withdrew due to reasons related with the use of the results of the competition (as discussed later.) The causes of other two drop outs are unknown to this research.

6.5 Prize R&D activities

6.5.1 Design criteria and sources

A key aspect that defines the R&D activities of prize entrants is the design criteria they use for their projects and the sources of inspiration for such designs. The three top design criteria used by GLXP teams are technical simplicity, project cost, and market value of the technologies, as indicated by seven teams (44 percent,) six teams (38 percent,) and three teams (19 percent,) respectively (Appendix Figure B.4 shows questionnaire data only.) All teams consider project costs within the top-three criteria and 12 teams (75 percent) consider technical simplicity within the top-3 criteria. Seven teams (44 percent) ranked novelty and market value within the top-3 criteria. The lowest ranked design criteria are environmental impact and standardization (i.e. seek compliance with industry standards.) There are no significant differences between types of teams (Table

6.14). Unconventional teams are more likely to consider technical simplicity as the top design criterion. Conventional teams are more likely to consider project cost as the main design criterion and market value, novelty, and technical simplicity among the 2nd or 3rd most important design criteria.

In interviews, team leaders suggested additional design criteria and insights on criteria that may be prize context-specific and/or represent innovative approaches to aerospace design.[19] The three criteria that were mentioned the most are reusability, or the design of systems that can be used for multiple missions; optimization, or the balance of efficiency and performance of the system with the accomplishment of the prize goal; and performance, or the design of systems that meet the mission's requirements and minimize failure and maintenance (Table 6.15). Other criteria were mentioned fewer times, yet resemble those attributes that characterize new non-government space developments. For example, there are "simple and smart" design and "minimalism." There is also "scalability," a design criteria used in telecommunications and software design. Some of these design criteria are exclusive of unconventional teams. These include performance, minimalism, robustness, and scalability. Finally, exclusive of the prize competitive environment, there is the "minimum technology development effort."

The words of a GLXP team leader are very insightful about what the key differences between prize R&D and traditional industry practices are:

> *"Government missions can be a bit more expensive because you've got other reasons for spending that money. […] We can't play that game for minimum cost solutions, and that impacts all aspects of the mission architecture. Also, we have a race so we have to have minimum*

[19] The interviewees mentioned several design criteria in addition to those pre-defined in questionnaires and emphasized their importance for their GLXP projects. Sometimes, interviewees referred to the same concepts using different statements and the researcher grouped them. There may also be some criteria that are not considered relevant and therefore were omitted by the interviewees as they spoke freely about their projects.

development time. So these two points together mean that we want to have absolute minimum technology development effort. We don't want to do fancy things; we want to do simple things in a smart way." (T20, 2010)

Another team leader explains the importance of accomplishment over other design criteria:

"*Almost is good enough. Never listen to ideals, optimality, or solutions that are the best. These are the bane to getting things done.*" (T4, 2010)

Table 6.14: Design criteria used by GLXP teams, by type of entrant

Design criteria	Percentage and type of teams that rank criterion as….								
	Unconventional teams			Conventional teams			All teams		
	Top-criterion	2nd-3rd criterion	4th-lower criterion	Top-criterion	2nd-3rd criterion	4th-lower criterion	Top-criterion	2nd-3rd criterion	4th-lower criterion
Technical simplicity	67%	22%	11%	14%	43%	43%	44%	31%	25%
Project cost	33%	67%	0%	38%	57%	0%	38%	63%	0%
Market value	22%	11%	67%	14%	43%	43%	19%	25%	56%
Novelty	11%	22%	67%	14%	43%	43%	13%	31%	56%
Reliability	11%	33%	56%	14%	14%	71%	13%	25%	63%
Environ. impact	11%	22%	67%	0%	0%	100%	6%	13%	81%
Standardization	11%	0%	89%	0%	0%	100%	6%	0%	94%

Note: N=16 cases.

Source: questionnaire applied to GLXP teams.

Table 6.15: Additional design criteria in GLXP projects as reported by interviewees

Design Criteria	Description[a]	Type of team that refers to the criterion[b]
Reusability	Design useful for multiple missions	Both
Optimization	Efficiency / performance vs. mission accomplishment balance.	Both
Performance	Meet requirements and minimize failure and maintenance	Unconv.
Minimum tech. dev. effort	"*do less engineering and buy cheaper components*" (T4, 2010)	Both
Simple and smart	Creative, simple solutions that work efficiently; *"...getting us from A to B as fast as possible."* (T20, 2010)	Both
Minimalism	Minimum capabilities required to accomplish mission	Unconv.
Robustness	System that resists many mission days	Unconv.
Scalability	*"...going to be useful in the future when we want to pursue larger missions"* (T16, 2010)	Unconv.

Note: the table shows additional design criteria mentioned in interviews yet not offered as options in questionnaire; a. statements used by the interviewees or interpretations of the researcher; b. either conventional or unconventional or both..

Source: interviews to GLXP team members.

The GLXP's designs are mainly based off the team members' knowledge, available commercial products, and past projects of the team members (Table 6.16; Appendix Figure B.5 shows percentages.) Nine teams (56 percent) consider team members' knowledge very important and five teams (31 percent) consider it important. The second source of design inspiration is available commercial products. Five teams (31 percent) consider that source very important and nine teams (56 percent) consider it important. Projects that the teams pursued before joining the competition are similarly important. Teams also draw upon ideas found in non-aerospace projects, yet it was not possible to identify what types of projects they are. Four teams (25 percent) consider those projects very important design sources. In general, the designs of other GLXP teams and designs of teams participating in other prizes are considered the least important among the set of sources of design inspiration offered in questionnaires. Eleven teams (69 percent) indicated that those sources are not important at all.

Table 6.16: Most important design sources of GLXP teams, by type of entrant

Sources of inspiration	Percentage of teams that consider each design source as very important/important		
	Unconventional	Conventional	All teams
Theoretical knowledge that team members already had	78%	100%	88%
Available commercial products	78%	100%	88%
Projects the team had before the GLXP	44%	86%	63%
Projects of NASA or other space agencies	56%	29%	44%
Designs found in non-aerospace projects	44%	29%	38%
Designs of teams participating in other prizes	33%	14%	25%
Designs of other GLXP teams	11%	0%	6%

Note: N=16 cases.

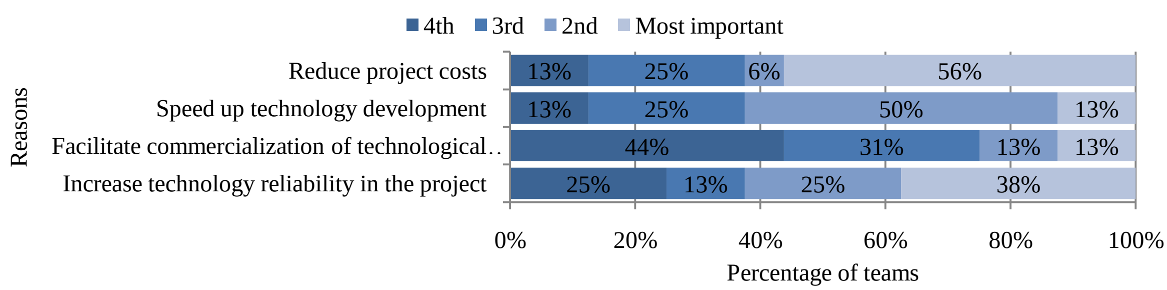
Source: questionnaire applied to GLXP teams.

Unconventional teams have slightly different sources of inspiration compared to other teams. In particular, unconventional teams find more inspiration in projects that space agencies have developed and designs found in non-aerospace projects. Their designs are also less based off previous projects of the team, which is related with the fact that most of these teams are newly created to enter the competition and, by definition, do not have industry experience. These teams may be also learning from other GLXP teams and teams that participated in other projects. Nonetheless, as the literature suggests, unconventional teams also bring new approaches to space development. A GLXP team leader refers to this explicitly: *"…the fact that our team isn't normally working on the subject and maybe we have somewhat like an outsider's perspective to this.* So, we are *looking at things differently like people who are doing this in an all day job."* (T11, 2010)

Three alternative design sources not included in questionnaires were mentioned in interviews: external expert advice, partnership networks, and online documentation. The use of external experts was mentioned by four teams out of seven that responded interview questions. Those external experts are either networks that the team members had developed in past projects or new contacts that the team develops to work on this specific project. Access to multi-disciplinary advice is also available to teams that partner with universities (T4, 2010). The use of partnership networks as knowledge sources for design was mentioned by only one team that also uses strategically the same network to source technologies for its project (T11, 2010). The third source, documentation published online, was mentioned by another team and refers to work produced by other organizations that is freely available on the internet, including work by rocketry clubs, declassified aerospace agency's documentation, and software tools provided by manufacturers, among others (T20, 2010). The interviews also revealed that some technologies developed for the NGLLC may be useful for the GLXP as well. In this regard, one team mentioned contacts with Armadillo Aerospace and Masten Space Systems (the winners of the NGLLC) (T16, 2010) and another (foreign) team mentioned unsuccessful intents to establish those contacts (T20, 2010).

6.5.2 Own development vs. use of existing technologies

To better understand the nature of the R&D activities performed by entrants to achieve the prize challenge, the GLXP teams were asked about the reasons to use existing technologies rather than developing new ones. In questionnaires, the respondents had to rank four pre-defined reasons for using existing technologies according to their importance. The teams indicated that the most important reason to use existing technologies is reducing project costs, as indicated by nine teams (56 percent) (Figure 6.6). Other six teams (38 percent) indicated that increasing technology reliability is the most important reason for using existing technologies. Only two teams indicated that speeding up technology development is the top reason, yet other eight teams (50 percent) ranked this reason as the second most important. Five teams indicated that both lowering costs and speed up development are the two most important reasons for using existing technologies. In some cases, according to interviewees, teams are obligated by agreement to use certain technologies provided by partners, even when that implies development or adaptation efforts.



Note: N=16 cases; the percentages indicate the proportion of teams that ranked each reason according to its importance.
Source: questionnaire applied to GLXP teams.

Figure 6.6: Reasons to use existing technologies in the GLXP

In interviews, team leaders and other members contributed additional insights not only about the reasons to use existing technologies but also about the reasons to develop their own subsystems (Table 6.17). The lack of knowledge or expertise is the only reason that forces teams to rely upon existing technologies. In all other cases, teams choose existing technologies as a strategy to achieve the prize challenge. There are a few cases of teams that adopt a collaborative effort approach in which partners provide technologies and components. Existing technologies maybe readily available COTS (e.g. parts or components) or built after teams order them from a catalogue (e.g. solid rocket motors.) There is also at least one team using surplus parts from NASA's space programs. Existing technologies reduce project costs and time, reduce development effort, and increase reliability. However, testing and adaptation efforts are required to be able to use existing components and parts. For example, Team Astrobotic has screened components in a cryogenic freezer to determine which bounce back from the extreme deep freeze—simulating the extreme lunar temperatures—and identified batteries, solid state drives, and processors that resume operation when the temperature warms back up to roughly minus 80 degrees Fahrenheit (Astrobotic Technology, 2010).

Some teams seek to develop their own technologies when they have other organizational goals. For example, a team that is very interested in gaining hands-on experience seeks to develop own technologies whenever is possible. An engineer explains: *"We're trying to find a happy medium where we're developing as much technology as we can to get to the moon, but at the same time, we want to try to be able to compete in the timeframe that we are given."* (T16, 2010) Some teams also choose to develop their own technologies when commercialization or other projects are the focus of their activities.

Table 6.17: Further reasons to use existing technologies or develop new ones in the GLXP

Seek to use existing technologies		Seek to develop own technologies
Reasons related with strategies to achieve the prize goal	**Reasons related with the characteristics of the teams**	**Reasons related with strategies to accomplish other goals**
• **Reduce costs and speed up project**: use of COTS compatible components (even non-space components) that are *"pretty expensive but they are still cheaper and less time consuming"* (T16, 2010); use of surplus parts of government programs (T4, 2010) • **Reduce development effort**: partners and "friend companies" collaborate (T4, 2010) • **Increase reliability/reduce risks:** use of proven solutions (T4, 2010; T16, 2010; T20, 2010) • **Collaborative effort strategy:** integrating technologies from 3rd parties is a strategy implicit in the organizational structure, using more extensive partnership networks (T11, 2010)	• **Lack of knowledge/expertise:** delegate development to individuals, organizations with expertise. *"Every partner that you can get that has that subject area expertise is crucial…"* (T4, 2010)	• **Facilitate commercialization**: develop subsystems that may eventually be commercialized (T20, 2010) • **Own use**: develop systems that are useful for other projects of the team (T13, 2010) • **Other team goals**: for example, get hands-on experience (T16, 2010)

Note: the reasons shown were provided by different teams.

Source: questionnaires to GLXP teams and interview with GLXP team leaders and members.

Teams use significant proportions of COTS technologies and also delegate significant development effort to contractors. All teams plan to use some COTS components and parts and all but one team plan to subcontract part of their projects. Most of the teams estimate that their systems will be between 20 and 50 percent subcontracted to others (seven teams or 47 percent) and/or COTS (nine teams or 60 percent) (Table 6.18). Two teams indicated that more than 50 percent of their systems will be subcontracted. Three teams indicated that more than 50 percent of their systems will be COTS. There are also a number of teams making a more significant development effort and using less than 20 percent of third-party technologies. Five teams (33 percent) indicated that less than 20 percent of their systems will be subcontracted and three teams (20 percent) that less than 20 percent of their systems will be COTS. The data suggest that unconventional teams might be less likely to subcontract their development efforts to third-parties. Two teams with vast industry/agency experience entered the GLXP with intentions to subcontract most of their projects to either a set of partner companies or a single company (T14, 2010; T20, 2010). Other three unconventional teams are pursuing own development efforts, yet they seek to reduce that engineering effort when parts/components are available COTS, from partners, or "friend companies." (T4, 2010; T11, 2010; T13, 2010) In some instances, partners provide cutting edge technologies that teams would not have access to if they were not engaged in this project. For example, the German carbon-fiber manufacturer Crosslink-Fibertech provides Formula One-grade technologies to Team Part Time Scientists in exchange for cooperation to open new markets (PTS, 2011a).

Table 6.18: GLXP teams that use subcontracting and COTS technologies, by type of entrant

Type of team	Number of teams that subcontract each percentage of GLXP project				Number of teams that use each percentage of COTS technologies in GLXP project			
	More than 50%	20% to 50%	Less than 20%	0%	More than 50%	20% to 50%	Less than 20%	0%
Unconven-tional		4	3	1	2	4	2	
Conven-tional	2	3	2		1	5	1	
Total	2	7	5	1	3	9	3	-

Note: N=15 cases (8 unconventional teams, 7 conventional teams); cells show number of teams for each range of subcontracting.

Source: questionnaire applied to GLXP teams.

6.5.3 Organization of R&D activities

The GLXP projects span across the teams' organizational boundaries as they involve multiple actors and relationships. Teams partner with multiple other organizations to source technologies, seek support and advice, and gather other types of resources needed to pursue their projects. There are clear reasons and advantages into that. GLXP teams are relatively small to pursue this type of space project and most of them (particularly unconventional teams) are new organizations. Some teams have members with no aerospace background/experience and, therefore, need to source know-how, facilities, and equipment they originally do not have access to. Certainly, having that access is an advantage. For example, teams with university partners access to multidisciplinary advice from different departments and may recruit engineering students as volunteers. Teams with corporate partners may access to specialized expert advice with hands-on experience in aerospace systems development.

Table 6.19 shows the number and type of partners that the researcher was able to identify by examining GLXP team websites and press releases. Conventional teams have partnered with more organizations than unconventional teams, though these data underestimate the real number of partners because—as team leaders explained—some partnerships are not publicly announced. Moreover, the researcher noticed inconsistencies in the number of partners reported by alternative data sources that cannot be attributed to normal variations related with team growth. Most of the GLXP teams' partners are private companies. At least 15 teams have small or large corporate partners. Unconventional and conventional teams are similarly linked to both large companies and SMEs, yet the median number of corporate partners is larger for conventional (median=4) than for unconventional teams (median=2.) Companies become partners of teams (e.g. Sierra Nevada Corporation, partner of the U.S. team Next Giant Leap) or, in a few cases, team up with other organizations to form new teams (e.g. Dynetics, a privately held U.S. company with defense technologies expertise that is new to the space business, teamed up with Teledyne and Andrews Space to form the team Rocket City Space Pioneers.)

Table 6.19: Number and type of partners of GLXP teams, by type of entrant

Type of team	Type of partner				
	Large corp.	**SMEs**	**Universi-ties**	**NGOs**	**Total**
Unconventional Teams	5	22	5	3	35
Conventional teams	5	21	13	10	49
All teams	10	43	18	12	83

Note: data as of January 2011, including 26 GLXP teams; based on teams that report at least one partner (i.e. seven unconventional teams; 8 conventional teams.)

Source: GLXP team websites and press releases.

Teams also partner with universities and NGOs. Twelve teams engaged 18 different university partners and 12 different NGOs. Conventional teams have been more likely to partner with universities and NGOs. Notably, the Charles Stark Draper Laboratory (a U.S. non-profit R&D lab) is partner with both Next Giant Leap and Rocket

City Space Pioneers. Finally, there is at least one instance of collaboration with government agencies as well. That is the case of Team Odyssey Moon, which signed a Reimbursable Space Act Agreement with the NASA Ames Research Center by which NASA provides technical data and engineering support to the team to develop a lunar lander and the team reimburses the costs and shares the data from tests and actual lunar missions (all GLXP teams can, under a Space Act Agreement, access NASA's engineering and technical expertise, subject to ITAR regulations.) (MacDonald & Marshall, 2008)

Interestingly, teams gain credibility to engage partners thanks to the brand image of Google, the competition's sponsor. The words of a team leader illustrate this: "*You could be a scientist in this specialized area, but they won't take you serious without having someone like Google sponsoring the money.*" (T11, 2010) Moreover, well connected team members are more likely to engage partners. A team leader of a well connected team explains: "*If you were a team and you had no connections and no one was helping you, it would be very hard to get things done*." (T4, 2010) The rest of the teams may face a more difficult situation, particularly when they begin their projects. For example, another team leader explains that during the first months of prize participation was difficult to get the attention of partners and available partnership opportunities did not allow the team to impose any condition (T20, 2010). In this initial stage, teams have less negotiation power and need appropriate skills to persuade partners. In the case of that team, after increasing visibility offered by the competition ("after the team built its brand") it was other organizations that sought to attract the team to partner and then the team was able to choose the best candidates and impose certain working conditions. This is not only the result of increasing visibility or performance of the team. The GLXP offers the opportunity to participate in a complex project from the engineering viewpoint and may help to build heritage for subsystems and components, which is very important in space industry and other industries that produce systems and components for extreme environments. In these partnerships, partners offer technologies, expertise, access to facilities, and other in-kind resources. Teams offer IP rights exchanges, publicity, exposure to potential customers, and sometimes a share of the potential cash purse or revenues from commercialization. Partners also require to be informed about the activities of the team and know not just its "public story."

Teams not only maintain R&D relationships with partners but also seek sponsors for their projects. These sponsors typically contribute monetary or in-kind resources in exchange for publicity. A GLXP team member explains that *"the competition has a special marketing value and then we can talk with the companies and say it's a good thing for you to advertise, if you help us or if you give us a discount or if you give us access to your technology. Often, they don't spend money, but they give access to technology, sometimes components. So, we don't have to pay for this."* (T11, 2010) Promotional actions for sponsors include, for example, sponsor's logos on prototypes or actual spacecrafts, acknowledgements/credits in conference presentations or websites, or even allowing the sponsor to name the team. The latter is the case of White Label Space, a team that expects to change its name to a sponsor's in the future.

The GLXP teams adopt different internal structures and organization of R&D. In questionnaires, teams were asked about the organization of their R&D work in terms of groups and locations. Four options were given to respondents to select the one that best describes the internal configuration of the team. None of the four internal configurations suggested in questionnaires predominates. Seven teams (44 percent) indicated that they organize their activities as different work groups that work on the project from different locations; five teams (31 percent) indicated that their members work remotely and only meet for some tasks; two teams (19 percent) have different work groups and regularly meet in the same location to work on the project; and, only one team is configured as only one workgroup that regularly meets in same location. The division of tasks among subgroups in different sites (sometimes even internationally) is a common characteristic of the GLXP teams. For example, there are groups focused on the development of the lunar lander and groups focused on the development of the rover or camera subsystems.

At least four types of exemplar team organizations are identified based on available data and attributes such as type of entity, goals, volunteer effort, partnerships, internal organization, and other R&D characteristics (Table 6.20). Three out of these four examples are unconventional teams. Also three of them were created to enter the GLXP. A non-aerospace experience is by definition their main attribute. These four examples include the Space Agency Legacy team, with strong space agency/industry experience; the University Partnerships team, led by aerospace students; the Partnerships Network, with multidisciplinary background and predominance of computer science/IT; and the University Spin-off with strong academic multi-disciplinary background and entrepreneurial experience. The Space Agency Legacy team has a main corporate partner and draws upon an extended network of space agency/industry contacts; the Universities Partnership team is a partnership of two universities and a newly-formed foundation that collaborate for the GLXP project; the Partnerships Network team emerged as an independent team that have built university and corporate partnership networks; and the University Spin-off is university based with corporate support.

Table 6.20: Organization of R&D activities of GLXP teams (identified examples)

Characteristic	Type of team organization			
	Space Agency Legacy	**Universities Partnership**	**Partnerships Network**	**University Spin-off**
Type of entity / type of team	Non-profit / Conventional team	Non-profit / Unconventional team	For-profit / Unconventional team	For-profit / Unconventional team
Goals	Professional reputation, publicity	Learning, other organizational goals	Pursue a challenging project	Demonstrate tech. leadership and commercialization of tech.
Size core team/volunteers	2 / 15	~5 / ~25 (est.)	40 / 10	20 / 8
Background / experience	Strong agency and corporate aerospace experience	Aerospace students leadership	Multidisciplinary backgrounds, computer science/IT predominance	Strong academic multi-disciplinary background, entrepreneurial experience
Linkages / partnerships	Corporate main partner; network of space agency/industry contacts	Foundation and university partners; university collaborations	University collaborations and network of corporate partnerships	University-based, commercial orientation; corporate and leading university support
Internal organization	Subgroups work from diff. locations (incl. intl.)	Subgroups work from different locations	Work remotely (incl. intl.) and only meet for some specific tasks	Workgroups meet same location, "everything under the same roof"
R&D characterization (based on description of team leaders and author's assessment)	• Flexible organization, no hierarchies • Formal communications and face-to-face interactions • R&D dependent on external funding • Standard procedures of development • Entire project is not known to all team members	• Rapid prototyping and testing • Flat, "cost effective organization" • Small core team that "knows it all" • Virtual collaboration • Access to specialized facilities • Analysis based on actual prototype testing • NASA-like risk management procedures	• Rapid prototyping and testing • Optimized workflow for idea sourcing • Low cost development structure • Agile organization • Open knowledge sharing • No bureaucracy • Small core team • Key "know it all" members at the center of the network • Virtual collaboration	• Flat organization • Face-to-face communications • Multi-disciplinary inter-departmental collaborations • "Craft culture" • Trial and error approach • Iterative prototyping and testing cycles that evolve design • Simulation supports process • Creative problem-solving when need to adapt technologies
Team example	**T20**	**T16**	**T11**	**T4**

Note: characterization of R&D activities based on assessment of the researcher and actual descriptions of interviewees; not all teams define themselves in terms of the same characteristics—this does not imply a lack of particular features, i.e. only features described by the interviewees are mentioned in the table.

Source: questionnaires, interviews, and site visits to GLXP teams.

Interviews and site visits exposed more diverse features of the internal organization of teams. In general, these organizations tend to be flat and flexible due to the small number of core team members. The main difference emerges at the moment of approaching the GLXP problem (this analysis does not seek to assess the organizational performance of teams.) The Space Legacy team has sought to implement more formal procedures and communications, documenting project tasks and using standards. This approach allows international collaborations and the pursuit of a project that goes beyond the GLXP mission. A GLXP engineer with vast industry experience explains that there is however much less paperwork and "red-tape" than compared with aerospace companies (T20, 2010). In this case, the project has become more complex and seems to depend more on external funding to make progress. The Partnership Networks and University Spin-off teams have quickly proceeded to prototyping and testing solutions for different subsystems. The results of tests inform further steps in development in those cases. In general, these teams do not document all procedures. The agility gained with informality has been paid with coordination issues in a few cases and the need for re-organizing groups internally. Two of these teams have core members that "know it all." The other teams that do not have those members suggest that that is because the project has become more complex (Space Agency Legacy) or because in that way "*you waste the cycles of all of your people, all of the time*" (University Spin-off.) The Partnerships Network has engaged a few key members with aerospace experience and its internal organization evolves over time as the team learns how to better approach problem solving after iterations or cycles of development (T11, 2010). The University Spin-off team has similar attributes, yet draws upon very experienced, multidisciplinary members and external advisors. Its approach is methodical yet not bureaucratic, which may result from past successful prize experience of key team members.

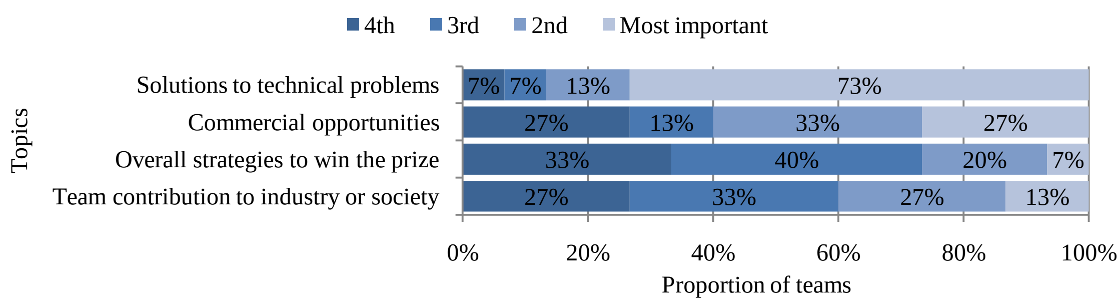
Unconventional teams have a tendency to rapid prototyping and testing. That approach is characteristic of new space missions –suggests the literature—yet, in this case, it is combined with key, considerable volunteer effort and special skills. A team leader defines it as "craft culture" and explains how that relates to cost and degree of achievement of project milestones. His words are very illustrative in this regard:

> "*So, it's a craft culture. To get something like that done might be $100,000. A group that has these values and experiences, and resources and facility* [he refers to his team] *might get the same thing done for $4,000. But the money isn't the key thing. My point is there is also a tremendous inefficiency in getting it done in that traditional way, where there is the idea of what is needed which is transferred to a designer that puts it into some tangible form, which moves it to analysis, which determines if it going to be this or that, that it should be changed in this way , which then sends it to a productions shop, which then orders the materials that then gets the things done, which then goes to the assembly, which then goes to an inspection, which sends it back with communication and bills and all that kind of thing. It's very common around here to conceive something that is needed at this time, at lunchtime one day and have that thing, just like that, the next day. And, people die for it. They are all nighters. Three o'clock in the morning. People that could not or would not ordinarily be an analyst that have tremendous craft skills. They're what matter.*" (T4, 2010)

There are significant knowledge flows between teams and other individuals/organizations external to the GLXP. Only one team—conventional, with vast aerospace industry experience—has not exchanged information about its project with diverse other entities. The latter include academic researchers, family and friends, consultants, contractors, colleagues with prize experience, and even other GLXP teams. All but one team mentioned at least three of those types of information exchange, and three teams mentioned exchanges with all the types of people/organizations. According to these data, 14 out of 16 respondent teams (88 percent) exchange information with academic researchers regularly. Also notably, 13 teams (81 percent) exchange information with providers or contractors and 12 teams (75 percent) with family and friends. Those three are the most important channels of information exchange. In addition, 11 teams (69 percent) mentioned exchanges with consultants, nine teams (56 percent) with colleagues with prize experience (e.g. former NGLLC competitors,) and seven teams (44 percent) with other GLXP teams.

Information exchanges are generally about knowledge to find solutions to technical problems (Figure 6.7). Eleven out of fifteen teams that exchange information (73 percent) consider "solutions to technical problems" as the most important topic for information exchange. Four teams (27 percent) indicated that the most important topic for information exchange is commercial opportunities (other five teams indicated this topic as the second most important.) "Overall strategies to win the prize" is the main topic for only one team. "Team contribution to industry or society" is the least important topic in information exchanges.

Collaborations between GLXP teams were not evident to this research and are certainly less intense than in prizes such as the NGLLC. However, they may exist and be more sporadic interactions rather than stable or formal collaborations. Attending the 4th GLXP Annual Summit was instructive in this regard. Representatives of only 11 teams attended the meeting (most of these teams are among the most active teams in terms of technology outputs.) The team leaders openly presented technical aspects of their projects and explained their progress. Informal conversations were also held between team leaders in break times. These presentations are not a requirement of the XPF. Indeed, a few teams suggested allowing presentations after the first GLXP Summit. The author also had the opportunity to assist a GLXP team's members meeting in which one of the members—specialized in computer visualizations—commented on his interactions with another team's member specialized in the same area. That team member illustrated those interactions with a simple "*we are making each other better*." (T4, 2010) Teams that are very open to share their developments on their websites or online social networks may also receive important feedback from the public, even about technical aspects of their projects (T11, 2010).



Note: N=15 cases.
Source: questionnaire applied to GLXP teams.

Figure 6.7: Topics of information exchange of GLXP teams with selected individuals and organizations

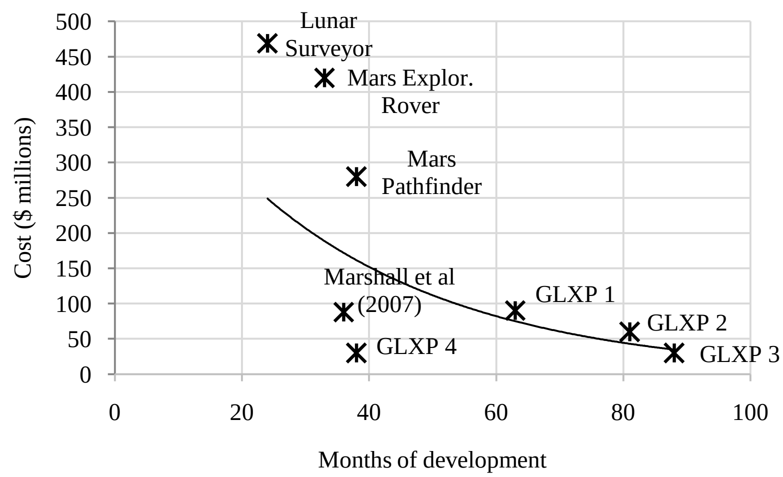
6.5.4 R&D effort

Space projects have significant funding requirements. For example, the total cost of the 1960s Surveyor program, which involved building, launching and landing softly seven Moon spacecrafts, was $469 million. The U.S. Mars Pathfinder, a mission designed primarily to demonstrate a low-cost way of delivering science instruments and a rover to the surface of Mars in 1997, had a total cost of about $200 million. Equivalent new space missions are likely to have lower budgets. Marshall et. al. (2007) suggests that a small unmanned lunar lander mission could be accomplished in under 36 months and for a total mission cost of about $88 million. The GLXP project may have a budget similar to small missions, which still represents a significant R&D effort for small teams. In 2008, the XPF estimated project expenditures between $15 million and $100 million, i.e. up to three or four times the total cash purse. For a $30-50 million mission, the expected breakdown was: $5 million for rover development, $10 million for lander development, $6-25 million for launch services, $2 million for payload integration, $5 million for development/acquisition of 3rd stage motor (trans-lunar injection,) $2.5 million for insurance costs, and $0.5 million for ground network use (communications) (XPF, 2008c). More recent estimates expect an average mission cost of $60 million, with up to two-thirds of that amount covered with hard cash and the rest with in-kind contributions and volunteer efforts (Pomerantz, 2011a). Interview data and team websites also show estimates that range from $4 million to $90 million, with only four teams that expect to accomplish the mission with $30 million or less (Figure 6.8).[20] In general, the lack of upfront funding exposes teams financially to a great extent.

Further examination allows a better understanding of the R&D effort required to accomplish the GLXP challenge. Figure 6.9 shows a simplified scheme with cycles or iterations and costs for an illustrative $30 million GLXP mission, based off discussions with GLXP team leaders and other sources (this scheme may not represent the process followed by most of the teams.) These costs do not represent cash flows yet provide insights about the financial gaps that teams may face. The Start-up is the initial phase after the team enters the competition; it contributes the initial ideas. Iteration A (about six months) comprises the initial models and mockups of spacecrafts that teams use not only for development purposes but for starting to seek fundraising and sponsorship opportunities. Teams also grow significantly in this stage. Iteration B (about 12 months) comprises further development of prototypes, tests, and initial production of subsystems.

[20] Range based on data gathered from five different teams. The estimate for other teams is very likely to be within the same range.

Teams also use their prototypes for public demonstrations that give them access to new members and increasing visibility. Iteration C (about 12 months) comprises the production of subsystems and further testing. Iteration D (about 12 months) continues with the production of systems and system-level tests. Iteration E (about one month) comprises final preparations, launch, and mission accomplishment.



Note: GLXP 1-4 represent cost/schedule estimates of four different teams for GLXP mission achievement. Source: own analysis based on data from sources cited in the text and team interviews.

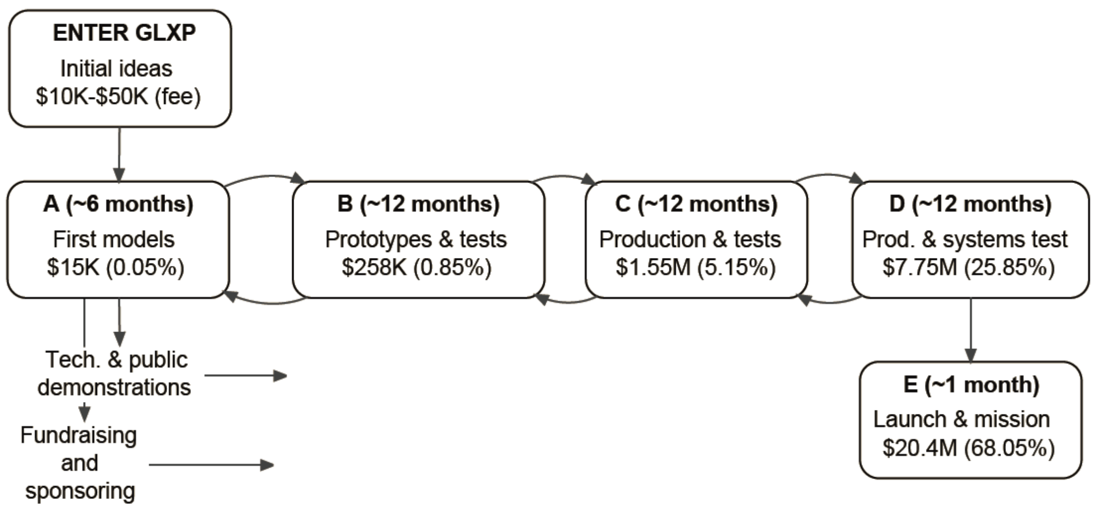
Figure 6.8: Schedule/cost comparison for past robotic missions, literature, and selected GLXP projects

Notably, about 70 percent of the total cost of the GLXP mission is related to the final iteration of mission accomplishment as the launching vehicle is the single most expensive item of the entire mission (this was confirmed by several team members that follow different mission approaches.) Commercially available launching rockets may cost between $10 million and $50 million depending on payload capabilities.[21] Rockets with smaller payload capabilities are less expensive, yet in turn require the team to exert a

[21] For example, SpaceX, preferred launch partner of the XPF, offers discounts of up to 10 percent in its Falcon 1e and Falcon 9 rockets, which cost about $10 million and $50 million before discount, respectively (SpaceX, 2011a, 2011b).

significant engineering effort to develop smaller and lighter spacecrafts. Rockets with larger payload capability allow teams to make less engineering effort and use cheaper components (T4, 2010). In general, teams have to pay this amount about 12 months before launch (this may be negotiated with the launch provider, who has to build and integrate the payload after the contract is signed.) Teams may also launch their spacecrafts as secondary payload on a larger launch vehicle to be able to share the costs with other spacecrafts. Launch costs may be significantly lower if a team develops its own launcher, yet cash flows are likely to be more significant earlier in the mission timeline (and, at least three GLXP engineers suggest, that would be impossible to accomplish within this time frame.)

Team leaders explain that there is almost no correlation between how much gets spent and what really gets accomplished in this type of project (T4, 2010). In terms of Figure 6.9, the most significant engineering effort is made during the initial iterations to develop crafts such as rovers and landers. This occurs between iterations A and C and represents about six percent of the total cost of this mission. In missions with costs between $4 million and $90 million, that percentage represents between $250,000 and $5.5 million to be afforded during the first 30 months of the project. These costs include the development of working models and prototypes among other tasks. Initial prototypes can be produced quickly and at relatively low cost. For example, Team FredNet developed a handful of small rover prototypes for concept testing purposes within its first year of competition; one of them, a small ball rover, was built for only $1,000 (XPF, 2009b). Team Part Time Scientists, within its first 16 months of competition, built a more complex prototype that demanded about six months of development and costs between $41,000 and $55,000 including all the mechanical parts, the electronics, and most of the other subsystems, yet excluding labor and an “unbelievably expensive” solar panel antenna introduced by the team (PTS, 2011b). This illustrates the kind of funding requirements faced by teams in early stages of their projects before the production of spacecrafts and launch. Production and further testing stages are more costly. For example, Team Odyssey Moon estimates the cost of its lander (developed under a Space Act Agreement with NASA) at around $3.5 million, including $500,000 in parts and $3 million in labor (Kay, 2010).



Note: the description of phases is only illustrative and does not represent the budgets and processes of all teams; duration of iterations may vary and/or overlap.
Source: interviews to GLXP teams and other sources cited in text.

Figure 6.9: Cycles and cost estimates of an illustrative $30 million GLXP mission

There is another interesting difference between teams that becomes evident in interviews and a more careful analysis of team activities. While there are some teams that optimize their efforts to satisfy the minimum requirements of the prize challenge, there are other teams that design, test, and develop technologies that may be helpful in a GLXP mission yet imply significantly larger efforts and increase development lead times. For example, a GLXP engineer explains such optimization with: *"...making something last five hours is significantly easier than making something that can last years, and even with a small budget and a very hard time constraint, if you really want to focus on this one goal, then you can ignore lots stuff."* (T11, 2010) On the contrary, there are also efforts that not only satisfy the GLXP minimum requirements but also increasing performance and functionality. For example, there is the effort of Team ARCA to develop the E-111 carrier airplane that is able to take-off from the sea and to transport another vehicle (a launcher also developed by the team) to a certain altitude for ignition (XPF, 2010). This variance in efforts is also evident in the diversity of design criteria (including efficiency/performance vs. mission accomplishment balance) and demonstrates that there are teams that seek the shortest path to achieve the prize challenge and there are teams that are focused on this and other goals as well.

Teams raise funding for their efforts from a number of sources. The most significant monetary contributions come from sponsors and, sometimes, private investors when teams are able to attract them. Sponsorships are more frequently available than private investments. Only a handful of teams may have received private investments. One of the main reasons for this is the economic slowdown started in 2007 (Pomerantz, 2010a). A team leader explains that, more generally, "*nobody is interested in investing in technology up front. They want to harvest the results after it's proven that it works*." Nevertheless, he continues, "*the fact that the competition is sponsored by Google is important for credibility. If Google is involved in a leading edge activity, then more people will believe that it makes sense*" (T4, 2010).

An example of teams that did receive equity investments is Next Giant Leap from Boulder, CO. This team has received investments from two private companies ($225,000,) eSpace: The Center for Space Entrepreneurship (more than $30,000,) and its own founder ($200,000.) Moreover, Draper Laboratory, one of the team's partners, recently committed over $1 million from its internal R&D program to fund the design and development of a guidance, navigation and control system testbed for use in the team's mission (Kolodny, 2011). Another example is Team Astrobotic, which seeks to raise at least $25 million from private investors and cover the rest of the mission cost—about $90 million—with progress payments from, for example, payload delivery services. Other teams find that technologies they have developed for their own projects (and not with commercialization goals) have some market demand and use the opportunity to cash in to fund their GLXP missions. For example, Team Phoenicia expects to cover between 15 and 20 percent of its total mission cost in this manner (Team Phoenicia, 2011).

Visits and direct observation of workplaces of GLXP teams also suggest that there are other valuable non-monetary resources and in-kind contributions used by teams (Kay, 2010): (a) teams with formal or informal linkages to universities have access to key equipment, laboratories, and special facilities such as clean rooms or test areas for propulsion systems; these teams have access to equipment through the work of student and faculty members as well; (b) also teams with corporate partners may have access to specialized facilities and resources such as workstations and expensive equipment; (c) teams also use facilities provided by family and friends to hold regular team meetings, meet potential sponsors or partners, assemble subsystems, or store equipment, parts and supplies; (d) teams use significant volunteer effort in the form of direct labor (including, for example, students, friends) and, sometimes, contribution of production effort, parts, and components.

The efforts of volunteers and collaborators are serious. For example, Team FredNet's mission has an estimated cost of $30 million, yet up to about $6 million may be saved thanks to volunteer effort (Kay, 2010). Another GLXP team leader refers to part of that volunteer production effort as "company friends" and explains that they represent an important contribution: *"…anywhere from 5-20 percent of our costs might be covered that way."* (T4, 2010)

6.5.5 Constraints and challenges

Teams face a number of constraints or challenges in their pursuit of the prize. Overall, both limited time and lack of resources to undertake their projects are the most significant constraints that GLXP teams face. Limited time is a great constraint for six teams (38 percent,) a moderate constraint for eight teams (50 percent,) and not a constraint for two teams (Table 6.21). Limited funding is a great constraint for six teams (38 percent,) a moderate constraint for five teams (31 percent,) and not a constraint for five teams. The third most significant constraint is unclear rules or technical requirements for the prize target (a great constraint for four teams.) The two least challenging factors are the competitive strategies of other teams and the time advantage that first-to-enter teams have. Unconventional teams have a peculiar perception of those constraints. In general, they consider less significant most of the constraints, being limited resources/time still the most widely perceived constraints, though they are considered moderate constraints. These teams are generally not concerned at all with the intelligibility of the rules, the advantages of other teams, the strategies of other teams, and the lack of knowledge/skills. Conventional teams show a higher level of concern with a number of constraints, particularly the limited resources and time available to the team. A number of conventional teams feel constrained to some extent by unclear rules, the lack of knowledge/skills, and the time advantage that other teams have.

The organizers of the GLXP point out that they have observed how the fundraising problem may become more challenging than the technical problem in itself (Pomerantz, 2010a). Team leaders also expressed that in interviews and emphasized the significance of a lack of funding more than limited time to accomplish the mission. Team leaders explain how funding dominates technology in this context using statements like these:

"…yeah, if they [the other teams] have more resources, they could win with worse technology. That's one of the limiting factors. If you don't have the money, you can't get much accomplished. So, if someone granted one of the other teams $100,000,000 up front, they could probably beat us, because they can buy some solutions or buy expertise, whereas we have to do it the hard way with internal work." (T4, 2010)

"To develop and acquire technologies, simple; to achieve the prize target, not a problem; but this... that depends on monetary issues, I mean, if we don't get the funding, then none of that applies. […] If you have the full funding, it's possible to achieve within time, no problem." (T16, 2010)

Other constraints discussed in interviews include the prize rules (T6, 2010; T11, 2010; T16, 2010; T20, 2010), the impediment to use ITAR restricted components (in the case of foreign teams) (T11, 2010; T20, 2010), and the limited access to professional and partnership networks (T6, 2010). The final version of the GLXP's MTA, which includes rules and other legal provisions for the competition, was released on January 2011, more than three years after the prize announcement (Table 6.22). These rules evolved favorably according to the teams and become "reasonable" and "positive." Initially, the rules had issues and restricted potential innovations (e.g. rules required pictures of the rover's tracks yet not all teams would use wheeled rovers.)

Table 6.21: Factors that constrain or challenge GLXP teams, by type of entrant

Constraints	Percentage and type of team that assess each constraint								
	Unconventional teams			Conventional teams			All teams		
	To great extent	To some extent	Not at all	To great extent	To some extent	Not at all	To great extent	To some extent	Not at all
Limited resources	22%	67%	11%	57%	29%	14%	37%	50%	13%
Limited time	22%	44%	33%	57%	14%	29%	38%	31%	31%
Unclear rules	22%	11%	67%	29%	71%	0%	24%	38%	38%
Lack of knowledge/skills	22%	11%	67%	14%	57%	29%	19%	31%	50%
Time advantage of other teams	0%	33%	67%	0%	57%	43%	0%	44%	56%
Strategies of other teams	11%	0%	89%	0%	29%	71%	6%	13%	81%

Notes: N=16 cases (9 unconventional teams, 7 conventional teams); cells indicate number of teams of each type and with each perception.

Source: questionnaire applied to GLXP teams.

Though the change of the original deadline (December 31, 2012) was something positive for some teams, others were disappointed (T11, 2010). During the first years of competition, the uncertainty around what the ultimate set of rules would be raised concerns and may have constrained the activities of teams (Werner, 2010). A team leader explains: *"I think a frustration for all the teams is the fact that the rules have not been finalized yet. I think that limits our ability to plan finally and decisively with regard to approach."* (Goldsmith, 2009) In relation to this, the author is also aware of at least one team that withdrew the competition after an emerging disagreement between the use that the XPF expects for the results of the competition (i.e. the achievement of the GLXP mission) and the goals of the team.

Table 6.22: Evolution of the GLXP's Master Team Agreement over time

MTA version / release date	**MTA 1.0 Nov. 2009**	**MTA 2.0 Aug. 2010**	**MTA 3.0 Jan. 2011**
Assessment	• "Great problem", "Some rules excluded themselves" • Issues with interpretation of technical requirements • Some rules impeded free negotiation of teams to partner and raise funding • Rules level the field, "…especially with the part of the government money"	• "A lot of things were fixed or corrected or reformulated" • Issues with interpretation of copyrights • Some requirements considered pointless from the engineering viewpoint • Roughly defined requirements "a good way to work because it leaves a lot of room"	• "Reasonable rules" • "Positive in general" • Conducive rules • Final version of MTA

Note: author's assessment of rules based on document analysis and interviews with GLXP teams
Source: own analysis.

In questionnaires, teams were also asked about their responses to a lack of funding and/or the need to speed up technology development. When facing a lack of funding, GLXP teams respond to great extent with the design of simplified technologies, additional fundraising, and the design of technologies that can be commercialized, as indicated by seven teams (47 percent,) six teams (40 percent,) and six teams, respectively (Table 6.23). Other teams (between eight and five) indicated that, only to some extent, those are their responses to a lack of funding. Fewer teams have responded (or plan to respond) to great extent to a lack of funding by relying upon existing or standard technologies and partnering with other organizations (only five and four teams, respectively.) The least common responses to a lack of funding have been to skip risk analyses or test phases and to think of withdrawing the competition.

Table 6.23: Selected responses to a lack of funding and the need to speed up technology development

Selected responses	When faced lack of funding…			When needed to speed up…		
	To great extent	To some extent	Not at all	To great extent	To some extent	Not at all
Designed simplified new technologies	47%	33%	20%	60%	20%	20%
Relied more upon existing technologies	33%	47%	20%	40%	40%	20%
Sought additional funding from investors	40%	47%	13%	33%	33%	33%
Partnered with other organizations	27%	53%	20%	36%	43%	21%
Designed tech. that can be comm.	40%	40%	20%	14%	29%	57%
Skipped risk analysis or test phases	7%	47%	47%	7%	43%	50%
Thought on abandoning the competition	7%	13%	80%	0%	29%	71%

Notes: N=15 cases (8 unconventional teams, 7 conventional teams); cells indicate percentage of teams with each response.

Source: questionnaire applied to GLXP teams.

The responses of GLXP teams to the need to speed up developments are similar. Most notably is the design of simplified new technologies, which is the most frequent response to the need to speed up projects. Nine teams (60 percent) indicated that have responded or planned to respond to great extent with simplified designs. A significant proportion of teams have also relied (or plan to rely) upon existing technologies to a great extent (six teams or 40 percent) or partnered (or plan to partner) with other organizations to a great extent (five teams or 36 percent.)

There is no significant correlation between the perception of time and funding constraints and the number of partnerships identified for each team.

In interviews, team leaders confirmed the importance of reducing engineering efforts to shorten achievement times and explained that a number of technologies needed for their projects are readily available at affordable price tags. An experienced engineer also explained that there is a limit to make things cheaper and the main approach its team uses to speed up developments includes drawing upon more volunteers and combining things "*to minimize the number of items you are building*" (e.g. develop a model that serves both testing and promotional purposes) (T20, 2010).

The data show only significant differences between types of teams with regard to the use of simplicity as design criterion (Table 6.24). Unconventional entrants are more likely to introduce simpler designs when facing a lack of funding or the need to accelerate projects. Four out of five unconventional teams that indicated time as a great/some constraint reported technical simplicity as the main design criterion. Moreover, four out of eight unconventional teams that indicated funding as a great/some constraint reported simplicity as the main design criterion. No conventional team shows similar relationships between perceived constraints and design criteria.

Table 6.24: Selected responses to a lack of funding and the need to speed up technology development, by type of entrant

	Unconventional teams			Conventional teams		
	To great extent	To some extent	Not at all	To great extent	To some extent	Not at all
When faced lack of funding						
Designed simplified new technologies	63%	25%	13%	29%	43%	29%
Relied more upon existing technologies	38%	38%	25%	29%	57%	14%
Partnered with other organizations	25%	50%	25%	29%	57%	14%
When needed to speed up developments						
Designed simplified new technologies	75%	25%	0%	43%	14%	43%
Relied more upon existing technologies	38%	38%	25%	43%	43%	14%
Partnered with other organizations	38%	38%	25%	29%	57%	14%

Notes: N=15 cases (8 unconventional teams, 7 conventional teams); cells indicate number of teams of each type and with each response.

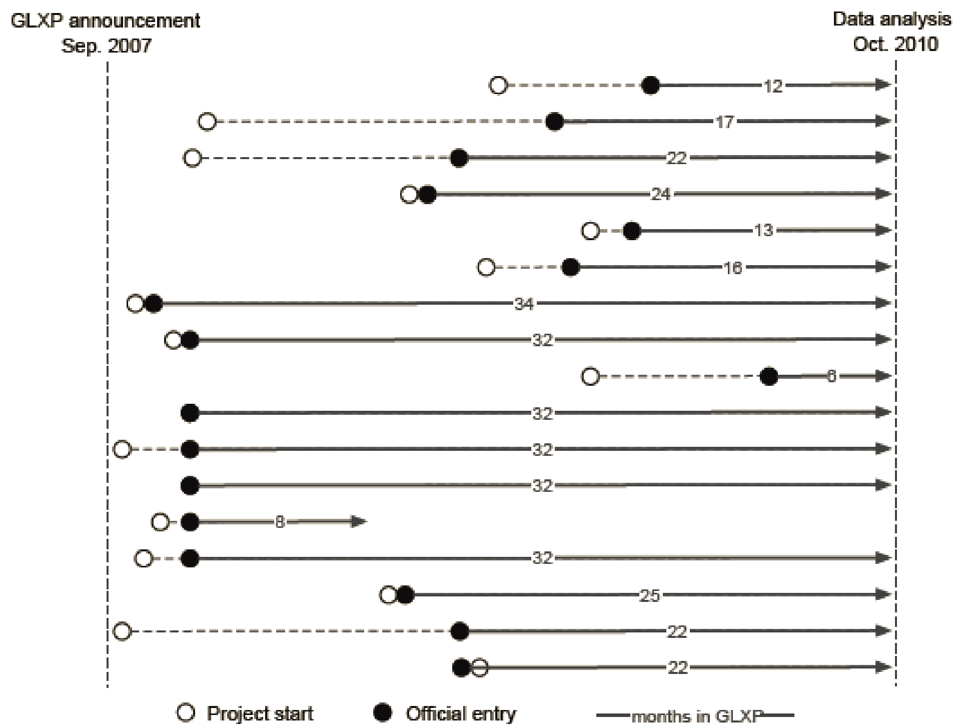
Source: questionnaire applied to GLXP teams.

6.6 Technology outputs

Teams may produce diverse types of technology outputs in their attempts to win the competition or pursue related goals. This research anticipated that the PTOs may be produced in the form of, for example, new concepts, designs, models, mockups, prototypes, and actual spacecrafts. The number and quality of these outputs are likely to vary among teams as they have been involved in the competition for different periods. Moreover, teams may begin their work in "stealth mode" before entering the competition officially and/or have previous work experience as a group before even thinking of competing for the prize. The questionnaires to GLXP teams requested information about the technological achievements during the competition and further investigation was done to discover the characteristics of the technology outputs in their various forms and assess their novelty and potential to become truly innovations as a result of their commercialization or introduction for the teams' own use.

The teams that participated in this study (17 teams) had a combined total of 450 months of technology development on their GLXP projects at the moment this analysis started. These teams entered the GLXP between September 2007 and April 2010. Nine teams (53 percent) had already more than 30 months of work on the GLXP project when they responded a questionnaire (Figure 6.10). None of these teams had completed more than 50 percent of its project at the moment of responding a questionnaire and according to each team's plans to accomplish the GLXP mission. Ten teams (63 percent) completed less than 20 percent and six teams (38 percent) completed between 20 percent and 50 percent. In average, these 17 teams have started their work on the GLXP about four months before their official announcement as GLXP teams. Two teams had worked up to 12 months before being announced as official competitors. According to team leaders, the teams use this initial time-period to hire members and gather the initial resources to start their projects.

The time that each team had spent in its GLXP project is only a hint of the actual technology outputs. A number of teams describe their GLXP projects as the continuation of past projects of the team or its members. Seven teams (41 percent) have past projects that relate to very great extent to the GLXP, and only two of them are unconventional teams. Other four teams (24 percent) have past projects that relate to the GLXP only to some extent. Six teams (35 percent,) four of them unconventional, reported that their projects are not related with previous projects of the team or its members. The nature of the relationships between past and GLXP projects are diverse. Five teams responded that the GLXP project is the expansion of ongoing projects. Four teams indicate that it is the application of results or knowledge from other projects. One team indicates that this is the restart of discontinued projects. Another team indicates that there is other type of relationship yet does not describe it.



Note: N=17 cases.
Source: questionnaire to GLXP teams.

Figure 6.10: Time of competition and time of actual development for GLXP teams

There is a wide range of planned development lead times to complete the GLXP missions. Teams reported in questionnaires that they expect to complete their projects in time periods that range between 31 and 91 months with a median of about 57 months. There are no significant differences between unconventional and conventional teams' development lead times. Lead times reported by conventional teams range between 31 and 91 months, and those reported by unconventional teams range between 38 and 81 months.

Large proportions of COTS technologies and the criterion of the smallest possible engineering effort anticipate that part of the systems used in GLXP projects are not novel. Teams were asked to assess the degree of novelty of their technologies and report whether they build completely new systems and components ("from scratch") or acquire, adapt or copy existing technologies. Only one-fourth of the systems designed for the GLXP are completely new according to that self-assessment. Most of the teams (63 percent) classified their technologies as "somewhat new." Only four teams (25 percent) responded that their technologies are "completely new" and only two teams responded "not new at all."

In particular, the subsystems most indicated as completely new are the lunar lander and rover (Table 6.25).[22] Eight teams (50 percent) indicated that their lunar landers are completely new and six teams (38 percent) indicated that their landers are somewhat new technologies. Similarly, eight teams indicated that their lunar rovers are completely new and seven teams (44 percent) indicated that their rovers are somewhat new. Using the same criteria, the systems that follow in terms of development effort are the photo/video system, the control/navigation hardware and software, and the Earth-to-Moon transfer vehicle. Four out of 16 teams (25 percent) indicated that these three subsystems are completely new. Moreover, nine teams (56 percent) indicated that their photo/video system is somewhat new, seven teams (44 percent) indicated that the control/navigation hardware and software are somewhat new, and only five teams (31 percent) indicated that the Earth-to-Moon transfer vehicle is somewhat new. Overall, the systems that were most characterized as not new at all are the Earth-to-Moon transfer vehicle and the ground support system, as indicated by seven teams (44 percent) in each case.

There are some differences between unconventional and conventional teams in the degree of novelty of their subsystems. Most notably, most of the unconventional entrants use control/navigation hardware and software, communications, and ground support systems that are not new at all. Moreover, contrary to the rest of the teams, most

[22] The GLXP does not require using a rover to accomplish the challenge. As discussed in the next section, there are teams that expect to introduce alternative approaches to traverse the required 500-meter distance.

of the conventional teams consider that their Earth-to-Moon transfer vehicles are not new at all.

Most of the teams (10 out of 15) consider that they have achieved significant innovations and reported achievements in the form of new products or components (Table 6.26). Eight teams (80 percent) also achieved innovations in the form of new uses for existing materials, products, or components. Six teams (60 percent) achieved innovations in the form of new ways to organize technology design and development. These innovations have been achieved either purposely or unexpectedly. Eight teams have planned innovations. Six teams mention to have achieved innovations unexpectedly. Unconventional teams report the achievement of significant innovations more often than other teams, innovate mostly in terms of new products, and plan most of their innovations. All the teams that reported significant innovations also indicated that their innovations are useful not only to accomplish the GLXP mission but also pursue other projects. The high proportion of innovating teams suggested that some of these innovations may actually be, for example, new designs that the teams are exploring and not actual technologies that the teams are introducing. Further investigation with interviews confirmed that that is the case with a few teams yet, in most cases, innovations refer to new-to-industry or "new-to-industry in this world's region" (i.e. Europe) subsystems that teams are implementing in their own missions. Most of the concerns with the interpretation of the meaning of innovation in questionnaires were also eliminated when at least three engineering-background team leaders acknowledged the difference between invention and the traditional concept of innovation (creation and commercialization) and explained how that relates to the work they are doing.

Table 6.25: Novelty in GLXP teams subsystems, by type of entrant

Subsystems	Percentage and type of teams that characterize subsystem as….								
	Unconventional teams			Conventional teams			All teams		
	Com-pletely new	Some-what new	Not new at all	Com-pletely new	Some-what new	Not new at all	Com-pletely new	Some-what new	Not new at all
Lunar lander	56%	33%	11%	43%	43%	14%	50%	38%	13%
Lunar rover	33%	56%	11%	71%	29%	0%	50%	44%	6%
Photo/video system	22%	56%	22%	29%	57%	14%	25%	56%	19%
Control/navigation hardware and software	11%	33%	56%	43%	57%	0%	25%	44%	31%
Earth-to-Moon vehicle	33%	44%	22%	14%	14%	71%	25%	31%	44%
Comm. Moon and Earth	22%	22%	56%	14%	71%	14%	19%	44%	38%
Ground support system	0%	44%	56%	14%	57%	29%	6%	50%	44%

Note: N=16 cases.

Source: questionnaire applied to GLXP teams.

The GLXP teams have produced various technology outputs in three years of competition (i.e. between the prize announcement in September 2007 and the end of the data gathering process in December of 2010.) Table 6.27 and Table 6.28 show one example of significant technology output for each of the 26 GLXP teams competing in that period. The list does not seek to be comprehensive yet offer illustrative examples of the outputs of each team. The list was created based on interview data and data collected from team websites by selecting at least three of the most widely publicized developments for each team. The data available on actual PTOs underestimate outputs that are not publicly shared by teams. The list includes assessments of the maturity of the technology in a scale equivalent to TRL levels and the assessment of the implementation of the technology (for own use or commercialization.) Figure 6.11 shows four selected examples of technologies under development (these were selected to show some variation.)

Table 6.26: Number of GLXP teams that achieved significant innovations, by type of entrant

Type of innovation	Number and type of team with innovations, by form of achievement				
	Unconventional		Conventional		Total teams
	Planned	*By chance*	*Planned*	*By chance*	
New Products	5	1	3	1	10
New ways to organize tech. design and dev.	3	2	-	1	6
New use for existing materials, products, or components	3	2	1	2	8
Other innovations	1	-	-	-	1
Total teams	5	2	3	4	10

Note: N=15 cases; cells indicate number of teams that achieved significant innovations of each type.
Source: questionnaire applied to GLXP teams.

Most of the teams (17 out of 26, or 65 percent) have produced significant technology outputs, that is, outputs that contribute significantly to the achievement of the GLXP. There is wide range of types of technologies under development and, although teams need similar systems to accomplish the mission, is not evident whether two or more teams are working on the same type of solution. Nine of them have implemented those technologies in their own missions and/or seek hardware commercialization (the latter is less frequent.) Only three out of nine teams exclusively motivated by the existence of the GLXP contributed some significant technology output, and other two of them have withdrawn the competition. A few unconventional teams have introduced novel concepts and produced lower TRL level technologies for experimentation and demonstration purposes. It is not clear whether these technologies will ultimately be deployed or commercialized. For example, there are teams such as Selene that are exploring concepts to find the simplest, most reliable, and cost-effective method to travel the required 500 meters, including the “classic planetary rover design” (GLXP, 2011a). Conventional teams have been more likely to produce technologies aimed at delivering launch, payload, and/or other services. Several of those technologies were already under development prior to the GLXP by the team or a partner, are under development at NASA and will be adapted for the GLXP (through Space Act Agreement partnerships,) or are based on designs of proven implementations in past space programs. Teams such as Team Italia seek to use high TRL level technologies purposely to contain project costs (GLXP, 2010c). Overall, nine teams have not introduced any significant technology output and four of them have already withdrawn the competition. The GLXP is an ongoing prize competition and therefore the PTOs are likely to increase over time.

Many of the PTOs of teams are actually produced by their partners or in collaboration with other organizations, particularly in the case of conventional teams. Those technologies may be already under development or be produced specifically for the prize. For example, Team Odyssey Moon is developing its lander based upon the engineering and technical expertise provided by the NASA Ames Research Center under the development of the Common Spacecraft Bus lander program. This team has also sold 75 percent of the available payload capacity of its spacecraft to five customers (Odyssey Moon, 2008). Team Rocket City Space Pioneers is developing its own propulsion systems based on previous work of a company owned by the team's leader (such company was acquired a few years ago by Dynetics, the leading corporate partner of this team formed by a handful of companies.) These systems may eventually be used in the team’s GLXP mission, yet the team is also aiming at creating a sustainable space business (the team even offered other teams to share the launch vehicle.) (GLXP, 2010a) Team White Label Space is drawing upon the work of Lunar Numbat, one of its partners, to develop an engine throttle controller (this is an open source effort.) (White Label Space, 2010) The hopping lander of Team Next Giant Leap is under development at Draper Labs with resources of such laboratory and labor that includes MIT students (GLXP, 2011b).

Table 6.27: Selected examples of GLXP technology outputs (unconventional entrants)

Technology Output (one row per team)	Lead time (months)	Novelty	Target	TRL equivalent
No evidence of significant outputs	31	-	-	-
No evidence of significant outputs	31	-	-	-
Stereo Vision Canera for 3D Mapping and Navigation	40	I	U	M
No evidence of significant outputs *(team withdrawn)*	31	-	-	-
No evidence of significant outputs	23	-	-	-
Solid-steam rocket motor prototype	25	N	E	L
Five-inch ball robot that can climb slopes	34	N	D	L
New, optimized software algorithms for systems error control and detection	24	N	C/H	M
Re-development of modular rocket system with parallel stages (25+ years old concept)	22	I	U	M
New air-launched, three stages orbital rocket	37	N	U	M
Lightweight, sealed, and scalable N wheeled-motor design	29	I	U	M
No evidence of significant outputs	30	-	-	-
Ion motor-powered Cubesat	40	I	D	M
No evidence of significant outputs *(team withdrawn)*	37	-	-	-

Note: the description of outputs does not seek to be comprehensive and is presented with illustrative purposes; assessment as of Dec. 2010 based on data available to the author.

Source: interviews with teams, GLXP website, team websites, and press releases.

References	
Lead time:	Months since project started (or since official entry if other data are not available)
Novelty:	C=Current-day technology, I=Significant improvements, N=New-to-industry technology
Target:	E=Only experimental (experimental technologies not necessarily used for GLXP project), D=Tech. demonstration/test for GLXP mission, U=Use in GLXP mission, C/H=Expect comm. of hardware, C/S=Expect comm. of services, N/A=unknown
TRL equivalent:	L=low (TRLs 1-4), M=medium (TRLs 5-6), H=high (TRLs 7-9)

Table 6.28: Selected examples of GLXP technology outputs (conventional entrants)

Technology Output (one row per team)	Lead time (months)	Novelty	Target	TRL equivalent
Hopping moon lander concept with regional-scale science measurement capability (based on spacecraft previously built by partner)	35	N	C/S	M
Propulsion systems for new launcher (based on technologies previously developed by team members)	3	I	C/S	M
No evidence of significant outputs	2	-	-	-
Spinning lander concept (concept previously developed by team members, with widely use in communication satellites) *(team withdrawn)*	8	N	U	M
No evidence of significant outputs *(team withdrawn)*	34	-	-	-
Leg-enabled robotic system prototyped	34	I	D	M
Lander's rocket motor and navigation control for engine (based on existing technologies)	34	I	C/H	H
Software for autonomous rover's travel	19	C	U	H
No evidence of significant outputs	19	-	-	-
No evidence of significant outputs *(team withdrawn)*	37	-	-	-
Adaptation (under Space Act Agreement) of NASA's Common Spacecraft Bus program's vehicle into lunar lander for payload delivery	39	C	C/S	M
Cubesats for demonstration of navigation techniques	37	C	D	H

Note: the description of outputs does not seek to be comprehensive and is presented with illustrative purposes; assessment as of Dec. 2010 based on data available to the author.

Source: interviews with teams, GLXP website, team websites, and press releases.

References	
Lead time:	Months since project started (or since official entry if other data are not available)
Novelty:	C=Current-day technology, I=Significant improvements, N=New-to-industry technology
Target:	E=Only experimental (experimental technologies not necessarily used for GLXP project), D=Tech. demonstration/test for GLXP mission, U=Use in GLXP mission, C/H=Expect comm. of hardware, C/S=Expect comm. of services, N/A=unknown
TRL equivalent:	L=low (TRLs 1-4), M=medium (TRLs 5-6), H=high (TRLs 7-9)

a) Prototypes “Asimov Jr.” R1 and R2 developed by Team Part Time Scientists

Source: Team Part Time Scientists.

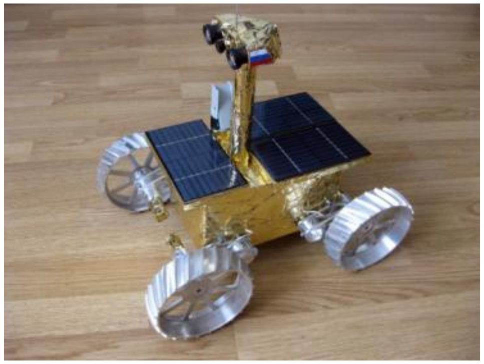
b) Prototype “Red Rover” developed by Team Astrobotic

Source: Team Astrobotic.

c) Concept of supersonic carrier E-111 developed by Team ARCA

Source: Team ARCA

d) Prototype of rover developed by Team Selenokhod

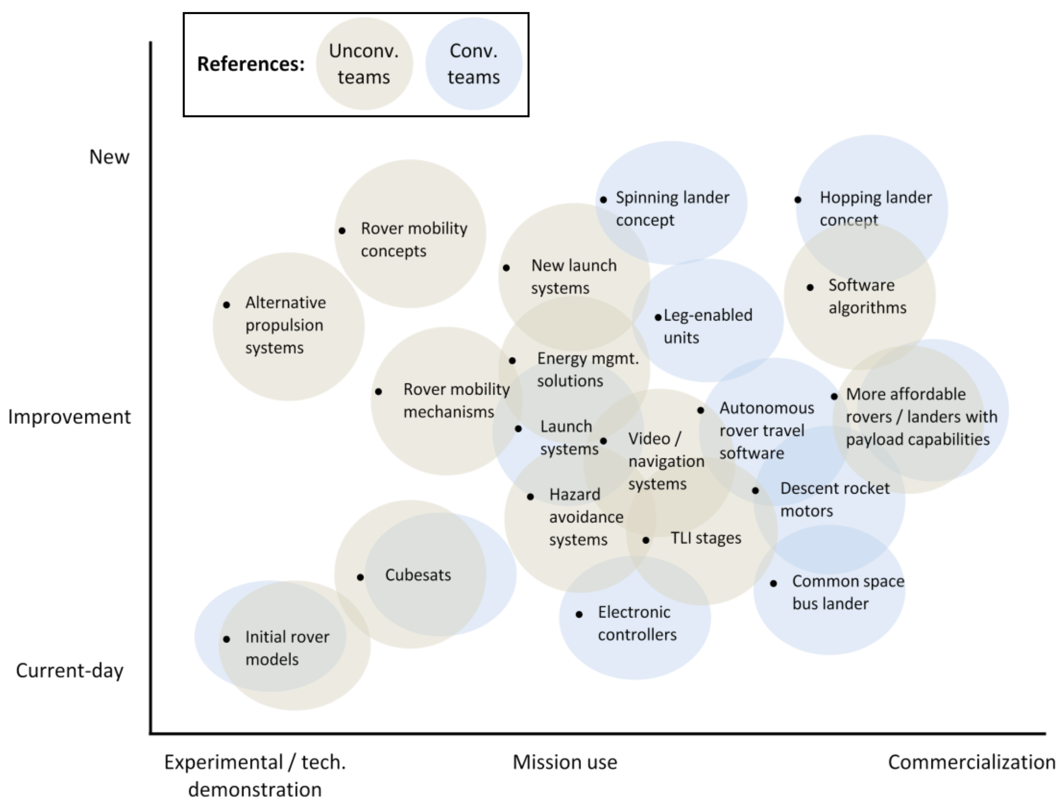


Source: Team Selenokhod

Figure 6.11: Selected examples of GLXP technology outputs

Further examination of the technologies in terms of the degrees of novelty and implementation shed light on the general characteristics of the GLXP's PTOs and possible patterns associated with types of entrants. Figure 6.12 shows that only unconventional teams have developments around the area formed by improvements/new technologies and experimental/mission uses. Also, several technology outputs are likely to be commercialized (by conventional entrants) in the form of service delivery or, in a few cases, hardware sales. Only a few of these technology outputs may become truly breakthroughs not only for aerospace application (e.g. new lander concepts) but also for broader industrial use (i.e. software algorithms.) Other technologies, particularly those aimed at providing services (e.g. payload delivery) are based on improvements of current-day technologies or technologies already under development. Several significant improvements in terms of mobility mechanisms and electronics and navigation systems are in progress to be used in GLXP's missions. Teams are also testing multiple conceptual designs of mobility systems (e.g. rovers or other units) and alternative propulsions systems (e.g. thrusters, fuels.) The overlay of outputs shown in Table 6.27 and Table 6.28 on this chart shows that unconventional teams' developments tend to gather around the area formed by improvements/new technologies and experimental/mission uses.

Though the evidence shows that most of the PTOs are not aimed at or yet readily available for commercialization/service delivery, most of the teams seek to generate revenues from their activities. Eleven out of 17 teams (65 percent of both unconventional and conventional teams) have at least one full- or part-time member exclusively dedicated to business development and commercialization of the prize technologies. Still, not all teams have been equally successful in that regard. For example, in October 2010, NASA awarded up to $30.1 million in Innovative Lunar Demonstrations Data (ILDD) contracts to six U.S. teams for a period of up to five years (NASA, 2010d) (the application process for ILDD contracts was also open to foreign teams—and some of them applied—but none of them was awarded.) The purpose of these contracts is the purchase of technical data resulting from the development and demonstration of capabilities of robotic lunar missions. The awardees include Team Astrobotic (Pittsburgh, PA), Team Next Giant Leap (through its partner The Charles Stark Draper Laboratory, Inc., Cambridge, MA,) Team Rocket City Space Pioneers (through its parent company Dynetics Inc., Huntsville, AL,) Team Omega Envoy (Orlando, FL,) Team Moon Express (San Francisco, CA,) and Team FREDNET (Huntsville, AL.)



Note: only selected outputs are shown, based on data available to this project; outputs are described in general terms and are not associated with any specific team or type of team.
Source: own analysis.

Figure 6.12: Selected technology outputs in a novelty/implementation scale

Teams' strategies also include revenue models based on products other than hardware sales, payload delivery, or IP licensing (Table 6.29). In their effort to raise funding or profit from their projects, teams also commercialize/plan to commercialize sponsorship opportunities, expertise/project management services, and a variety of final consumer services related with social networking, photography and video, and remote exploration experiences. These diverse revenue sources have different strategic implications to mission financing. For example, data licensing or moon experience commercialization requires the mission to be executed to produce revenues. Payload delivery services and sponsorship opportunities may generate revenues through payments in advance (this is typical in the space business for payload delivery.) Certainly, the value of expertise/project management services is associated with the team's performance during the competition. On the other hand, revenue sources are linked to technical capabilities as well. For example, commercialization of moon experience through 3D video and remote driving of the rover requires longer mission times and technical capabilities to perform certain functions not required to claim the reward.

Table 6.29: Planned/actual revenue sources in the GLXP (selected examples)

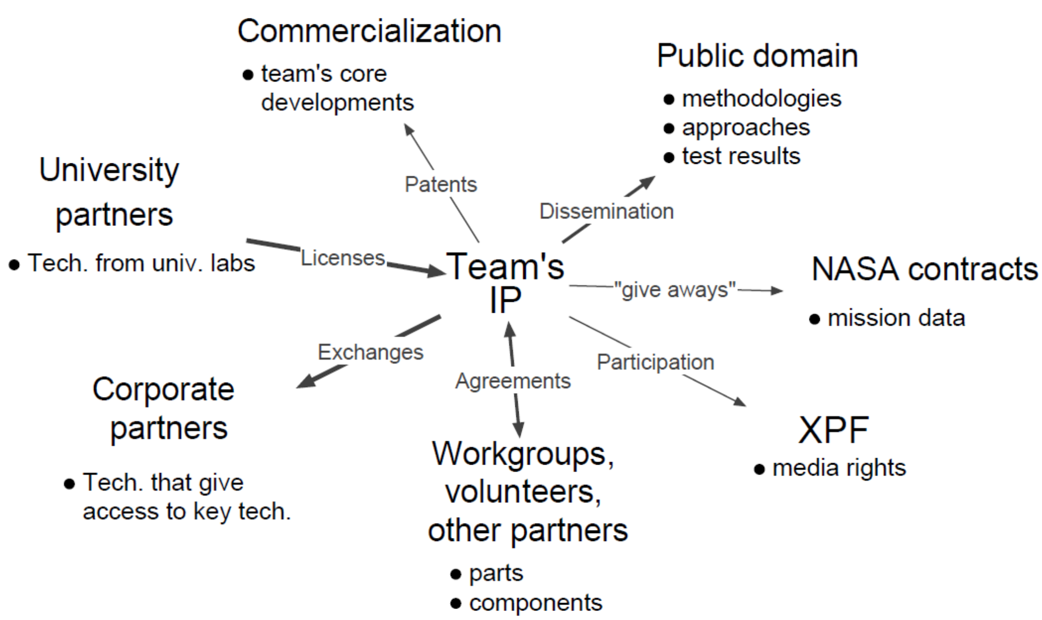
Source of revenue	Description
Sponsorship opportunity	Commercialization of the naming rights for team's space vehicles, mission, or other appearances of the team or its members; space in team's logo (to the extent allowed by GLXP's rules)
Communications	Chat, voice, e-mail, and social networking via/with team's spacecrafts
Payload delivery services	Delivery of scientific (e.g. scientific instruments,) commercial (e.g. human remains, personal objects, corporate-related instruments,) or artistic (e.g. objects, inflatable sculptures) payload in landers/rovers
Commercialization of expertise	Consulting or project management services based on expertise from GLXP mission
Moon experience	3D video and images, remote driving of rovers
Hardware commercialization	Agency or corporate contracts for hardware demonstration

Note: the description of the services does not seek to be comprehensive for each team; only relevant examples are mentioned.

Source: interviews with teams, team websites, and press releases.

The GLXP does not require teams to place their technologies in the public domain and that enables not only the commercialization activity but also the R&D activities of teams. Figure 6.13 illustrates the diverse sources and uses of the intellectual property (IP) created by GLXP teams. Interview data were the most insightful in this regard. In general, teams define themselves as "fairly open" to share their technologies. Most of them publish progress updates on their websites and the official GLXP website (the XPF requires teams to use the latter to post updates on their general activities.) Sometimes, teams disclose or share technical details and other project management information openly. An overall assessment of the digital media published on the GLXP's and teams' websites (e.g. online videos) suggests that unconventional entrants are more inclined to share such details. Teams are more likely to publicly share methodologies, approaches to solve specific problems, and test results. The teams that have access to university resources such as laboratories and machine shops enter/plan to enter in agreements to license the technologies developed at universities. Some teams have created more dense networks of corporate partners to source key technologies in exchange of other technologies they have developed. Six GLXP teams have already signed ILDD contracts with NASA for the provision of mission data. The teams that are organized as workgroups, use collaborators/volunteers, and have other types of partners enter in agreements to share the technologies developed for the prize. A few team leaders explained in interviews that they will eventually seek to file patents for some of their technologies, yet the cost of doing that is a constraint. This research cannot foresee all the alternative schemes that the teams will pursue to commercialize technologies, yet it is possible to anticipate a wide range of approaches. These approaches may range from direct commercialization of hardware through licenses to the creation of a consortium of flexible smaller companies to produce and commercialize the technologies on the basis of co-owned IP (the latter is an example offered by only one team.)

Discussing with entrants the possibility of working in a similar project if the GLXP did not exist contributes other insights on the overall effect of the competition. In this regard, eight teams that participated in this investigation (i.e. 50 percent) reported some probability or certainty of pursuing robotic planetary exploration projects if the prize did not exist: six teams consider this "very likely" and two teams "likely" (Table 6.30). On the other hand, seven teams responded that it would be not likely for them to work in this area if the GLXP did not exist. Not surprisingly, conventional teams are those more likely to pursue similar projects. This supports the idea of the ability of prizes to allow the participation of unconventional entrants that, otherwise, would not be involved in technology development. Five out of nine unconventional entrants indicated that they would not work on this type of project if the prize did not exist.



Note: the purpose of this scheme is to illustrate the diversity of uses and sources of the IP created by prize entrants; line width indicates the overall importance of the link in the GLXP according to the assessment of the author.

Source: analysis of interview data (N=7 teams) and documentary sources.

Figure 6.13: Sources and use of intellectual property created by GLXP teams

Table 6.30: Number of GLXP teams that would pursue similar projects if the prize did not exist, by type of entrant

Type of entrant	Number of teams that would pursue similar projects if the GLXP did not exist			
	Very likely	Likely	Not likely	Do not know
Unconventional	2	1	5	1
Conventional	4	1	2	1
All teams	6	2	7	2

Note: N=17 cases; cells indicate number of teams that indicated each type of response.

Source: questionnaire applied to GLXP teams.

CHAPTER 7

DISCUSSION

7.1 Prize incentives and the motivation of entrants

H1 anticipated that for any given technology sector and its general context, more significant PIs are more likely to induce the participation of unconventional entrants and more significant TIs are more likely to induce the participation of conventional entrants. There is evidence to reject H1 and elaborate alternative explanations.

In principle, the participation of conventional and unconventional entrants is generally associated with the perception of TIs and PIs, respectively. The immediate caveat is that conventional entrants are also particularly incentivized by the potential recognition from NASA and other space agencies for potential future contracts, which is linked to the value of the prize technologies yet, by definition, is considered an incentive created by the prize (PIs.) The recent award of NASA's contracts to six GLXP teams (including five newly created teams and a team led by established companies) is an example of how prizes support the realization of the market value of the prize technologies. This is a sector-specific phenomenon as it results from the combination of both the effect of the prize and the features of the space sector. The GLXP a) creates a platform in which the activities of new, small startup teams are visible and can be followed by space agency and corporate officials, and b) contributes to building reputation by highlighting the achievements of the teams and, ultimately, distinguishing the winner and runner-ups from the rest of the participants and other non-participant organizations. The reputation and publicity values created by the competition reflect the value of Google's sponsorship, the promotional effort undertaken by the XPF, and the symbolic value of being recognized as a competitor. Yet, most importantly in this case, those values also reflect the existence of high entry barriers to the space sector, which has been traditionally dominated by space agencies and large corporations or companies that have develop space heritage after years of work and delivery of proven solutions. It is fair to say that instruments other than prizes also build reputation in this industry, though not based on visibility or publicity. For example, hardware demonstration contracts awarded by space agencies also help awardees to increase credibility and raise more funding (Culver et al., 2007). Certainly, the reputation/publicity values may have also their effect on those teams that seek to produce and commercialize aerospace technologies to private customers or enter other related markets.

The motivation of H1 has been testing whether attracting groups of interest (e.g. unconventional entrants) is possible by designing prizes that offer certain types of incentives. The fact that the relationship between types of entrants defined in this research (i.e. unconventional and conventional) and perceived incentives (i.e. PIs and TIs) is not straightforward calls for further elaboration of alternative explanations for the types of incentives, the motivations of teams, and the relationships between them.

The GLXP offers several monetary and non-monetary incentives (PIs) (Table 7.1). The monetary incentives include the cash purses and other equivalent in-kind benefits such as access to discount price services from the XPF's preferred partners. The cash purse is particularly interesting to conventional teams, who consider that potential source of revenue to close their business cases. Other entrants may consider the value of the cash purse for their personal strategies.[23] The fact that there are 2nd place and bonus prizes creates a more sustainable incentive as runner-ups can still win some money even if they were not the first to accomplish the challenge. This distribution of prizes also allows a second set of teams to continue attracting the interest of investors and engaging more members and volunteers (Pomerantz, 2010a). The Diversity award is probably targeted by a few teams involved in education and outreach activities. Still, the contribution of the cash purses to the entrant effect of the GLXP is moderate. Their

[23] See, for example, the case of the Kremer Prize of 1977 discussed in Chapter 3).

relatively significant value (up to $30 million) raises more public and media awareness (as suggested by, for example, Diamandis, 2009) and help in increasing the reputation/visibility of the teams.

Table 7.1: Prize incentives offered by the GLXP

Type	Incentive	Description
Monetary or equivalent in-kind	Cash purse	$30 million in Grand and 2nd place prizes, bonus prizes, and Diversity Award
	Access to software and services at discount cost	These services are exclusively aimed at supporting the GLXP project. Teams that prepare business cases may reach a break-even point sooner by drawing upon these in-kind contributions.
Non-monetary	Opportunity to pursue a challenging technical goal	This drives curiosity, desire of participation, desire to compete and demonstrate technological leadership.
	Reputation, publicity, and competitive environment	These are necessary to gather resources to accomplish the prize challenge or pursue other goals (e.g. commercialization.)
	Access to a platform with new actors, activities, networks, and rules	These are valuable resources to pursue multiple types of personal/organizational goals (e.g. teams get to know business contacts and gatekeepers to test ideas and/or access further resources and opportunities for commercialization and, eventually, enter the industry sector linked to the prize.)

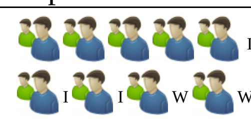
Source: own analysis.

The non-monetary PIs are the most significant incentives offered by the GLXP. There is the opportunity to pursue a challenging technical goal, gain reputation or visibility, and the valuable access to a prize platform that comprises diverse actors (e.g. teams, sponsors, partners, collaborators,) R&D and business development activities, events (e.g. annual GLXP summit, presentations at space conferences and industry fairs,) collaboration networks, and participation rules. Teams may use this platform to, for example, recruit new members, raise funding, learn, find customers for them and for their sponsors and partners, and gather other key resources. Even team members may use this to promote themselves (e.g. Masten Space Systems, winner of the NGLLC, saw an increase in interest in its employees after it won the prize.) (Masten Space Systems, 2010) Furthermore, this platform may transcend the competition time frame to become not only problem solving communities but also become the stepping stone to emerging sectors that target niche markets. In relation to this, the literature has addressed the potential ability of prizes to lower the entry barriers to industry sectors. This research maintains that it is through this platform that teams that demonstrate exceptional performance (generally the winner and/or the runner-ups) are able to successfully enter the technology sector as they build reputation, visibility, and relationships.

TIs are also potentially significant yet uncertain. The markets for lunar exploration technologies may be worth up to $1.5 billion in the next 10 years. However, it is not clear what the top market segments, market values, and required capabilities to exploit them will be. Most of the anticipated revenues in the medium-term are expected from government agencies with NASA as the primary demand. In the short-term, there are only relatively small, concrete opportunities for commercialization of payload delivery, mission data, and hardware for only a handful of teams—mostly demand from NASA as well—yet they also signal potential opportunities for other well performing teams.

To explain how different types of incentives weigh on the decision to participate, motivations can be linked to priority goals. Beyond their more or less significant industry experience, teams have diverse goals and therefore distinct perceptions of the value of the GLXP. Team goals are explicitly revealed by the teams or are implicit in their strategies. Interviews and other data gathered from multiples sources (e.g. prize summit, team websites) offered insights to assess the priority goal of teams and classify them on that basis. There are at least three types of teams based on their priority goal: *challenge teams*, *industry/startup teams*, and a *diverse majority* (Table 7.2).

Table 7.2: Re-classification of GLXP entrants based on priority goals

	Challenge teams	**Industry/startup teams**	**Diverse majority teams**
Main driver	**Challenge-driven** (seek *"Glory" or self-fulfillment, focus on winning the prize)*	**Profit-driven** (*"money rather than fame, glory or glamour")*	**Opportunity to pursue other goals through prize participation** (the prize is aligned with personal/team goals)
General de-scription	New teams or teams with prize experience	Existing space companies, companies that re-direct activities, teams backed by established companies	Very diverse, mostly newly formed teams
Team strat-egy	Seek shortest path to win the prize	Seek to create a sustainable business	Accomplish other personal/ organizational goals
Classifica-tion criteria	Strong intrinsic motivations, willingness to compete, leadership	Clear and explicit focus on the creation of a sustainable business enterprise; prize participation closes business-case	Explicit or implicit goals beyond the prize and not necessarily related with creation of new business enterprise
Number of unconven-tional teams			
Number of conven-tional teams			

Note: based on the analysis of 26 GLXP teams that entered the competition before December 2010; each icon represents a team; I: inactive in terms of technology outputs; W: withdrawn.

Source: own analysis.

Challenge teams focus their efforts on winning the competition. These teams are driven by strong intrinsic motivations, willingness to compete, and the opportunity to channel all their ideas and energy. These are only a handful of unconventional teams in the case of the GLXP. They are probably the least risk-averse entrants as well. These teams "pick up the gauntlet" of the challenge as their members have the "this has my name on it" feeling. They describe themselves in terms of leadership and progress toward the target. These teams also perceive other opportunities—including commercialization of technologies in the case of two out of four GLXP challenge teams—yet winning the competition is still the priority (the idea of predicting the prize winner by looking at this group is very appealing.)

Industry/startup teams are profit-driven teams. These teams consider the prize's reputation/publicity and platform values to close their business cases for commercialization of lunar technologies. Most of the conventional teams are part of this group. Winning the competition is also important for them as a good prize performance is likely to build even a better reputation. However, they also do a cost-benefit analysis in this case and profits dominate the pursuit of the prize challenge.

Finally, the *Diverse majority* comprises teams that find in the GLXP the opportunity to accomplish other very diverse personal/organizational goals or enjoy the mere participation in a project that, otherwise, they would not have access to. These teams may seek to win the competition, yet most of them honestly know that they do not have the best chances for that. These teams outnumber the teams of other types. They are predominantly unconventional teams and comprise most of the teams that have withdrawn or are relatively inactive in terms of technology outputs.

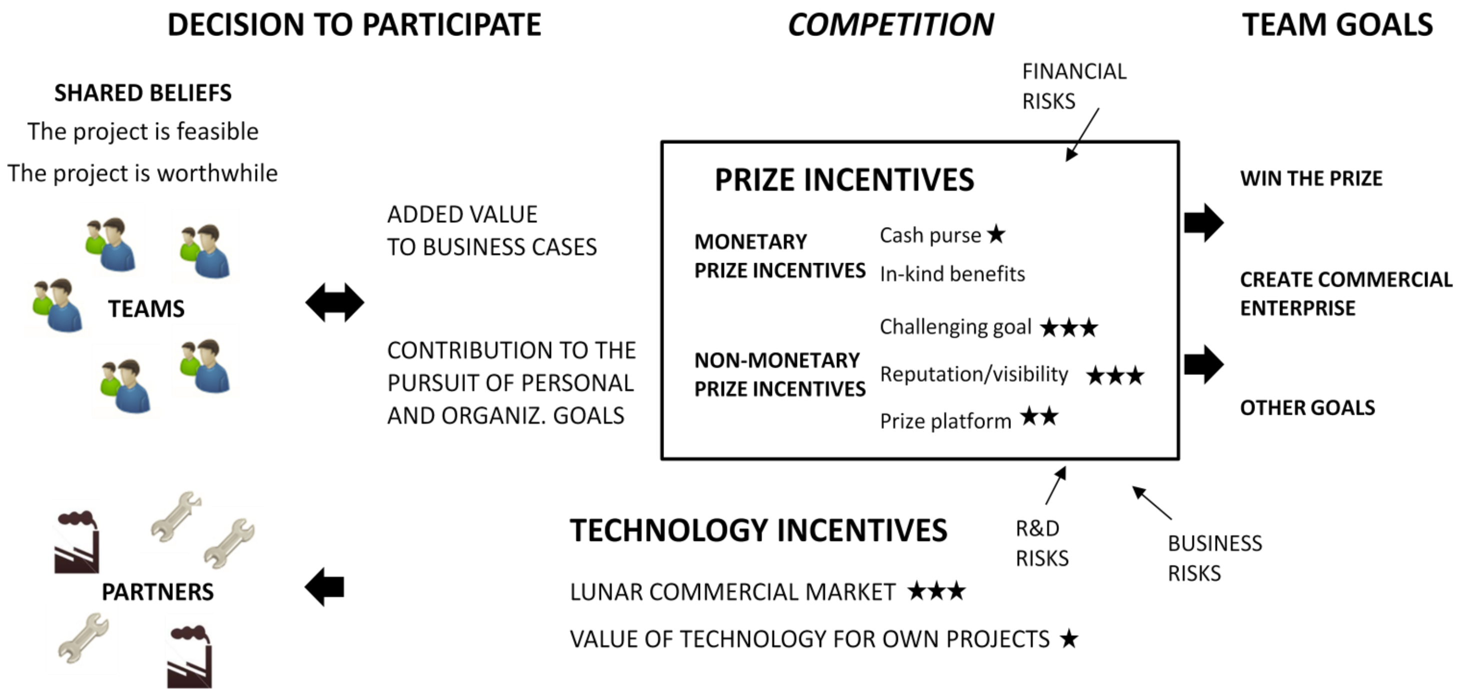
Considering that classification of entrants, three factors are likely to explain why teams decide to participate in prizes and why they choose the GLXP. The first factor is an essential component of the decisions of those that participate. The second and third factors (together or individually) are the ultimate determinants in that decision, and depend on the goals of the entrants.

1. SHARED BELIEFS: there are shared beliefs among teams and prize organizers. These are a) the belief about the technical and/or commercial feasibility of the project (which may be based on own knowledge, previous experience, or even ingenuity,) and the belief about the merit of the pursuit from the social,

commercial, or personal perspective. These beliefs are stated implicitly in the spirit of the competition or explicitly in the prize rules and the sponsor's promotional actions.

2. ADDED VALUE OF THE COMPETITION TO BUSINESS CASES: the prize is a catalyst that adds value to the business cases of those teams that seek to create a commercial enterprise. This happens through different means: a potential cash purse that might help in closing a business case (e.g. in the GLXP, the cash purse represents a 20 percent ROI in a $100 million mission;) in-kind benefits (e.g. access to free software, discount launch services;) and access to the prize platform to find new customers, partners, and gather other key resources. Potential entrants that consider the project commercially viable yet do not perceive this prize added-value would pursue a similar project without entering the competition and having to abide by prize rules.
3. PURSUIT OF PERSONAL AND ORGANIZATIONAL GOALS: participation in prizes gives the opportunity to, for example, win a cash purse, demonstrate leadership, gain prestige/popularity, and participate in an exciting project.

Those factors can explain why teams enter the GLXP and why other entities do not (Figure 7.1). In general, teams share the belief about the feasibility of the project and consider it worthwhile as it is commercially attractive, contributes to other team goals, and/or benefits society. The source of this belief is with the teams and their more general perceptions as a group or as individuals. For example, experts have suggested the existence of a new generation of entrepreneurs inspired by the possibilities offered by space exploration that were not fulfilled in the past. The context of the prize is also conducive in that regard. The new space industry and movements toward a more open space activity offer success stories and demonstrations that the achievement of low-cost, low-technology space projects is possible. This is inspiring for the GLXP teams. The other two factors ultimately encourage teams. Industry/startup teams perceive the added value of the competition to their business cases. That is the reason why four of these teams officially entered the GLXP more than 24 months after the prize announcement. For example, participating in a competition sponsored by Google, Inc. speaks of the seriousness of the team and helps in fundraising. Other teams that seek to create a commercial enterprise (Challenge or Diverse majority teams) also consider such value, yet they are primarily driven by the opportunity to accomplish their personal/organizational goals through participation. For example, some teams seek to demonstrate leadership or raise society's interest in science. These teams consider the GLXP a means to accomplish those goals.



Note: stars indicate overall importance in the GLXP (more starts, more importance.)
Source: own analysis.

Figure 7.1: Factors that define participation in the GLXP

Traditional industry players (e.g. Boeing, Lockheed) and many other established space companies did not enter the competition simply because they consider that the GLXP does not have any commercial merit. The GLXP mission is a discrete, one-off product and winning the competition is, in principle, not a sustainable business over time.[24] Established companies have a costly structure to maintain and that requires pursuing projects that are likely to generate sustainable revenues through, for example, space hardware sales or provision of services. Though there is at least a source that anticipates attractive lunar commercial markets, the prospects are very uncertain. Certainly, there may also be company-level strategies whereby, for example, firms acquire small startups rather than developing the technology themselves (e.g. Northrop Grumman completed its acquisition of the AXP's Scaled Composites after this team won the competition.)

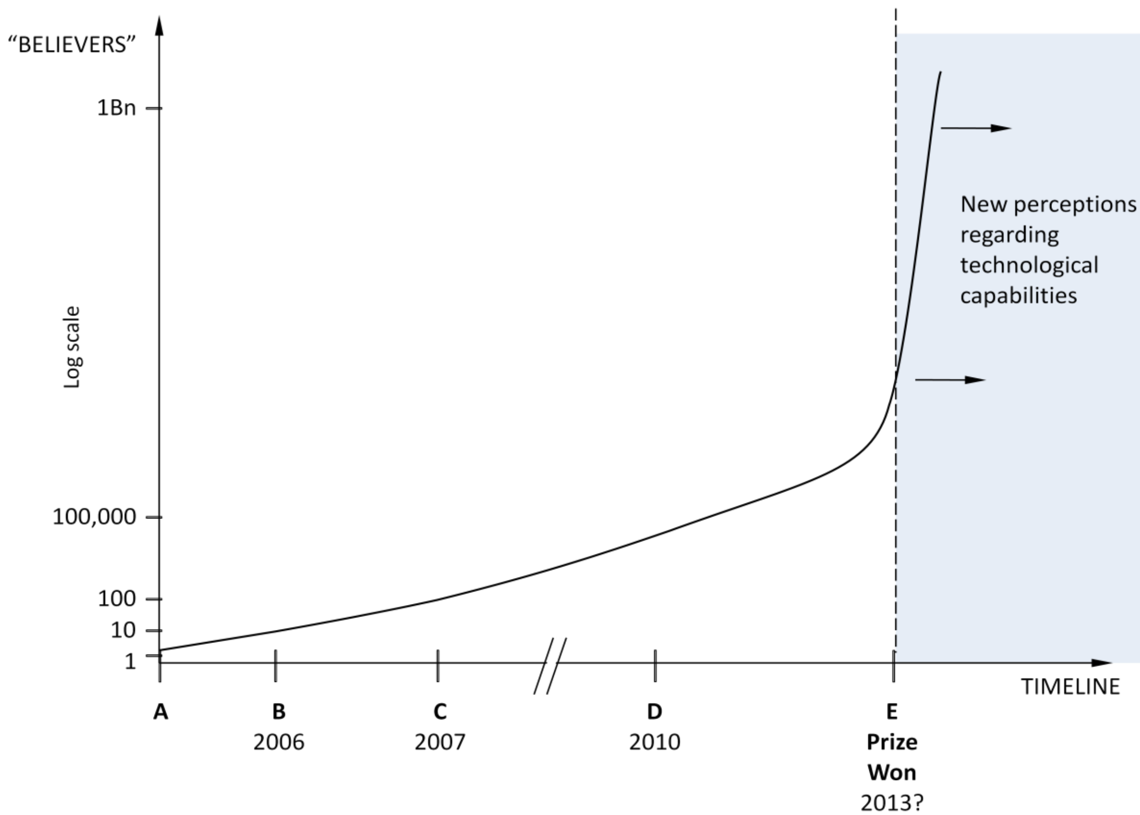
Partners follow a similar rationale than traditional industry players. The project is technically feasible for them, yet direct participation is not worthwhile from the commercial standpoint (i.e. it is not profitable.) Large traditional companies (e.g. Raytheon) enter the competition only through partnerships with GLXP teams to provide technologies and other in-kind support based on their existing technical solutions. Other companies, particularly the smaller ones, participate to benefit from increasing exposure to potential new customers or developing heritage for their technologies.

All late entries are possibly explained by these factors as well. There are nine teams not included in this research that entered more than 36 months after the prize announcement, just before closing the registration period to enter the competition. This fact strengthens two plausible explanations: a) there is a period for prize entrants (and team members, sponsors, and partners) to "convince themselves" about the feasibility of the project and the merit of the pursuit; and, b) since the chances of winning the

[24] It is possible the case of teams that seek to participate in multiple prizes to generate sustainable revenues over time. To the author's knowledge, no participating team in these three prize case studies has participated in more than two competitions (i.e. in a 15-year period.)

competition may decrease substantially for late entrants, there has to be priorities beyond winning the prize and/or there has to be a significant added-value of the prize to the strategies of these teams. However, still remains uncertain how other strategic factors at the team-level may affect the timing of the decision to enter the competition. Early entries have the advantage of longer public exposure and priority to access certain resources or partnerships. Yet, at the same time, these early entries possibly expose themselves to higher technological uncertainty and higher costs of attracting partners and investors (as the competition may not be visible yet.)

Ultimately, shared beliefs are at the core of prize competitions and can explain their later outcomes. An illustrative, graphical representation of the evolution of the GLXP in terms of its number of “believers” (i.e. people that consider the prize challenge both feasible and rewarding) is instructive in this regard (Figure 7.2). At the beginning, the sponsor comes up with the idea for a prize (point A in chart, probably at the time Blastoff! went out of business) and shares it with experts to assess its potential (point B.) The XPF consulted a number of experts in 2006 and most of them considered the feat achievable. The sponsor also contacts potential entrants to discuss their interest in an eventual competition, “trades” prize design features to make it even more interesting to potential entrants, and announce the prize (point C.) At this point, only a certain number of people (probably around 100) possibly know about the competition and are convinced that the prize challenge is feasible and worthwhile. After the prize announcement, not only new entrants convince themselves about the merit of this project but, most importantly, the media begins to support the idea and help in disseminating the vision and spirit of the competition. This is also a very important time period in which teams have to convince new members, sponsors, partners, and investors—and even their friends and family—that their projects are rewarding and valuable. The entry period for the competition closes (point D) and entrants continue their work toward the achievement of the prize challenge. The media helps considerably during this process to communicate progress and further engage the public. When the prize is won, the facts themselves transform the general belief of the rest of the industry, the media, and the public about the feasibility of the prize target. Still, this is more likely to occur only when the achievement of the prize challenge is evident and clear to the general public and represents a notable accomplishment.



Note: the chart is for illustrative purposes based on the GLXP case. Legend for X-axis is: A: Sponsor comes up with prize idea; B: Sponsor test the idea with experts; C: Sponsor test the idea with potential entrants and announce the competition; D: Prize registration closes; E: Prize won.
Source: own analysis.

Figure 7.2: Evolution of the number of "believers" in the GLXP

Patterns like this were also observed in the most popular, historic prize competitions. For example, the Orteig Prize initially did not attract participants and it was renewed for other five years. Yet, when it was won in May 1927, it sparked a widespread interest in aviation and follow up investments in this industry (O'Sullivan, 2009; Kessner, 2010). Inspired in the Orteig Prize, the more recent AXP—purposely designed to change beliefs—may have also had a similar effect on public perceptions about private space industry capabilities (Maryniak, 2010). On the contrary, the NGLLC had a weaker effect as the achievement of the competition was not evident to the public (i.e. it was, among other things, based on the unapparent flight precision achievement) and the prize target did not induce a race as exciting as other competitions. This is not necessarily a negative assessment of this prize, since it was not designed with such purpose.

Overall, individuals and organizations that enter prizes tend to be less risk-averse than traditional industry players. Experts consulted on the matter suggest that there is high uncertainty about the characteristics and value of the markets for the GLXP technologies and that contributes to the primary reason why traditional companies do not enter the competition. Still, there are GLXP teams that seek to create a commercial enterprise based on the prize technologies anyway. In particular, unconventional teams perceive lower risks than conventional teams as they perceive the competition as an opportunity to expand their activities, professional relationships, and/or personal experiences. On the contrary, conventional entrants already work on related projects and may consider the competition as an additional risk as it compromises other personal or professional activities of the team members.

From the point of view of the implementation of competitions, the classification based on agency/industry experience is still valuable—to analyze the possibility to target “outsiders”—and can be conveniently operationalized. Moreover, the evidence shows that unconventional teams also have other distinctive attributes (Table 7.3). In particular, unconventional entrants are in average larger teams, tend to use more volunteer effort and students, and, by definition, have no predominant experience with the prize technologies. These teams are generally organized as new, non-profit or independent groups. Unconventional teams perceive less significant constraints and are less risk-averse as well. The most important risk for them is an excessive financial exposure. These teams would generally not pursue similar projects if the prize did not exist.

Table 7.3: Classification of entrants based on industry experience

Attribute	Unconventional entrants	Conventional entrants
Composition	• Larger in average, more volunteer effort, and students, non-aerospace experience	• Smaller, less volunteer effort and students, space agency/industry experience
Type of entity	• Generally new, non-profit or independent entities	• Pre-existing or new, generally for-profit entities
Motivation	• Participation in a real technical challenge, benefits to society, learning, reputation, make money and use technologies in other projects in some cases	• Make money, develop technologies for own use, benefits to society, participation in a real technical challenge
Perceived constraints	• Time/funding (to some extent)	• Time/funding (great extent), unclear rules , advantages of other teams, strategies of other teams, lack of skills
Perceived risk	• Financial (in some cases)	• Financial, diversion from other activities, invest yet lose the competition
Would pursue similar projects if the prize did not exist?	• Less likely	• More likely

Note: only more significant differences are shown
Source: own analysis.

7.2 Prize R&D activities

H2 anticipated that shorter lead times and more significant funding requirements posed by the prize lead to simpler technological designs, more significant use of existing or standard technologies, and more collaborative R&D efforts. The evidence does not reject H2 conclusively yet suggests a spurious relationship influenced by entrant- and context-level factors. Moreover, there are other stronger alternative explanations and other unique characteristics of R&D organization in the GLXP.

In general, there is a weak relationship between designs, technology sources, collaborations and the conditions posed by the PC. Teams do introduce simpler designs and rely more upon existing or standard technologies when facing a lack of funding or the need to accelerate projects. Most of the teams also partner with other organizations. However, there must be other explanatory factors to this because teams introduce simpler designs, use existing technologies, and partner with other organizations even when they do not perceive time- or funding-related constraints for their projects.

The examination by type of entrant is instructive. Unconventional entrants have been more likely to introduce simpler technologies to shorten development lead times and respond to a lack of funding, yet, at the same time, these teams are more likely to consider that time and funding are not a constraint. In other words, they may effectively implement approaches to problem-solving based on simpler solutions that help to accelerate their projects and/or overcome funding shortages. On the other hand, conventional entrants are more likely to partner with other organizations when facing time/funding constraints, which may be explained by more dense, pre-existing professional networks. These teams have also been more likely to perceive significant constraints in the form of lack of time and funding, possibly explained by approaches to space projects inherited from traditional industry practices. Compared to unconventional teams, the differences in the use of existing technologies have been, nonetheless, minimal.

Further comparisons with the organization of R&D activities in the new space industry and other emerging space initiatives are also insightful (Table 7.4). Design criteria such as simplicity, minimalism, and low cost are characteristics of other space private/amateur initiatives as well. Cost is an independent variable in these cases yet, in contexts other than prizes, minimum mission requirements can be internally adjusted by R&D performers to match budgets. Prize teams balance the use of existing technologies with in-house development depending on teams' ultimate goals. Yet, there is a wide range of technology sourcing approaches in the GLXP. Generally, there is a strong reliance on COTS technologies and subcontracting and the principle “minimum engineering development effort.” These attributes are explained by the need to reduce costs and shorten lead times. Other non-prize efforts also tend to use COTS technologies yet seek to develop technologies in-house.

Compared to other non-prize space activities, it is more difficult to find distinctive patterns of internal organization of R&D. The most prominent difference is the density of partnership networks created by GLXP teams. Teams also draw upon significant volunteer effort, but this is not a prize-specific feature. Moreover, there are several entrepreneurial- or startup-like styles in the GLXP that differ from new space industry enterprises mainly in terms of fundraising and revenue models. New space industry’s startups depend mostly on government contracts, venture capital, and commercial contracts/services. GLXP teams have also raised funding from private investors and received contracts from NASA, yet their most important support comes from partners, sponsors, and significant in-kind efforts (e.g. volunteers) and resources (e.g. access to specialized facilities.) Significant knowledge exchanges also occur in the context of prizes. This suggests an open innovation approach to leverage external research and complement internal technological activities with increasing knowledge flows (Chesbrough, 2003, 2006). In prizes, partners are sources of expertise. The new space industry and other amateur initiatives are also key sources to find solutions to specific technical problems. For example, some GLXP teams have discussed technical solutions with former NGLLC teams (now space startups) or considered designs introduced by amateur rocketry associations.

Design criteria, technology sources, and the extent of collaborations are more distinctive attributes at a lower level of analysis—the R&D organization of each team. This research was able to identify four illustrative examples named Space Agency

Legacy, Universities Partnership, Partnerships Network, and University Spin-off. These forms of organization are diverse and demonstrate that, ultimately, the R&D organization that teams adopt expresses their goals, knowledge, skills, and available resources, and may not be directly influenced by the prize. For example, while some teams draw upon existing COTS technologies to reduce engineering effort and costs, others seek to produce in-house to gain hands-on experience, develop technologies for other projects, or commercialize hardware. This also relates with approaches based on trial-and-error or more standard and formal project management procedures.

Table 7.4: Main differences between selected instances of technology R&D in space projects

	Traditional Space	New Space Industry	Other space initiatives (e.g. Copenhagen Suborbitals)	GLXP
Design criteria	• Performance and reliability are top criteria • Cost is dependent variable • Project requirements given by space agency in the context of long-term programs	• Reliability and security • Cost-benefit analysis • Requirements given by emerging market segments (e.g. space tourism, scientific payload delivery)	• Simplicity and low cost, minimalism • Cost is independent variable • Simple, concrete goals set the specifications for new space projects	• Simplicity and low cost, minimalism; new criteria, e.g. scalability, "simple and smart" • Cost is independent variable • Specifications in the form of minimum capability and implicit reference to the cost of the expected solutions
Technology and technology sources	• High-technology, low TRL levels • Engineering effort • Use of in-house development capabilities • Prime contractors	• Engineering effort • In-house development	• Significant use of proven, commercially available off-the-shelf technologies • Use of non-space components • In-house production	• Significant use of proven, commercially available off-the-shelf technologies, gov. programs' surplus • Subcontracting • Minimum development effort
R&D organization	• Large, bureaucratic, integrated organizations with significant in-house engineering capabilities • Program budget • Specialization and part-nerships yet retaining project control	• Startup-like organization, small companies • Government (e.g. SBIR, COTS) and commercial contracts, private investors, venture capital, prizes (e.g. NGLLC)	• Small organizations • Volunteer effort • Donors support, in-kind contributions • Collaborations, open-source approaches • Move fast from idea to construction	• Flat, flexible, small organizations • Volunteer/collaborative effort • NASA contracts and commercial contracts; partnerships and sponsors; investors in some cases; in-kind contributions • Collaborations, open-source and networked approaches • Rapid prototyping

Note: these characteristics do not seek to be comprehensive; only the most distinctive features are shown.
Source: own analysis based on data presented in previous sections.

This research was not able to uncover all the diversity existing in other teams, yet contributed some evidence of new-to-industry approaches to space R&D in the GLXP. Most notably, there are open source-like organizational forms (i.e. with explicit open-source strategies to coordinate distributed efforts,) highly networked organizational forms (i.e. organizations that draw upon significant number of partners to source technologies and expertise,) and open-innovation organizational forms (i.e. that are open to significant knowledge flows from multiple sources.) In this regard, the geographically distributed efforts inside the organizational boundaries of teams and between teams and their partners are very interesting. Generally, face-to-face communications enable more rapid feedback, decoding, and synthesis of complex information in contexts such as engineering projects (Kessler & Chakrabarti, 1999). For a GLXP-like project, it may be expected for teams to co-locate their activities to perform even better or, at least, lower costs. Yet, on the contrary, teams generally engage members and collaborators from multiple locations and even multiple countries. The explanation for this might be in the pursuit of projects with lower levels of systems complexity and in very efficient use of new communication technologies and virtual collaboration tools (there is some evidence of cases of miscommunication, though.)

Though the overall development of the prize competition approximates an open-innovation process, the evidence suggests that the collaborative efforts performed by GLXP teams represent competitive strategies and are, possibly, competition-specific (i.e. the examination of other competitions may uncover different configurations.) There are at least two factors that explain collaborative strategies in this context. First, teams use specialized partners to reduce programmatic and technology risks by using their proven technological solutions and relying upon their expertise. Second, building a reputation of proven solutions is very important to succeed in the space business. The GLXP gives many non-traditional aerospace organizations (particularly, smaller companies) the opportunity to invest in building reputation by providing technologies to prize entrants.

For those organizations, this is a unique opportunity to demonstrate their capabilities in a sector that has been traditionally reserved to government agencies and large corporations. This opportunity is not only available for aerospace-related companies but also for companies that manufacture components and systems that have to deliver high performance and reliability in harsh environments other than space.

On the other hand, collaboration between GLXP teams is not significant according to the evidence available to this research, at least in a comparison with competitions such as the NGLLC. A potential explanation for this is the very competitive environment created by the prize and the diversity in entrant goals. Moreover, team headquarters are widely distributed in many countries which reduces the chances of face-to-face interactions, something that only occurs at the annual GLXP summits and/or industry conferences. Not all teams, however, participate in the annual summits and even fewer coincide at conferences. The NGLLC, which held annual races with participation of all teams, created many more opportunities for interaction and collaboration between teams. Collaborations in the context of the competition may be the basis for the formation of stronger problem-solving communities that transcend the prize time frame. The literature has found that this is the case of online prize platforms (Bullinger et al., 2010; Hutter et al., 2011). Furthermore, collaborations in those competitions are also key for individual innovators to succeed. Similarly, the GLXP website allows posting comments on teams' profile web pages, but neither incentivizes nor offers tools for more intense virtual interactions and collaborations.[25]

The evidence suggests that, ultimately, the lead times allowed by the GLXP are not as stringent as the funding requirements emerging from the PC definition, and that the most unique characteristic of the overall organization of prize R&D activities is not in the

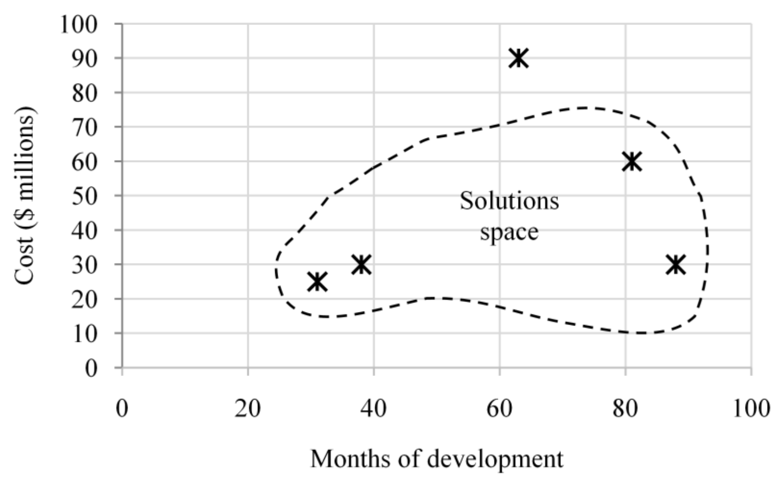
[25] The GLXP website originally hosted an online forum open to the public as well. According to the XPF, "*the small team that works on GLXP simply ran out of the time resources required to moderate such a large and active forum community*." (GLXP, 2009) Therefore, the forum was moved to a third-party, space specialized website (SpaceFellowship.com GLXP Forum.)

design criteria, technology sources, or collaborations. Past government-led missions have executed even more complex projects and with more bureaucratic procedures in shorter development lead times and there are GLXP teams that plan mission achievements one or two years shorter than the prize maximum lead time. The GLXP is, nonetheless, a competitive context and the externally imposed deadline has a unique significance. The prize deadline has the more general effect observed in studies of task performance under time constraints (Amabile et al., 1976): it causes the energizing effect that makes teams work harder and induces them to make decisions about the organization of their individual work based on their perceptions of the time needed to accomplish the task, which, in this case, as discussed earlier, depends on the ultimate goals of the team.

Therefore, both the deadline and implicit funding requirements have, in conjunction with the minimum mission requirements, the key role of defining the boundaries of the *solutions space* or area of convergence for the expected solutions to the challenge (in other competitions such as the NGLLC there are also technical specifications to deliver some technology.) (Figure 7.3) This space, however, does not necessarily dictate the design criteria and technology sources in GLXP projects and certainly is not a precise focus. The expected development lead times in GLXP projects range between 30 and 90 months and the expected mission costs range between $5 million and $100 million. These wide ranges are explained by teams' distinctive goals, strategies, and access to resources. This also points to a feature of prizes widely discussed by the literature, yet with an interesting twist in this case. Contrary to other prizes such as the NGLLC, the GLXP neither requires creating a spacecraft of certain type/characteristics and demonstrating its capabilities nor specifies how the prize challenge has to be achieved. The potential result is, as suggested by the literature, unexpected approaches to the prize challenge which may include, in this case, more novel, affordable, and/or flexible project management approaches to planetary exploration. Those approaches might be implemented in future missions and become one of the most significant (organizational) innovations induced by this competition. The interesting part of this explanation is that this is not only valid for unconventional entrants which may bring their unorthodox R&D approaches—as the literature suggests—but also for conventional entrants that seek to be the first to accomplish the prize challenge.

The basic prize problem solving activity observed in the GLXP—aimed at winning the competition—encompasses both the convergence of solutions toward that solutions space and the interaction between R&D activities and fundraising/commercialization efforts. This process is characterized by iterations or cycles with significant learning opportunities during the competition. The ability of teams to retain the IP and commercialization rights on their technologies enables this process as it allows to develop partnerships, exchange resources, and raise funding. This has important theoretical implications because the development of this innovation process requires for the prize technologies—contrary to the general assumption of economic prize models—not to be placed in the public domain.

The general approach of teams to solve the GLXP problem can be explained as follows (Figure 7.4). The prize poses a challenge in the form of soft-landing-, mobility-, and communication-capability requirements that can be approached in multiple ways. Any approach still requires significant funding to be carried out, particularly due to the expensive launch vehicle. Teams are free to choose their launch services or even develop their own launch vehicles. Most of the teams, however, consider using proven, commercially available solutions since the development of new launch vehicles is not feasible within the GLXP's timeframe (this timeframe is relative for those teams with extra-prize goals.) Those commercial launch solutions determine both the minimum funding requirements and the maximum payload capabilities. Teams perform significant effort on fundraising and/or business development to finance their missions, which diverts their engineering efforts and sometimes imposes new design requirements/development efforts. For example, the successful commercialization of payload transportation services generates revenues yet, on the other hand, increases the spacecraft mass and, eventually, the launch costs. Other revenue models—such as those based on data sales—do not impact spacecraft designs, but require accomplishing the mission first. Teams also seek to reduce engineering efforts to produce their technical solutions. COTS technologies or technologies sourced from partners help in that regard, yet those technologies may be not readily compatible with the team's systems and thus require some adaptation effort. Teams also perform significant trial-and-error and prototyping iterations to find solutions to specific technical problems when they do not have resources to acquire certain parts or components. Overall, the R&D-fundraising interaction makes project management more complex and induces a spiraled evolution that converges into a final solution.

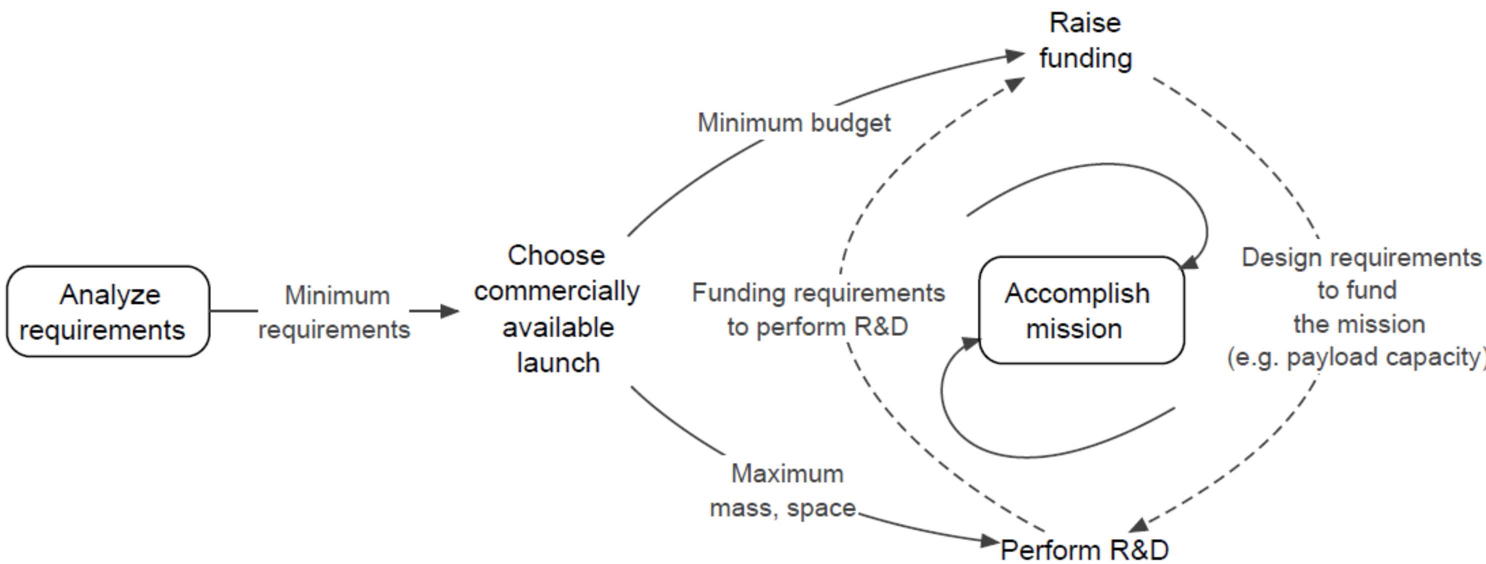


Note: based on data available for costs and duration of five GLXP projects.
Source: own analysis.

Figure 7.3: Approximation to the solutions space created by the GLXP

To a limited extent, the interrelation between budget and R&D activities also exists in other contexts. For example, in agencies' space programs, changes in project goals and actual developments are introduced due to both the uncertainty about the funding available for a program and the constraints resulting from annual revisions of budgets (Bitten, 2008). The examples shown for other private space initiatives also depend greatly on fundraising, yet the interaction in those cases might not be as strong as in prizes since they are not in a competitive, race-like context or do not seek to commercialize technologies. On the other hand, the much discussed, general interrelation between corporate R&D management, investment, and debt policies depends on very different factors that include, for example, predictability and movement of debts, profits, and cash flows (see, for example, Hall, 1992; Himmelberg & Petersen, 1994; Bond et al., 1999; Hall, 2002)

Finally, there is also evidence that builds upon that interaction between R&D activities and fundraising/commercialization and stresses the entrepreneurial or commercially-oriented forms of R&D organization in the GLXP. In general, similar responses to a lack of funding and a lack of time suggests that both factors, schedule and cost, have analogous effects and that there is no tension between them, i.e. faster development is likely to be less expensive as well. This is generally also the case of space projects due to large overhead costs of agencies and large contractors. There are a few GLXP teams, however, that refer to the relationship cost/schedule as a trade-off, in the sense that more funding can "buy time" or shorten development lead times. This type of trade-off has also been noted by the specialized space literature to describe recent NASA's smaller missions (Dornheim, 2003) and has largely been discussed by the new commercial product development literature (see, for example, Mansfield, 1988; Gupta & Wilemon, 1990; Swink et al., 2006)



Notes: the chart is a simplified representation of the problem-solving process according to data gathered from several GLXP teams; this overall description of the team activities does not represent necessarily the strategies or approaches of all teams.

Source: own analysis

Figure 7.4: Basic innovation-related problem-solving cycle in the GLXP

7.3 Prize technology outputs

H3 anticipated that, for any fixed prize challenge definition, unconventional entrants are more likely to introduce novel technologies and conventional entrants are more likely to advance more mature technologies for commercialization. There is some evidence compatible with this hypothesis, yet is not conclusive to completely explain PTOs as a function of the types of entrants that produce them.

Unconventional teams have introduced a small number of novel concepts and produced new models and prototypes aimed at technology demonstration and experimentation. Those developments have been mostly related to landers, rovers, and propulsion systems/transfer vehicles. These teams have also reported significant innovations in the form of new products or components that are useful for both the GLXP and other projects. However, only a share of these technologies might ultimately be further developed and enter a production phase for own use/commercialization as teams generally use them to explore and test alternative approaches to accomplish the GLXP challenge. In other cases, technologies may not reach a production or implementation phase if unconventional teams lack resources, skills, or further incentives (about half of the unconventional teams that entered the GLXP before December 2010 are inactive or have withdrawn the competition.) The newness of these technologies not only results from fresh ideas and unorthodox approaches as suggested by the literature and the evidence of a number of new design criteria. These teams also draw upon larger volunteer efforts and are less risk-averse which allows, for example, more significant trial-and-error iterations.

On the other hand, most of the conventional teams advance existing technologies and seek their implementation to commercialize payload delivery, launch, or other types of services. There is little evidence of commercialization of hardware which might signal this is not the top lunar market segment as private estimates foresee (see Prize Context in previous section.) These teams have focused their engineering efforts not only on new landers and rovers but also, to some extent, on the development of new photo/video systems and control/navigation hardware and software. Some of these teams have also reported significant innovations. A few of these teams have worked on introducing novel designs (e.g. hopping lander) that may be used not only to accomplish the GLXP mission but also to deliver commercial services.

More generally, the GLXP induced significant outputs from similar numbers of unconventional and conventional teams. Most of the teams contributing significant PTOs have advanced technologies at medium-high levels of technology maturity (somewhere between TRL levels 6 and 8) that might eventually become proven technologies after successful achievement of the challenge. Figure 7.5 illustrates the distribution of significant technology outputs of the GLXP at different TRL levels. The bell-shaped curve reflects the concentration of outputs at higher maturity levels and the introduction of fewer experimental and novel technologies as well. At least four main types of outputs have been produced in three years of competition:

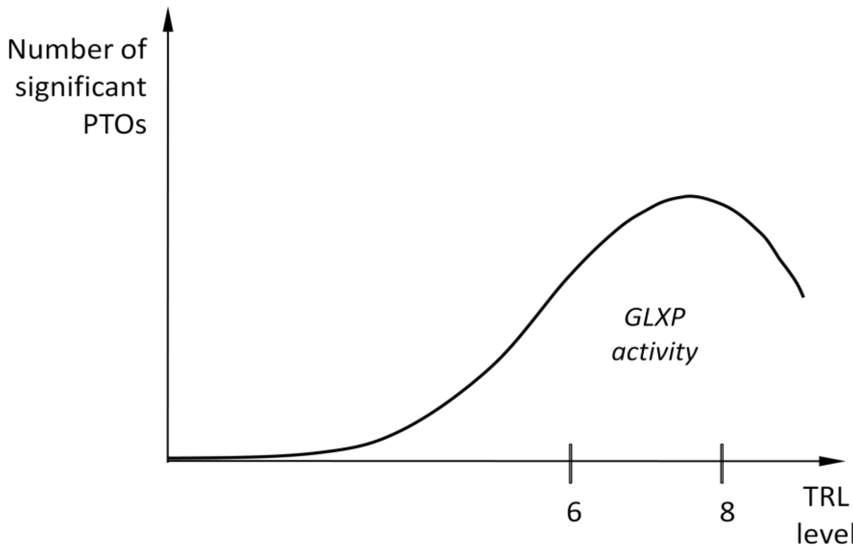
a. NEW CONCEPTS AND EXPERIMENTAL TECHNOLOGIES: these outputs either contribute new-to-industry concepts or solutions (e.g. new mobility concepts such as ball-shaped robots, new software algorithms) or advance the maturity of existing technologies (e.g. hoppers or leg-enabled systems.) Some of these may not reach production/implementation phases in the foreseeable future yet others may become truly breakthroughs in planetary exploration or other industrial applications. The evidence does not allow establishing a causal connection between these outputs and the design of the prize competition, yet they are undoubtedly enabled by an open-ended definition of the PC.

b. CREATIVE SOLUTIONS TO SPECIFIC, WELL-DEFINED PROBLEMS: these outputs address specific technical problems such as operation in the harsh lunar environment and balance of mass/size/capabilities of spacecrafts. These are problems found in previous planetary missions and are well-known to the teams. The solutions are still unproven, generally introduced by unconventional teams, and likely to be first implemented in GLXP missions (e.g. solar panel-antenna integration, internal mobility mechanisms.) These solutions are the "smart response" of teams to solve those problems while reducing project costs and shortening technology development lead times.

c. MORE AFFORDABLE AND SIMPLER VERSIONS OF EXISTING SYSTEMS: these outputs comprise mostly landers and rovers based on existing, more mature technologies (e.g. wheeled rovers) and are aimed at the achievement of the PC or delivery of payload services. The quality of these outputs respond to specific team goals and generally result from engineering efforts to satisfy the minimum requirements of the prize (e.g. producing a rover with life-time to traverse 500 meters only) or commercially oriented spacecraft developments. These technologies are relatively similar between teams and can be considered as "me-too" systems rather than original developments.

d. NEW DEVELOPMENT AND MISSION APPROACHES: these outputs are already implemented by some teams for their GLXP missions and are likely to be commercialized, in the form of expertise—by the team members individually or as a new enterprise of the team—and/or provision of mission support services. These new approaches combine partnerships and other forms of collaborative effort, more affordable technologies, and new business models. These outputs can be connected to the new schedule/funding requirement conditions posed by the GLXP.

An elaboration on the team goals, the PC definition, and the maturity of planetary exploration and related technologies can explain the GLXP's PTOs. Ongoing industry projects, relevant technical solutions, and more affordable and reliable non-space grade components allow major proportions of the GLXP projects to be based on existing—particularly COTS--technologies. Moreover, these technologies attenuate projects risks as well. Therefore, to win the prize, teams generally seek to perform the least possible engineering effort by either a) working on advancing technologies that are closer to be flight-ready or b) adapting/using existing, proven technical solutions. Since this competition does not explicitly require building any system, decisions about a) and b) depend on whether technologies and/or funding are available to teams. Generally when facing a lack of funding, teams partner with other organizations to source/develop technologies or they explore creative ways to solve technical problems. While the latter is associated with the introduction of more novel ideas, experimentation, and lower TRL levels, both a) and b) are linked to higher TRLs. Other teams that have goals beyond the prize (e.g. having fun, creating a company, other organizational goals) do not have to optimize their prize performance in that way. These entrants may seek to explore novel technologies, use existing solutions, or produce technologies with commercial merit, which involves R&D in a wide range of maturity levels. Decisions in those cases depend on specific goals and resources available to teams and require individual, team-level analyses for their interpretation. In the GLXP case, this diversity comprises experimental tests of alternative propulsion methods, novel mobility systems concepts, and landers with characteristics not required by the competition (e.g. scalability or modularity,) among others.



Note: the chart is illustrative based on evidence available to this research as of December 2010.
Source: own analysis.

Figure 7.5: GLXP technology development activity

The consideration of the same factors in the three case studies—PC definition and technology gap and state of the art of relevant technologies—offers interesting insights for further elaboration (see Table 7.5).

Let us discuss first, at least briefly, the case of a historic prize to start this elaboration. The French government's Food Preservation Prize of 1795 was aimed at creating a new technology. It offered a sizable cash award of 12,000 francs (about $44,000 in current dollars) to any inventor who could devise a cheap and effective method of preserving large amounts of food for troops in foreign land. This prize was won in 1809 by Nicolas François Appert, who invented the canning method based on the discovery of new principles (the method involved boiling and seal-packing food in airtight glass jars.) No empirical evidence exists on other approaches used in the attempt to win the prize. The fast commercial implementation of Appert's solution (only a few months after) demonstrates that its newness was not in its technological complexity. Yet, it took more than 50 years until Louis Pasteur provided the scientific explanation of the method's effectiveness (KEI, 2008; McKinsey & Company, 2009).

The recent AXP involved the development of suborbital spacecraft technologies building only upon some prior experimental research (the USAF/NACA X-15 program.) The idea of space tourism was not new, yet the XPF defined it in concrete terms or minimum requirements. The winning entry—the most notable technology output of this competition—was a spacecraft based on existing technologies and materials, but it featured a novel configuration at lower-medium TRL levels. Other entries analyzed here were based on even more experimental methods such as balloons. While the prize spanned eight years of competition, the winner reported that the winning entry had a development lead time of only three years. But, subsequent works to develop and manufacture new flight-ready suborbital vehicles based on such technology have taken Scaled Composites about six years.[26]

The NGLLC spanned even shorter lead times and more mature technologies. It involved building and flying a VTOL vehicle with relevant technologies readily available, including the 1990s antecedent Delta Clipper program. All cash purses were won after four years of competition, with outputs primarily observed in terms of converging rocket technology developments and efficiency improvements at medium-high TRL levels. Subsequent developments have taken place since with support from NASA contracts.

Finally, the existence of a significant pool of knowledge and relevant technologies available to GLXP entrants (some of them readily commercially available) has enabled the pursuit of commercially viable approaches to space technologies. The longer lead

[26] These new vehicles will be soon introduced by Virgin Galactic to provide the first regular space tourism flights.

times to win the GLXP can be explained by challenging fundraising activities and unfavorable economic conditions.

Two patterns can be probed in these prize cases. First, there is the relationship between the maturity levels of the prize technology outputs and the availability of prior technical solutions. In general, it can be posited, the larger the pool of knowledge and technologies readily available to address the problem, the higher the maturity levels the prize can target. For instance, in both AXP and NGLLC, but particularly in the former, the technologies were still experimental at the moment the prize was won. In the case of the Food Preservation Prize, the method just discovered was quickly introduced and disseminated, yet the underlying scientific principle was not understood until 50 years later. The GLXP technologies are concentrated at higher maturity levels.

Second, in the same vein, there are the development lead times that prizes had to allow to come up with a solution to the challenge, which may be significantly longer at lower maturity levels when controlling for contextual factors and resources available to teams. In this prize cases, discovering a new principle (i.e. the Food Preservation Prize) took 15 years, developing new technologies (i.e. AXP) took a few years, and increasing efficiency and incremental development took months (i.e. in each NGLLC competition.) In the GLXP, technology and services commercialization started as soon as the prize was announced.

This perspective on prizes suggests that a) prizes may not be effective to induce technology development if they pose challenges for which the relevant technologies are not yet up to the PC requirements (e.g. may not be effective to induce commercialization of technologies if these are not mature yet;) or, b) prizes may effectively produce such effects but only if they allow longer development lead times, provide more significant incentives, and/or development support. Theoretically, this line of thought finds support on the sequential and cumulative nature of innovation by which each successive invention builds in an essential way on its predecessors and follow-up developments substantially enhance the commercial value of the technologies (Green & Scotchmer, 1995).

On the other hand, the examples of Table 7.5 also bring to mind the question of whether technology prizes should explicitly require building new systems or let entrants decide about the means to accomplish the challenge. Two of the examples—the AXP and NGLLC—are prizes for technology demonstration, i.e. they explicitly required to build certain equipment and demonstrate its capabilities. The other two—GLXP and Food Preservation Prize[27]—are prizes for technology-based achievement, i.e. entrants choose the means to accomplish the feat, which may involve building new systems of unspecified characteristics. With that requirement, sponsors can set minimal technical parameters (i.e. design and/or functional requirements) that focus efforts and increase the likelihood of obtaining a winning entry compatible with the expectations of the sponsor. That may, however, limit the introduction of more creative, affordable, or efficient methods and technologies that are not exactly up to the characteristics required by the prize. Interestingly, the latter may be still preferable in some circumstances. If sponsors do not use the requirement of developing a new technology with certain characteristics, entrants may unexpectedly find a solution based on current-day methods and technologies and win the competition "by cheating," i.e. without producing any technological development or innovation. For example, if the AXP did not require building a spacecraft, entrants would probably have adapted existing aircrafts with operational capabilities to reach higher, suborbital altitudes.

[27] This research has no data on whether the Food Preservation Prize actually required building, for example, a new device or equipment. Considering the type of function required by the prize challenge, it is likely that the sponsor expected any kind of method to accomplish that function, which may have involved building something new or not. Ultimately, the prize was won by applying a newly discovered principle.

Table 7.5: Selected prize cases, prize challenge definitions, technology gaps, and technology outputs

	Prize cases (selected examples)			
	Historic prizes? e.g. French gov. Food Preservation Prize (KEI, 2008)	**Ansari X Prize**	**NGLLC**	**GLXP**
Sponsor's goal	Need to preserve food for troops in foreign lands	Change belief about private industry capabilities	Commercial development of VTOL vehicles	Commercialization of lunar technologies
Prize offered in	1795	1996	2006	2007
Prize won in	1809	2004	2008, 2009	?
Type of prize[a]	Prize for technology-based achievement	Prize for technology demonstration	Prize for technology demonstration	Prize for technology-based achievement
Chal-lenge definition	Create a method to preserve large amounts of food	Build and launch a reusable manned spacecraft into space twice within two weeks	Build and fly a reusable, rocket-powered vehicle simulating a flight on the moon within pre-specified timeframe, performance, and location	Land a spacecraft on the Moon, traverse 500 meters, and send back high-definition video footage
Past related solutions	N/A	USAF/NACA X-15 project	NASA Apollo landers, DC-X Delta Clipper	NASA Apollo missions, planetary missions, startups (e.g. LunaCorp, Blastoff!)

Note: a. Type of prize according to required output.

Source: own analysis and cited literature.

Table 7.5: Selected prize cases, prize challenge definitions, technology gaps, and technology outputs (Contd.)

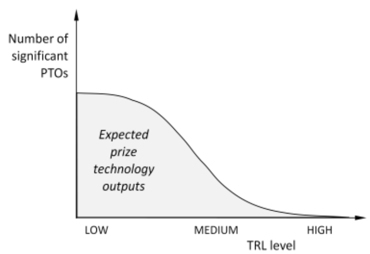
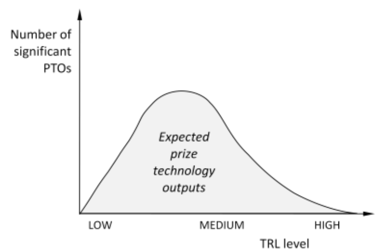
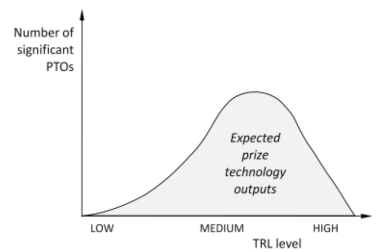
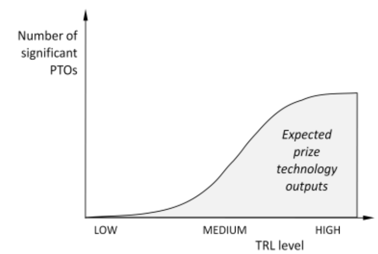
	Prize cases (selected examples)			
	Historic prizes? e.g. French gov. Food Preservation Prize (KEI, 2008)	**Ansari X Prize**	**NGLLC**	**GLXP**
Technology gap	Nature of solution unknown	Demonstration of technology feasibility	Demonstration of technical efficiency	Profitable implementation of technologies
Technology outputs	**Winning entry**: new invention, canning method	Varied conceptual approaches including balloons, aircrafts with different configurations, rockets. **Winning entry**: Spacecrafts with new application of materials, new configuration and conceptual approach	Converging conceptual approaches, more efficient VTOL technologies and methods **Winning entry**: New controls, rocket engine components, operational capabilities	Use of existing launch technologies, creative solutions to specific problems, COTS components, new business development approaches; some novel concepts under development
TRL levels	**Low TRLs**	**Medium TRLs**	**Medium-High TRLs**	**Medium-High TRLs**

Note: a. Type of prize according to required output.

Source: own analysis and cited literature.

Those examples allow exploring alternative classifications of competitions to further probe the effect of prizes and systematize the implementation of prize programs, despite the number of factors that demonstrate how unique each prize is. The generalization of the perspective discussed in prior paragraphs leads to the typology shown in Table 7.6. These four types of prizes are characterized by the relationship between the expected technology outputs of the competition and state of the art of the technologies in the technological field in which the prize is announced. This typology is a useful source for the creation of hypotheses and case modeling in future research.

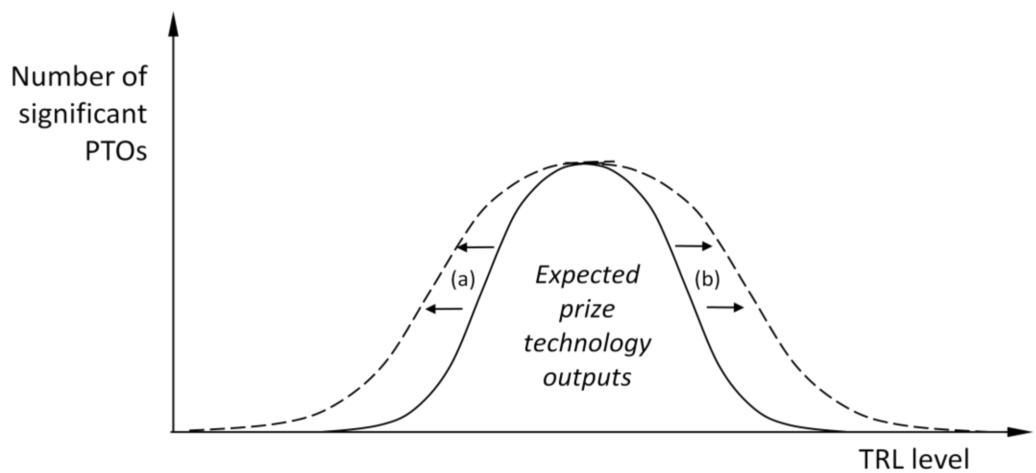
Table 7.6: Typology of prizes based on expected technology outputs

	Typology of prizes based on expected technological outputs			
	Prizes for novel solutions and concepts	**Prizes for technology development**	**Prizes for incremental improvements**	**Prizes for technology implementation**
Generic challenge definition	Find or create a method to perform new function	Develop technology to accomplish a feat	Improve technology to achieve higher performance standards	Implement technologies under newly-defined prize challenge cost/schedule conditions
Technol-ogy state of the art	Unclear what basic principles the solution should draw upon	Basic principles known, experimental research performed	Existing technologies with at least medium level of maturity	Existing technologies with medium-high level of maturity
Technol-ogy gap	Nature of solution unknown	Demonstration of technological feasibility	Demonstration of technological efficiency	Efficient/profitable implementation of technologies
Expected technol-ogy out-puts				
Examples	French gov. Food Preservation Prize, Longitude Prize	Ansari X Prize	NGLLC, DARPA Challenges	GLXP

Source: own analysis.

The evidence on the GLXP also suggests that two factors—both parameters in prize design—may affect the focus of the expected technology outputs if the appropriate development lead times are allowed (Figure 7.6). First, significantly low target budgets and/or funding constraints to accomplish the mission in commercially viable terms may represent a new technical problem that induces engineering effort at lower TRL levels to find more affordable solutions, despite the existence of related technologies. In the GLXP, this can explain the use of creative solutions to specific well-defined problems, more affordable versions of existing systems, and new development and mission approaches. This effect depends on the minimum funding requirements to perform R&D activities for the technologies involved in the prize. In more general terms, significantly lower target costs may lead to the advancement of technologies with lower maturity levels if that implies finding more affordable solutions to the prize challenge (effect shown by (a) in Figure 7.6). Second, the perception of a sizable market value for the prize technologies and/or a prize challenge that includes a commitment to buy prize technologies may lead to advancing technologies toward implementation/commercialization stages at higher TRL levels (shown by (b) in Figure 7.6). In the GLXP, for example, the perceptions of a sizable market are generally driving the development and, most importantly, the implementation of technologies to deliver lunar commercial services.

It is also compelling to examine how teams with different goals contribute technological outputs in the GLXP. Table 7.7 shows examples of outputs and the assessment of the contributions of the three groups of teams according to priority goals. Challenge teams can be associated with more creative solutions to specific problems, more entrepreneurial orientation, and development of technologies at medium and high TRL levels. These outputs can be generally explained by efforts to shorten typical development lead times and reducing project budgets by introducing simpler and more affordable solutions. A few—yet potentially valuable—new conceptual approaches have also been introduced by this group (e.g. open source development, new mobility systems.) Industry/startup teams have a clear profit-driven approach and work mostly on the advancement of more mature technologies for commercialization. There are some novel concepts in this group yet, even in those cases, technologies are developed based on existing projects and commercial developments of partners or target the provision of services. Finally, there is a majority of teams that contribute very diverse technologies, including more affordable versions of existing technologies and new development and mission approaches. Several teams in this group have not contributed significant outputs.



Note: the figure is illustrative and does not represent any prize in particular.
Source: own analysis.

Figure 7.6: Generic effect of more stringent prize challenge conditions and increasing technology incentives on expected prize technology outputs

Interestingly, the duplication of R&D efforts suggested by the literature is not generally apparent in the analysis of technology outputs, as a wide range of technologies is under development. If there is duplication of efforts, it must be related with the development of, for example, more affordable landers and wheeled rovers. However, it is difficult to find similarities beyond the more visible 4-wheel or 6-wheel traditional configurations. Overall, a possible explanation for the diversity of technologies is that, in spite of the low barriers to enter the competition and the number of would-be entrants interested in the prize, only 35 teams ultimately entered the competition–26 analyzed here—and several teams that did enter the competition are inactive in terms of technology development. There is a handful of teams offering similar payload delivery services based on those alternative lander/rover designs, which is a positive outcome considering the sponsor’s goal of promoting space commercialization (i.e. a larger number of companies offering those services would lead to lower payload delivery costs.) By design, the GLXP has sought to have multiple back-end business markets that can be supported by the technologies developed in pursuit of the prize. Yet, in this case, the data suggest that the wide variety of technologies under development is, more likely, the direct consequence of the diversity of teams and team goals, and are certainly allowed by the open-ended challenge definition and relaxed criteria of eligibility to enter the competition.

Two final considerations apply to this analysis. The GLXP is an ongoing prize competition and therefore the number of significant PTOs is likely to increase over time. This consideration is more relevant to the possible implementation of novel technologies. A hint of the near-term developments in terms of PTOs is given by the fact that, after three years of competition, similar proportions of both unconventional and conventional entrants have team members exclusively dedicated to business development or commercialization of the prize technologies. This suggests that more technologies may eventually be advanced toward commercialization. Finally, the assessment of the level of maturity of the technologies has been made at the level of the technology subsystem/system and is not detailed enough to capture the full range of possible new technologies at the level of, for example, materials or components. That might be a reason for the small number of novel technologies found in the GLXP, though, considering the competitive context, the lack of up-front funding, and the minimum possible engineering effort criterion, it seems less likely for teams—yet not impossible—

to develop new basic principles or materials. Moreover, this analysis mostly depends on the information that teams publicize about their projects.

Table 7.7: Examples of PTOs based on team goals

	Type of team		
	Challenge teams	**Industry/startup teams**	**Diverse majority**
Examples of technology outputs	• New solar panel-antenna configuration • Alternative internal mobility mechanisms • Video/navigation systems • Software algorithms • New conceptual approaches to mobility • New approaches to space development	• Landers with payload capabilities • Propulsion systems • Navigation and control systems • Hopping rover • Application of NASA's lander technologies	• Alternative propulsion systems • More affordable and simpler versions of existing systems (e.g. landers, rovers) • New/improved launch vehicles • Descent rocket motors • New controllers using non-aerospace components • New approaches to space development
Overall assessment	• Creative solutions to specifically defined, known problems; a few new conceptual approaches • Medium-high TRL levels	• Technology advancement for commercialization of lunar services • Mostly high TRL levels	• Fewer significant outputs • Development of technologies of a wide range of TRL levels

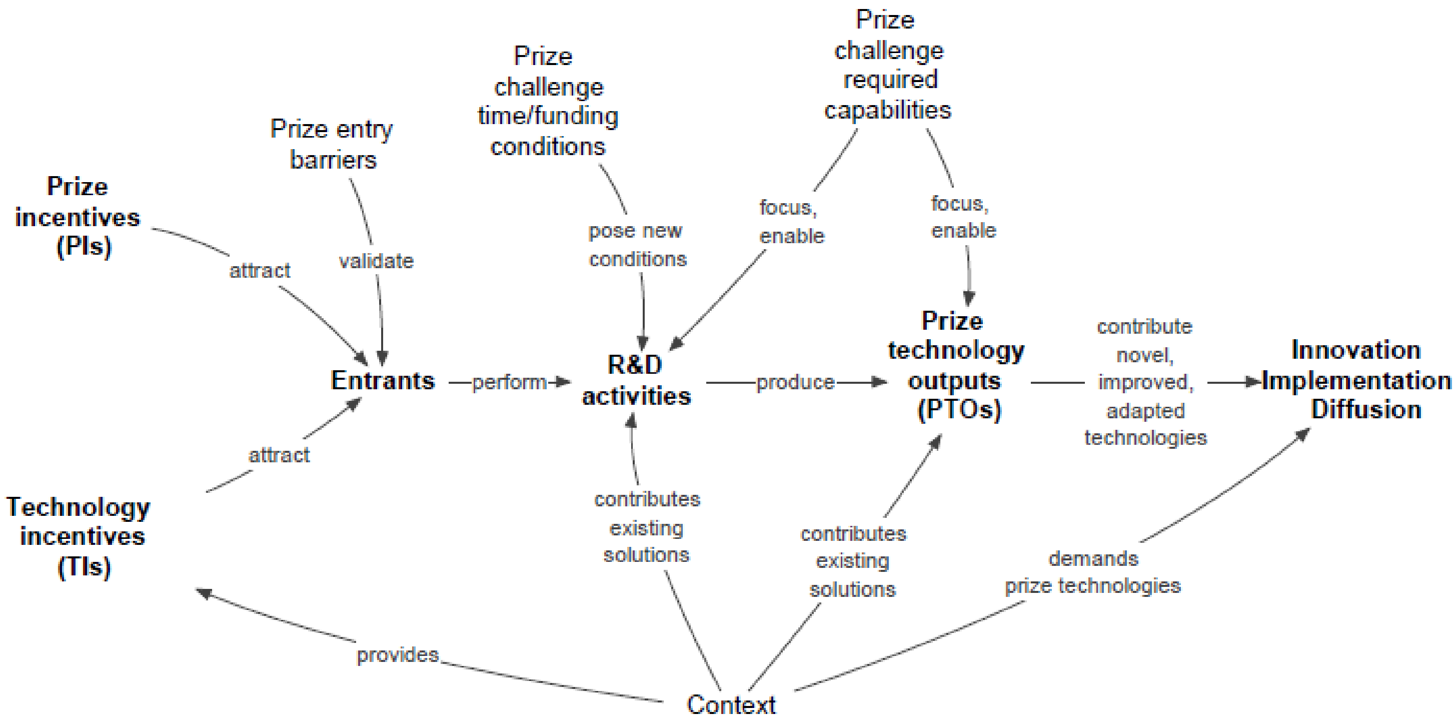
Note: based on the analysis of 26 GLXP teams that entered the competition before December 2010.
Source: own analysis.

7.4 The overall effect on innovation

H4 anticipated that for any fixed technology sector and its general context, more significant prize incentives and more open-ended challenge definitions are more likely to induce innovation. The evidence suggests that, effectively, under certain conditions, increasing PIs are more likely to induce innovation. However, the effect of those incentives is indirect and other intervening factors are required to explain the complex incentives-innovation relationship. In general, the evidence suggests that technological breakthroughs cannot be directly induced but only enabled by prizes.

Figure 7.7 draws upon the model used in this research and the findings to present the main factors that significantly affect the innovation effect of the GLXP. The PIs position the competition in the right place from the media and public standpoint, and attracts diverse types of entrants. Yet, entrants—based on their perceptions, strategies, and resources—ultimately decide R&D effort levels in the competition and bring their ideas and focus on certain technologies. A few other factors may indirectly influence the ultimate output and innovation effect. The PC time/funding conditions influence the R&D approaches adopted by teams. The PC definition has also the dual effect of focusing and enabling efforts and technology outputs, though, in this case, the definition is very open-ended and, with regard to technical specifications, only minimum capabilities are required (i.e. it is more an enabling effect.)

The context of the competition has also a key role to regulate the prize effect. The GLXP addresses a technological problem for which solutions, relevant knowledge, and technologies are available, even if the problem posits new budget conditions. Broader trends and practices in the new space industry and other private space initiatives provide help in solving specific technical problems by example. The space sector also offers market opportunities (TIs) and some short-term demand for prize technologies. Yet, the broader economic context represented an unfavorable environment for doing business in these first three years of competition. And, even with a favorable business context, the interests of potential customers and investors might have been in low orbit technologies and not in planetary exploration. In sum, the context moderates or intensifies—maybe significantly—the process triggered by the prize.



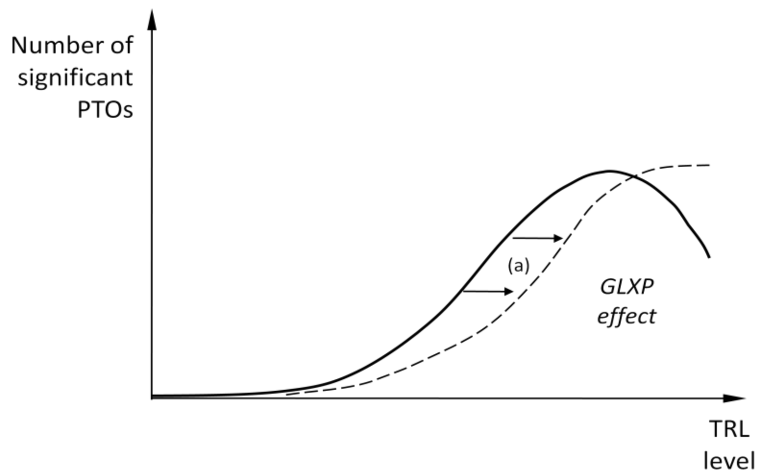
Note: based on GLXP case.
Source: own analysis.

Figure 7.7: Main factors affecting the ultimate innovation effect of prizes

From the more dynamic perspective of an ongoing competition, feedback effects are not likely to affect the causality patterns drawn by these factors within certain levels of activity. For example, increasing R&D activities (in magnitude or visibility) may attract more entrants or partners to the competition, and certain technologies developed by teams may change the perceptions of would-be entrants about the feasibility of the project.

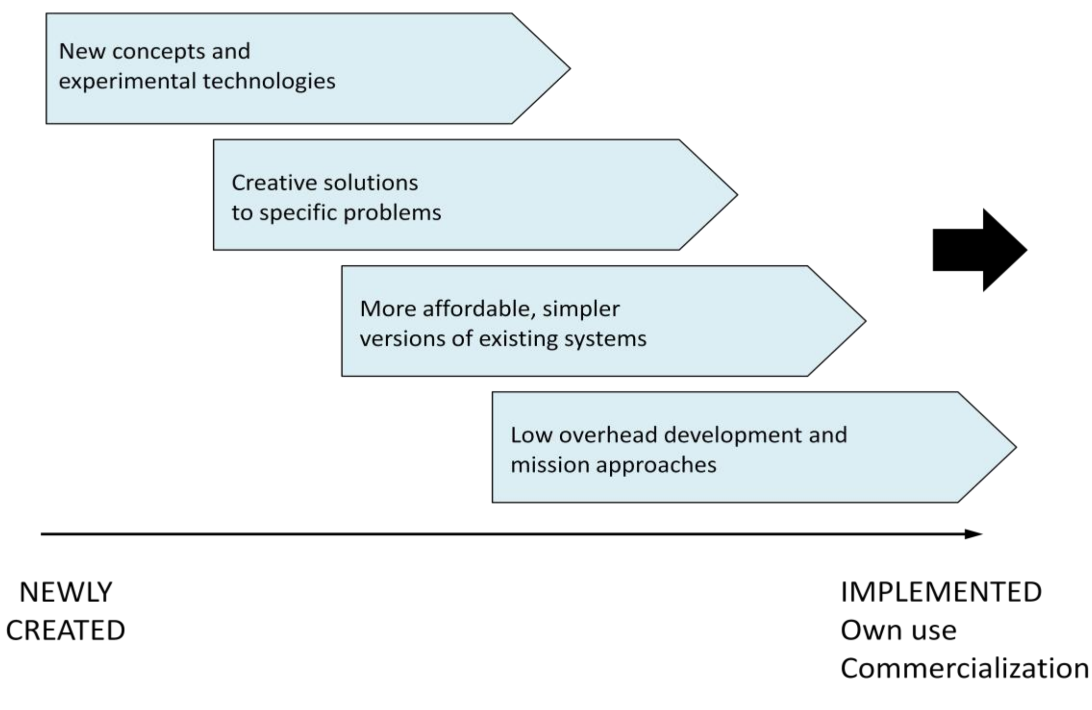
The examination of the PTOs anticipates the ultimate innovation effect of the GLXP. Figure 7.8 shows graphically (and intuitively) that effect in terms of the advancement of the maturity of the prize technologies. The GLXP has induced R&D efforts at medium-high maturity levels and pushed developments further toward commercialization, with less emphasis on lower TRL levels. Though teams have proposed some novel conceptual designs and a few of them are under actual development, it is not clear yet whether those technologies will be further advanced and implemented. Moreover, the GLXP challenge does not involve producing radical innovations to win the competition. That means that, more generally, breakthrough innovations are not directly induced but only enabled by this competition. As described later, new development and mission approaches are likely to be the most innovative contribution of the GLXP to this field (which is a target of the sponsor for this prize.)

More in-depth examination of the prize innovation process unfolds its complexity. In the GLXP, there is a number of R&D “threads” aligned with different stages of the “creation-to-implementation” innovation pathway (Figure 7.9). These are not necessarily parallel threads, but different components of the same process at different levels. For example, new concepts and experimental technologies (e.g. software algorithms, navigation systems, new concepts for planetary exploration) are tested during the competition but may never reach implementation/commercialization stages. There are also affordable systems that are part of new project management and mission approaches, which are already implemented by teams to accomplish the GLXP mission.



Source: own analysis.

Figure 7.8: Anticipated effect of the GLXP on innovation



Note: the chart is based on general categorization of outputs observed in the GLXP.
Source: own analysis.

Figure 7.9: Contribution of different types of prize technology outputs to innovation

This process of innovation triggered by the GLXP raises questions regarding the efficiency of the incentives provided by prizes and the uncertainty implicit in competitions. Prizes may effectively induce R&D activity and advance technologies, but the ultimate characteristics of both R&D activities and final outputs are difficult to predict. Moreover, this also calls into question the efficiency of prize programs, which may depend on whether additional incentives and longer development lead times are offered for entrants to further advance low maturity technologies that ultimately might represent truly breakthroughs. There is little evidence that further research can draw upon to examine this topic. For example, John Harrison, the winner of the historic Longitude Prize, received different amounts of money over 25 years until he completed the most efficient version of his chronometer to measure longitude at sea (Sobel, 1996). The more recent DARPA Challenges provided seed funding to 11 qualified entrants in the form of a competitive proposal with awards up to $1 million each, dependent on performance. This helped some of the best performers, particularly those with smaller teams, to remain in the competition (Whitaker, 2010).

The broader innovation literature contributes another key concept to explain the innovation process induced by the GLXP. von Hippel (1976, 1977, 1982) introduced and developed the notion by which innovation may be produced by users of products and services and not only by suppliers, in both consumer and industrial markets. He has also tested the possibility to predict the sources of innovation and maintained that users innovate if they see an in-house benefit from doing so and typically do not consider whether other users have similar needs. Notably, innovations produced by those lead users have more commercial merit than regular products as they are generally preferred by all users (von Hippel, 1988).

Thinking of the GLXP's innovation as a user-led process has its appeal. The GLXP teams have engaged in a process to find existing solutions from diverse sources (e.g. previous experiences, colleagues, existing components,) adapt them, and optimize their application to deliver and accomplish the feat within the boundaries of the solutions space defined by maximum schedule/costs and minimum capabilities. From this point of view, user-led innovation in prizes is a sector- and type-of-prize-specific phenomenon. Significant knowledge and technologies needed to accomplish the GLXP mission are readily available. Some of them are space grade technologies and others are technologies successfully adapted from other industries. This is enabled by broader trends of miniaturization and significant reduction of costs that teams have taken advantage of. Even teams that pursue commercialization are opening up new business opportunities for service delivery mostly based on the adaptation and implementation of technical solutions that otherwise would be primarily used for government-led space programs.

The evidence of the three case studies also shows how the innovation process in the new space industry is built upon the contribution of both prize entrants and ongoing industry projects and how prizes might lead to subsequent—efficient or inefficient—technological developments and industry decisions. It may occur that a few entrants have a key role and dominate the dynamics and ultimate achievements of the competition and acquire enough visibility to potentially set industry standards and influence investment decisions. For example, the AXP was greatly marked by the achievements of Scaled Composites with additional contributions of a handful of other teams (most notably, de Da Vinci Project and ARCA.) More advanced, new versions of the cargo aircraft-launcher/spacecraft configuration of Scaled Composites will be soon introduced by the company Virgin Galactic to offer the first regular suborbital tourism flights. Simultaneously, for example, XCOR—a private rocket engine and spaceflight development company that did not enter the AXP—has developed a reusable, single horizontal takeoff and horizontal landing vehicle, also with human transport capabilities (though in this case, for only one passenger.) These two alternative configurations may have more or less equivalent capabilities and efficiency, yet the AXP has given Scaled

Composites' achievements much global exposure. This visibility may ultimately influence investment decisions in the sector and, possibly, may have defined the decision of Virgin Galactic to invest in Scaled Composites' configuration.

Technology development in other prizes is a more widely distributed process as several entrants make significant advances. For example, Masten Space Systems and Armadillo Aerospace dominated the NGLLC, yet most of the teams developed and tested vehicles during four years of competition. Still, both companies have become key players at that moment and now in this emerging sector. Other companies such as Blue Origin have developed—yet more secretly—similar VTOL technologies. Blue Origin's New Shepard is inspired by the old NASA Delta Clipper DC-X concept (NASA, 2010a). These technologies may serve different niche markets but, also in this case, the visibility given by the prize may influence future technology development decisions (e.g. GLXP teams have consulted with or analyzed the designs of those NGLLC teams.)

To the author's knowledge, no GLXP-like mission is being undertaken by private entities other than the GLXP teams (there might be, for example, a withdrawn GLXP team that secretly continued its activities.) The GLXP has engaged 35 teams with varying contributions to this process. The visibility offered by the competition to the achievements of the teams may also have significant effects on further innovations. The achievement of the GLXP challenge with, for example, a hopper or a leg-enabled system rather than a more traditional wheeled-rover will certainly influence assessments on what the most efficient technologies for space exploration are. Alternative solutions might not be the most affordable or valuable from the commercial standpoint, yet they might ultimately be the most visible and signal—correctly or incorrectly—what methods, technologies, and markets industry and investors should aim for.

However, though prizes may be able to influence industry and investment decisions by showcasing the winning entry (or other significant prize outputs,) they are not necessarily able to signal the value of the technologies. This research has not gathered positive evidence in this regard and the analysis of the context suggests that the perceptions of the industry sector in relation with the value of the prize technologies are not affected by the announcement of the prize.

The ultimate effect of the GLXP on innovation also depends to great extent on the special characteristics of the space sector. A sizable, yet uncertain potential market value and a demand-side restricted to only a few actors overshadow the incentives offered by the GLXP and also moderate its effects on innovation. As of today, the decision of NASA to buy data and fund hardware demonstrations is the main reason for commercialization to occur in this prize. Increasing demand would have not only attracted more entrants (through the perception of the benefit of reputation offered by the GLXP) but also induced a more intensive R&D effort and collaborations from partners. Private investors also request stronger commitments from NASA or other space agencies to fund space initiatives. In relation with the literature, this expands the potential of prizes to induce more vigorous R&D races as not only larger rewards but also other non-monetary incentives have that positive effect.

On the other hand, the evolution of the new space industry is also part of the background of this competition. Past initiatives (e.g. LunaCorp, BlastOff!) had not benefited from the more promising context that now includes more successful business cases such as Armadillo Aerospace, Masten Space Systems, XCOR, SpaceX, and Scaled Composites. More general changes in beliefs regarding the potential for private space initiatives has benefited the GLXP as teams are more likely to attract investors and private customers.

The GLXP case also illustrates how the influence of the broader context may moderate the ultimate prize effects. The economic slowdown started in 2007 has affected the activities of teams and delayed their projects. Certainly, high return rates expected by private equity and venture capital to fund space projects have not contributed positively to the situation. Similar phenomena occurred in the case of the AXP with the economic slowdown after the terrorist attack of September 11, 2001, and after the increasing risk perceived in aerospace activities due to the loss of the space shuttle Columbia in 2003 (Maryniak, 2010). On the upside, however, the GLXP has kept the R&D focus of teams that managed to attract sponsorships and other in-kind contributions from multiple sources and sectors to fund their projects. This suggests that prizes may be particularly useful to maintain levels of R&D activity and innovation in contexts of recession or business contraction cycles. Considering that some teams have entered the GLXP even in a context of economic recession, prizes might also help in recovering stagnated economic sectors.

The GLXP's challenge definition is very open-ended and has enabled the innovation processes described earlier. This type of open-ended challenge definition is a necessary condition to allow alternative solutions to technical problems and alternative approaches to find them, yet it is not an innovation driver in itself (e.g. open-ended challenges do not determine whether technological outputs are successfully introduced or commercialized.) There is a limit in which further relaxation of the prize requirements may have a negative effect on innovation, as the R&D effort would be less focused. On the other hand, a more specific challenge definition to deliver technologies with certain specifications might have induced a more focused effort at the cost of less diversity in approaches and proposed solutions.

The GLXP has induced increasing R&D activities and induced the development of technologies that may become significant innovations. Most of the teams are newly formed and have produced some significant technology output. The GLXP has been the main reason of half of the teams to engage in this type of project. A number of them have implemented those technologies in their missions or seek hardware/services commercialization. The GLXP has also created a new platform that facilitates the entry of new participants to the space sector. It accelerated and expanded existing projects or even helped to re-initiate projects started more than 10 years ago (e.g. LunaCorp and

Astrobotic.) Moreover, more than 80 companies, universities, and NGOs have directly or indirectly participated in (and learned from) technology development through partnerships with GLXP teams. The teams themselves engaged at least 500 people during 2010. Most importantly, the GLXP led to the creation of networks of partnerships and collaborations that may transcend this competition. Though the global GLXP's R&D expenditures are still uncertain (and difficult to calculate with accuracy anyway,) teams may ultimately invest up to $465 million in their projects during the competition.[28]

This analysis of the effects of the GLXP on innovation considers the peculiar characteristics of space technologies. Space projects are discrete, one-off products that, generally, to be deemed truly innovative, must satisfy pre-established requirements and meet specific performance criteria or properties (Bain et al., 2001). Moreover, the potential customers in this sector are very limited in number and generally are those that establish the project requirements and develop the roadmaps for future technology development. The study of the effect of prizes linked to, for example, consumer product technologies may differ substantially from this analysis, as innovation in those other sectors is driven by information that companies have on markets with numerous customers and non-obvious inventions companies introduce to address them. Even further research on the effect of space prizes may require more in-depth, technical examination of the characteristics of the technology outputs and their implementation to fully understand the effect on innovation. Future research should also examine innovation processes in other entities not directly involved in the competition (e.g. partners, collaborators.) This research has drawn upon self-reported data yet those data were considered with caution due to the potential issues that self-reporting methods might introduce into the analysis.

[28] This is a very optimistic figure. It is calculated based on the mission budgets reported by seven teams and an average of $15 million for each of the remaining 9 teams with significant outputs that entered the GLXP before December 2010. The $15 million average is the minimum mission expenditure expected by the XPF when the prize was announced (XPF, 2008b).

CHAPTER 8

IMPLICATIONS

8.1 Theoretical implications

Prizes are only one of the forms of intervention to stimulate technological innovation. Other much more widely utilized mechanisms are patents, research grants, and R&D contracts. The effect of these incentives has been generally investigated using formal economic modeling techniques and little empirical evidence has been contributed. In particular, the literature has mostly contributed models in which a prize sponsor offers a unique monetary reward—the cash purse—to induce increasing R&D activity in a specific technological field or the production of a single innovation. This innovation is, theoretically, placed in the public domain. Moreover, prize entrants have generally been considered rational, profit-maximizing innovators that factor out only monetary benefits, costs, and the probability of success in their choices and decisions to participate.

The findings of this research in four key themes (i.e. motivations, R&D activities, technology outputs, and effect on innovation) (summarized in Table 8.1) have shown that, in fact, prizes are a more complex mechanism that requires analyses of other entrant- and context-level factors and models with more advanced assumptions. This research has offered an innovation model applied to prizes that encompasses both entrant- and context- level factors in addition to the prize competition as unit of analysis. This model allows multiple types of monetary and non-monetary incentives, is flexible regarding the characteristics of entrants, and accepts their subjective and boundedly rational decision-making processes.

Table 8.1: Summary of research probes and general implications

	Dimensions of GLXP case study			
	Motivations	**R&D activities**	**Technology outputs**	**Effect on innovation**
Theme	Weight of different types of incentives and relationship with the characteristics of entrants	Characteristics of prize R&D activities and differences with traditional industry practices	Prize technology outputs (PTOs) and their relationship with the characteristics of entrants	Overall effect of prizes on innovation
Anticipated relationship	H1: Type of entrants depends on types of incentives	H2: R&D organization depends on lead times and funding requirements	H3: Type of technology output depends on types of entrants	H4: Innovation effect depends on prize incentives and challenge definition
Dependent variables	•Type of entrants	•Design criteria (simplicity) •Technology sources (use of existing technologies) •R&D organization (degree of collaborative effort)	•Degree of novelty of technologies •Implementation of technologies	•Innovation effect
Independent variables	•Type of incentives (PIs, TIs)	•Development lead times/funding requirement conditions	•Type of entrants	•Prize incentives (PIs) •Openness of challenge definition
Control factors	•Technological field •Broader context	•Technological field	•Prize Challenge (PC) definition	•Technological field •Broader context

Note: implications reflect findings from GLXP case and pilot cases.

Source: own analysis

Table 8.1: Summary of research probes and general implications (Contd.)

	Dimensions of GLXP case study			
	Motivations	**R&D activities**	**Technology outputs**	**Effect on innovation**
Observed relationship	Relationship between type of entrants and types of incentives is not straightforward yet present some patterns; priority goal-based classification may be introduced to explain weight of diff. types of incentives. The effect of non-monetary incentives is significant.	Designs, tech. sources, and collaborations are more likely to be associated with individual teams' goals, strategies, and resources, and are not directly influenced by prize. R&D activity/fundraising activities interaction is unique to this context.	Evidence connecting type of entrants with PTOs is weak; stronger plausible explanations can be found in entrant goals, PC definition, and state of the art of the tech. The quality of the outputs is not predictable.	Innovation effect depends on PIs but also on the characteristics of entrants, the technology sector, and broader context; open-ended challenge definition enables innovation.
General implications	Prizes can selectively incentivize individuals and organizations to advance technologies or pursue related goals using both monetary and non-monetary incentives.	Prizes can induce increasing levels of R&D activity and enable the implementation of unorthodox approaches. However, the development/evolution of competitions cannot be completely anticipated.	Prizes can selectively focus on the advancement of technologies at different levels of maturity, yet the quality of the technological outputs is still unpredictable and depends on entrant-level factors.	Prizes can induce innovation over and above what would have occurred anyway, yet their overall effect depends significantly on the characteristics of the prize entrants and the evolution of the context of the competition. Technological breakthroughs can be enabled but not directly induced.

Note: implications reflect findings from GLXP case and pilot cases.

Source: own analysis.

Prizes can be, scholars suggest, an alternative to the patent system when they offer rewards equivalent to the social value of the innovation or in alternative schemes that combine the use of prizes with methods to gather information about the value of the technologies (Kremer, 1998; Shavell & van Ypersele, 1999; Scotchmer, 2005). That perspective, however, does not consider that the entrant's choice between prizes and alternative paths is not necessarily a rational, profit-maximizing decision and depends greatly on the value added by non-monetary benefits of competitions to the entrant's strategy.

In fact, modern technology prizes—which systematically offer rewards below (or equal to) expected R&D costs—complement and not replace patents and other incentive mechanisms. The ability of entrants to retain IP rights on their technologies enables the R&D process, particularly when the technology and funding gaps implicit in the prize challenge are significant or the prize is aimed at technology diffusion or commercialization. Entrants trade IP rights as a means to get access to key technologies and other resources such as expertise and labor for their projects. Patented prize technologies are still disclosed but not in the public domain. Moreover, hybrid prize schemes that include financial support for qualified entrants (e.g. R&D grants) or commitment to purchase prize technologies (e.g. procurement contracts) are potentially effective optional designs for these competitions.

In that context in which corporate and academic R&D choices are generally limited to other traditional incentive mechanisms, prizes can induce innovation. Their ability to do that is larger when there are larger prize incentives, more significant technology gaps implicit in the prize challenge, and open-ended challenge definitions. H4 reflected this relationship properly but further elaboration unveiled intervening factors. The case studies demonstrate that more and more diverse entrants and more favorable conditions of the context for fundraising, technology sourcing, and/or commercialization, can also increase this ability of prizes.

In a context in which there is a widespread use of prizes, however, their effects also depend on the uniqueness of competitions. The AXP, NGLLC, and GLXP have not had rival prizes held simultaneously and therefore do not fully represent that situation. Scaled Composites and XCOR, for example, chose different paths when the set of options included only entering a prize (i.e. the AXP) and the pursuit of contracts or traditional commercial development. More generally, a prize announced in a context in which no other equivalent competition (or no other any competition) is simultaneously held has more incentive power than a similar prize in a context in which other rival prizes also seek to attract entrants, resources, and the public's attention.

That implies that, in practice, the routine use of prizes, and/or challenge definitions that overlap, can weaken the incentive power of the mechanism. In the case studies, this is apparent in, for example, the incentives offered by competitions. In the case of the GLXP, entrants have found Google's sponsorship to be an important asset at the moment of raising funding from investors. Private sponsors and investors would not be attracted to the GLXP in the same manner if other important brands (or organizations) sponsored simultaneous space prizes. Moreover, in the process of disseminating the idea of the prize and the achievements of entrants, media attention to each competition may fade if an increasing number of prizes are announced.

Two types of incentives are perceived in technology prizes. *Prize incentives* are those created by the announcement and development of competitions and include the cash reward and other non-monetary benefits (e.g. reputation, visibility, opportunity to participate in technology development, opportunity to accomplish other personal and organizational goals, including the pursuit of valued ideals such as the contribution of S&T to society or the environment.) These incentives can be purposely created by prize sponsors. *Technology incentives* are those linked to the market value of the technologies involved in the prize competition. Prizes cannot influence or provide information on the market value of these technologies but can still influence industry decisions by showcasing technological options side-by-side and publicizing the effort of participants.

At the core of the decisions to participate in these prizes is the belief about the feasibility and the social, personal, or commercial value of the technological pursuit. Yet, ultimately, the choice between prize participation and alternative paths of technology development with similar focus depends on either the value the competition adds to entrants' strategies or the opportunity given by the competition to accomplish other goals. Entrants focused on winning the competition—which may be a small share of all entries—and those with other diverse personal or organizational goals perceive the non-monetary benefits of prize participation above other incentives. The probability of success may be implicit in the decisions of those who seek to win the competition, but its calculation is not straightforward and requires considering entrants' diverse goals and perceptions of the seriousness of other entries. Entrants focused on starting a new business based on the prize technologies are more likely to assess the potential market value of such technologies or the potential benefit of introducing those technologies in own processes. H1, simplified to probe a relationship between types of entrants and types of incentives, failed to capture how all these factors interact to define entrants' choices.

Overall, the monetary reward is not as important as other prize incentives. It is, however, still important to disseminate the idea of the prize: it helps to position the competition in the media and attract the public. From this perspective, the calculation of the monetary reward has to consider not the social value of innovations but the purpose of the competition and the amount necessary to attract attention in the technological field or industry. A sizable reward can also distinguish a competition from others. In prizes that seek commercialization of technologies, an appropriate reward may help to close business cases of entrants. When there are other significant non-monetary or technology incentives in place, the reward should represent an attractive recompense only (which depends on the type of entrant the sponsor is interested in, as described later.)

When announced in a particular technological field or industry sector, prizes trigger new R&D activities and induce the convergence of ongoing R&D processes (that are internal or external to the sector) toward the prize challenge. The configuration of those R&D activities—which H2 sought to explain on the basis of prize-level factors such as limited development lead times and lack of up-front funding—is still difficult to anticipate and cannot be directly influenced by any particular prize design. Such configuration generally depends on the characteristics of entrants (e.g. background, experience, connections, strategies,) the technology gap the prize posits, and funding requirements implicit in the prize challenge. Compared with traditional industry practices, the most distinctive feature of prize R&D is its iterative development and the interaction between R&D and fundraising activities. Prize rules can nonetheless influence R&D activities if special requirements are set with that purpose.

By engaging numerous participants, prizes spread risks of R&D and commercial development broadly among individuals and organizations that participate directly or indirectly in competitions. Moreover, the evidence suggests that, generally, prize entrants are less risk-averse than traditional industry players, particularly those that are *unconventional*, i.e. individuals and organizations generally not involved with the prize technologies. However, compared to other incentive mechanisms, prizes involve higher programmatic risks as their R&D effects and quality of technological outputs are generally difficult to anticipate.

Both the extent to which the prize mechanism depends on its context and the fact that, in principle, winning a prize is not a sustainable business, suggest that prizes are not able to create markets by themselves. On the one hand, the conditions of the general context can frustrate (or facilitate) technology sourcing and fundraising efforts of entrants for R&D projects. This is more relevant for prizes that require significant funding and, in particular, for those aimed at commercialization of technologies, whose success also depends on the perceptions of entrants and their financiers about the market value of the technologies. On the other hand, winning a prize is not necessarily economically attractive for entrants. Sponsors can systematically set rewards that are lower than expected R&D costs and still attract entrants by offering other valuable non-monetary incentives.

Similarly to contracts and grants, prizes can procure focused R&D. Using open-ended challenge definitions and relaxed technical requirements in rules, prize technology outputs can be expected within a more or less defined solutions space (this allows exploring unorthodox solutions.) Using more strict specifications, prize outputs focus on the advancement of concrete technologies with the risk of constraining creativity or ignoring other valuable innovations. While H3 posited a relationship between types of entrants and the technologies they develop, the evidence revealed that the ultimate characteristics of the technology outputs depend on entrants' goals, the prize challenge definition, and the maturity level of the prize technologies. Entrants generally seek to perform the minimum possible R&D effort and draw upon simpler and existing technologies to win competitions. Entrants with other goals present a less distinctive pattern and may produce technologies of diverse quality, but these are not directly influenced by prize design.

The investigation of prize cases with different technological goals in the creation-to-implementation innovation pathway has also shown that prizes may not be equally effective for all technological goals in a given field. Due to the sequential and cumulative nature of innovation, the relevant knowledge and technologies have to be available to competitors for prizes to successfully induce technology research, development, improvement, or diffusion/commercialization. In general, the larger the pool of knowledge and technologies readily available to address the problem, the higher the technology maturity levels the prize can aim for. Otherwise, entrants would need further incentives, support, and/or longer development lead times to be able to achieve the prize target. For example, to induce more basic research or discovery of new principles in a field not investigated by corporate or academic research, prizes may require significantly longer development lead times. This calls into question the feasibility of some proposals to implement prizes in fields as diverse as agriculture, medicine, and nanotechnology, and suggests considering this perspective to make more efficient the literature's competitions (see, for example, Horrobin, 1986; Kremer, 2000; Masters, 2003; Anastas & Zimmerman, 2007; Charlton, 2007).

Prizes may lead to a socially undesirable duplication of R&D efforts in the sense that there may be many entrants in the pursuit of the same technological goal. This is particularly true when prize challenges are narrowly defined (Maurer & Scotchmer, 2004; Newell & Wilson, 2005). Yet, analyses that consider this to be an issue have not considered the social and economic benefits of increasing numbers of individuals and organizations involved in competitions, collaborations, and knowledge spillovers, which favor technical training, education, increasing interest in S&T, and the achievement of other personal and organizational goals of participants. Moreover, even when entrants produce similar technologies to achieve the prize challenge, the side-by-side comparison of their diversity at the subsystem- or lower levels and their R&D and project management approaches are a valuable source of knowledge for the sponsor, entrants, and industry players.

8.2 The prize process

In practice, the innovation process in prizes begins when the sponsor announces a reward to attain certain technological goal and communicates the purpose and spirit of the competition. Both non-monetary incentives and the cash purse offered by the competition raise the interest of individuals and organizations with diverse goals (including goals beyond the prize) but similar beliefs about the feasibility and merit of the pursuit. A proper announcement and a sizable cash reward also attract industry and media attention.

Individuals and organizations form teams to enter the competition and bring together companies, universities, independent R&D groups, entrepreneurs, and individuals with diverse expertise. Would-be entrants make their decision to enter the competition based on the value added by the prize to their strategies. Traditional industry players only enter the competition if there is a foreseeable commercial benefit in that. Other participants only engage indirectly. Partners, for example, may perceive a commercial benefit but only in the provision of services or products to teams. Volunteers may find in prizes a unique opportunity to participate in technology development without having to create a company or team.

With the announcement and first entrants, the prize competition creates a technology platform that adds value to the strategies of participants and comprises entrants, new and existing industry entities, R&D and business activities, new relationships and networks, and sets of rules that govern the competition. This platform attracts human, technical and monetary resources from diverse sectors. Numerous collaborations and knowledge spillovers can develop as well, including collaborations between teams when competitions are organized as races. This platform can transcend the competition and give birth to a technology-centered community.

The competition accelerates and/or re-directs ongoing industry projects, triggers new R&D processes and re-starts others. Teams raise funding, recruit new members, commercialize developments, and develop partnerships to source expertise and technologies, speed-up projects and reduce risks. The R&D effort to win the competition is likely to concentrate in a minor share of teams. The rest of the teams may have difficulties to raise funding or recruit members with appropriate expertise; or may perform R&D for projects on the side and not necessarily aimed at winning the competition.

The R&D organization and effort of teams are ultimately determined by their goals, knowledge, skills, and available resources, and may not be directly influenced by the prize. Due to the lack of up-front funding, there are significant interactions between prize R&D and fundraising activities. This may divert efforts from R&D and, potentially, constrain technological development. Prize R&D activities may be also moderated or halted by sector crises or major economic slowdowns. Nonetheless, prizes induce converging R&D processes and are open to resources from sectors other than those of the prize technologies. Moreover, the GLXP demonstrates that less risk-averse teams may enter competitions even in those recessive contexts and maintain certain levels of R&D activity.

Though entrants seek to produce the technologies required to win the competition, prize outputs are difficult to anticipate. Competitors introduce methods and produce technologies in a wide range of maturity levels with focus on a level of maturity given by the state of the art of relevant technologies, the definition of the prize challenge, and the technology gap created by the prize. The ability of the competition to induce the introduction of novel methods and breakthrough technologies also depends on the successful recruitment of more and more diverse participants and the conditions of the broader context for technology sourcing and successful fundraising.

Prizes produce broader outcomes as well. Most importantly, prizes with open eligibility criteria democratize the process of technological development by engaging individuals and organizations generally not involved with the prize technologies and promoting collaborations among entrants and between them and partners. Prize participation also triggers significant learning processes in participating individuals and organizations. Prizes also signal the interest of the sponsor and showcase technological options by publicizing the R&D approaches, technologies, and achievements of all participants to audiences such as industry experts, investors, consumers, and policy-makers. Hence, prizes may influence industry decisions, follow-up investments, and regulatory measures related with the prize challenge. Similarly, prizes can raise public awareness on S&T topics when they attract the media to reach out to broader audiences.

8.3 Team strategies

There are different perspectives to the R&D strategies followed by prize entrants to win the GLXP. Most of the features of these strategies can have application to other prize competitions and be particularly expected in other prizes aimed at commercialization of technologies. These examples provide useful insights for entrepreneurs, companies, and other individuals interested in prize participation.

Prizes are generally open to participants of diverse composition and may include companies, universities, independent R&D groups, entrepreneurs, or simply individuals attracted by the prize. This research was set out to analyze them based on their industry experience or familiarity with the prize technologies. From this perspective, teams can be classified into conventional and unconventional. The latter are those individuals and organizations that are not generally involved with the development of the prize technologies. These entrants are attracted by the opportunities to participate in a challenging project, learn, and contribute to society and would generally not pursue similar projects if the prize did not exist. They are generally organized as independent or non-profit entities and form teams that recruit above average number of people, including volunteers and students. These teams are generally less risk-averse and not always interested in the economic value of the technologies.

Teams enter prizes to win the competition and/or accomplish other diverse goals. This research classified teams based on generic priority goals to analyze *Challenge teams*, *Industry/Start-up teams*, and *Diverse Majority teams*. Challenge teams seek the shortest path to win the competition. They perform the minimum possible engineering effort, use simpler methods and technologies, and use existing technologies whenever these are available. They distribute effort among partners and volunteers to accelerate their projects and minimize risks. Industry/Startup teams seek to create a sustainable business and, therefore, optimize their R&D effort for the development of commercial products and services. The prize target is still important but secondary in that regard. These teams tend to develop technologies with higher levels of maturity and design criteria linked to their business strategies. Low entry barriers to the competition allow the participation of Diverse Majority teams. These generally pursue goals that may or may not directly relate with the prize target. Their strategies are very diverse and linked to varied personal and organizational goals.

The analysis of the configuration of R&D activities at the team-level unveils at least four strategies to win the competition. In general, these are flat and flexible organizations and recruit team members with diverse backgrounds and experience (i.e. these are generally unconventional teams.) Their constant adaptation, collaborative effort, and use of communication tools for remote collaboration are also common traits of these teams. A strategic R&D feature is also the open innovation approach used by teams to leverage external research and complement internal technological activities with increasing knowledge flows. Flat, flexible, and collaborative teams can not only speed up technology development but also reduce project risks and costs.

Based on the organization of R&D activities, the four strategies identified by this research are:

- Open source: this is the widest distributed effort, which leverages the R&D effort with participation of hundreds of volunteers from remote locations. A small core team still coordinates the effort and leads the project. This strategy is based on the non-profit organization of activities and sponsorship support. Partners and subgroups develop and test subsystems that compete with alternative designs and are later integrated into the main project. The number of connections with other entities leads to complementary, diverse projects and new opportunities beyond the competition.

- Partnerships Network: this strategy is a much focused effort that involves partnerships with key players from diverse sectors to source technologies and services that support the project. This is also a geographically distributed effort yet with a core, leading team. The organization of this effort is under continuous adaptation to maintain its competitiveness. IP rights on technologies are key to engage partners and, potentially, create a new business.
- Entrepreneurial: this strategy involves a for-profit orientation for the prize project with the goal of becoming eventually a sustainable business based on the prize technologies or the provision of related services. Key university partners provide multidisciplinary know-how; key business partners and multiple revenue sources finance and support the prize project. Winning the competition is the top priority and the team's business model is adapted to accomplish such goal.
- Universities partnership: this strategy brings together universities and a non-profit entity to take advantage of trained volunteers and specialized facilities needed for the project. The initiative seeks to implement methods that can be scaled up in similar yet larger projects. Though winning the competition is a priority, members' involvement is also related with the opportunity to accomplish other personal or professional goals such as gaining hands-on experience and participating in a challenging project.

8.4 R&D program and policy implications

Prizes are an incentive and support mechanism for technological development and also an indirect mechanism to influence industry and public perceptions about S&T issues. Prizes can target certain technologies, R&D performers and geographic areas, induce increasing levels of R&D activity and, under certain conditions, induce technological innovation as well. Prizes also leverage funding significantly due to their widespread, decentralized impact but involve higher programmatic risks than other more traditional mechanisms. Prizes can induce research, development, diffusion or commercialization of technologies, and diverse related effects (Table 8.2). This can be achieved by setting a number of parameters that focus the prize, such as the technological problem, prize incentives, and eligibility criteria for participation.

Table 8.2: Potential technology-related effects of prizes

Types of effects	Specific effects
On innovation, in general	• New concepts and experimental technologies • Creative solutions to specific, well-defined problems • More affordable and simpler versions of existing systems • New development and project management approaches
More specific, technology-related	• Induced collaborative R&D effort • Engagement of both conventional and unconventional entrants • Engagement of communities of interest (e.g. students, women) • Development of an innovation platform • Leveraged R&D investment (including attracting funding from other sectors)

Note: the table is not comprehensive and shows only general effects based on research findings.
Source: own analysis.

The selection of the proper technological problem has to consider four factors. First, prizes should address very specific problems for which the achievement of a solution is clear, verifiable, and visible to the sponsor, the competitors, and the public. Second, whether the relevant technologies to accomplish the prize challenge are available to all entrants define appropriate types of prizes and expected outcomes of competitions.

Third, prizes that involve advancing less mature technologies are likely to require longer development lead times, more significant incentives (created by the prize or linked to the prize technologies,) and/or further support (e.g. seed funding.) Fourth, the conditions of the context of the technological field can frustrate (or facilitate) fundraising efforts of prize entrants for certain targets. This is particularly relevant for prize projects that require significant funding or are aimed at commercializing technologies with uncertain market potential.

Prize programs can be designed to selectively target different points in the creation-to-implementation innovation pathway or TRL levels, from idea sourcing and experimental research to product launch and/or dissemination/adoption of new technologies. Prize sponsors, however, have to select the appropriate type of target for each technological goal. This research suggests four possible types of technology prizes according to the target maturity level of the prize outputs and the state of the art of the prize technologies (Table 8.3):

- Prizes for novel solutions and concepts are aimed at creating new methods to perform certain technological functions. These prizes are appropriate when it is unclear what basic principles the solution should draw upon to solve the prize challenge.
- Prizes for technology development are aimed at demonstrating technological feasibility. These prizes should be applied to problems for which the basic principles are known and/or experimental research was already performed.
- Prizes for incremental improvements are aimed at advancing technologies with specific (commercial or other) applications. These prizes should be applied to further develop technologies with at least medium levels of maturity.
- Prizes for technology implementation are aimed at accelerating diffusion, adoption, or development of end-user communities or markets that are held back for some reason. These prizes should be applied when the relevant technologies

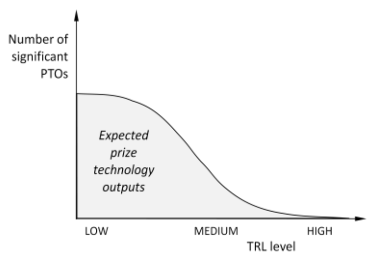
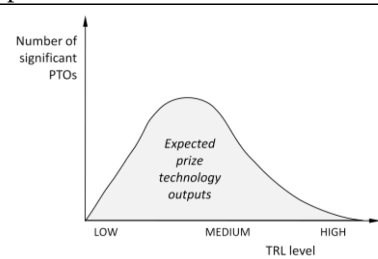
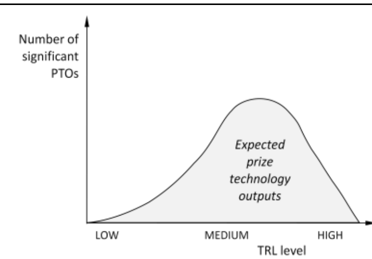
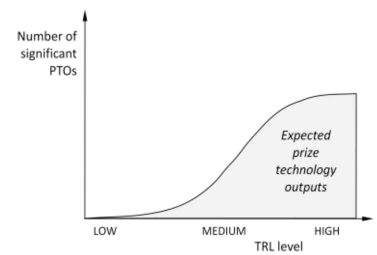
are at medium or high levels of maturity and there are uncertain yet potential markets.

Prizes can also target individuals and groups of diverse age, professional background, or experience by both defining special criteria of eligibility or offering particular incentives (Table 8.4). Target communities may be defined as, for example, K-12 students, engineering students, teachers, or government employees. This makes prizes an appropriate mechanism to engage people in Science, Technology, Engineering, and Mathematics (STEM) education or technical training programs. The eligibility criteria can be relaxed to attract more and more diverse entrants, but this can increase the cost of program operation significantly and change the spirit of the competition.

More generally, prizes may effectively attract individuals and companies that are less risk-averse for both technical and commercial endeavors. In particular, prize challenges that balance a sizable market potential and uncertainty about market segments, market values, and required capabilities to exploit them are more likely to engage less risk-averse entrepreneurs and discourage traditional industry players.

Prizes can be also implemented within specific regions or seek broader participation to tap into widely distributed ideas and creativity. For the aerospace industry, for example, the GLXP has represented the opportunity for certain countries to engage in the development of space technologies through the participation of individuals and private organizations, an opportunity that probably they would not have had otherwise. At the state/city level, prizes may help to mobilize resources into underserved areas. Regional targets require announcing competitions in proper venues to attract the attention of local entrepreneurs and other potential entrants.

Table 8.3: Types of prizes and possible target areas for prize programs

	Types of prizes and target technology areas			
	Prizes for novel solutions and concepts	**Prizes for technology development**	**Prizes for incremental improvements**	**Prizes for technology implementation**
Generic applica-tions	High-risk, exploratory approaches to find “out-of-the-box” solutions	Demonstrate technological feasibility	Advance technologies with specific (commercial or other) applications	Accelerate technology diffusion, adoption, or development of end-user communities or markets that are held back
Generic challenge definition	Find or create a method to perform new function	Develop technology to accomplish a feat	Improve technology to achieve higher performance standards	Implement technologies under prize challenge cost/schedule conditions
Technol-ogy state of the art	Unclear what basic principles the solution should draw upon	Basic principles known, experimental research performed	Existing technologies with at least medium level of maturity	Existing technologies with medium-high level of maturity
Target technol-ogy out-puts (PTOs)				
Prize examples	Food Preservation Prize, Longitude Prize	Ansari X Prize	NGLLC, DARPA Challenges	GLXP

Source: own analysis.

Table 8.4: Selected motivation targets and recommended prize design actions

Broader program goals	**Specific target**	**Recommended (generic) action**
Tap into widely dispersed creativity to address technical or social issues	Attract larger number of entrants	Set prize challenge that more (industry or academia) experts consider feasible
	Attract unconventional entrants	Set challenging technical goal
	Attract social entrepreneurs	Set prize challenge that address problem considered socially worthwhile
	Attract general media and public attention	Set larger cash purse
Advance technologies for commercialization	Attract entrepreneurs, less risk-averse companies	Set prize challenge that address a problem considered commercially valuable, yet the proper business model is still uncertain
	Attract entrepreneurs and not traditional players	Align prize challenge with potentially sizable, yet uncertain commercial opportunities; set cash purse that can close business cases for the prize technologies of startups
	Attract conventional entrants that seek commercialization	Increase prize visibility/reputation by obtaining endorsement of key sector players

Note: unconventional entrants refer to individuals and organizations not usually involved with the prize technologies; conventional entrants refer to individuals and organizations with industry experience with the prize technologies.
Source: based on research findings.

Prizes can produce other valuable outcomes that are generally difficult to anticipate. Most importantly, prizes that are wide open for participation democratize the innovation process as they offer the opportunity to engage in technology development to certain groups of interest and organizations (e.g. students, minorities, the “lone garage inventor,” professionals that work in large, centralized and bureaucratic organizations, independent research groups, NGOs.) This is also the opportunity for the sponsor to tap into the creativity and fresh ideas that those groups might contribute.

Prizes also generate significant knowledge spillovers when they bring together new and pre-existing small and large companies, universities, and NGOs to develop prize technologies. Collaborations and other relationships may transcend the competition time frame and create problem solving communities. Collaborations between participating teams are more likely to occur when competitions are organized in the form of "races"—such as the NGLLC—that bring teams together and foster interactions between them.

Increasing visibility of prize competitions can also raise public awareness and change beliefs about S&T topics linked to the sponsor's mission. Both successful historic and modern prizes have not only been able to attract individuals that believed in the feasibility and merit of the prize goal, but also have spread that belief to industry and the broader public. Success stories such as the Orteig Prize are the foundation of modern prizes and have inspired entrepreneurs, philanthropists, and other individuals that seek opportunities to participate in challenging projects. Sponsors of modern prizes have had powerful communication means at hand to disseminate the achievement of competitors and transform beliefs about scientific and technological possibilities. The inspirational value that prizes might create for innovations to come is as important as the immediate effects of their implementation.

Successful prize program design requires setting a number of parameters properly. Program managers should consider the following points. First, a significant part of the effort to implement programs has to be devoted to attract serious entries with diverse profiles. Second, the prize design should focus on the appropriate definition of the prize challenge and incorporate expert insights. Third, the costs of the prize program may exceed significantly the cash purse if additional support (e.g. seed funding) is offered to entrants. And, fourth, the success of prize programs is context-specific and competitions have implementation time frames that are more appropriate than others.

The prize challenge has to be technologically complex and ambitious from the programmatic standpoint yet also attractive and captivating for a number of potential entrants that believe the challenge is feasible and has some merit. The definition of the challenge includes setting a prize deadline that allows, according to expert opinion, a reasonable lead time for technology development. To induce commercialization, challenge definitions can combine a) shorten development lead times to induce the introduction of commercially viable project management approaches with flexible, low overhead cost organizations; and, b) technological feats that require external funding to induce fundraising efforts and the introduction of new revenue models.

There is no single rule for determining the proper size of the cash purse. Some successful prizes have offered rewards of about one-third of the expected R&D costs to achieve the prize challenge. Cost estimates should rely on historical costs to develop similar technologies and discussion with entrepreneurs or industry experts. Competitions should balance the prize purse with the potential market value of the prize technologies and other benefits that the competition may offer to participants.

Table 8.5 shows examples of technology prize program goals and recommendations for the definition of the prize challenge and cash reward. Other more general recommendations apply to increase program effectiveness and efficiency: 1) prizes should balance the openness of the competition and the eligibility criteria (through the implementation of fees or a procedure to evaluate entry applications) to tap into widely dispersed creativity and allow only serious entries; 2) prizes should address problems that do not imply significant funding requirements for entrants; and, 3) when there is still a significant funding requirement, prizes should be announced only in favorable economic conditions.

Prizes can create attractive non-monetary incentives. A challenging project can drive curiosity, desire of participation, and desire to compete. Prizes can also offer the opportunity to gain reputation, publicity, and create a competitive environment that inspires people that seek recognition. Low entry-barriers to the competition also incentivize participation and give access to a set of resources available only through the prize platform. In particular, the reputation/publicity value created by prizes supports the strategies of entrants that seek to enter markets that require a proven track record in successfully delivering technical solutions, such as aerospace, defense, and medicine. The official endorsement of the competition aimed at technology commercialization/diffusion by key industry players or industry/consumer organizations can increase the incentive power of the competition.

The registration period to enter competitions should remain open to allow would-be entrants to evaluate the benefits of participation. Increasing activity in the competition can attract the attention of new participants as it disseminates through media channels.

Table 8.5: Examples of prize-based program goals and definition of key prize design parameters

	Program goals (examples)			
	Explore new, experimental methods and technologies that imply high-risk R&D	**Induce technological development to break critical technological barriers**	**Accelerate technological development to achieve higher performance standards**	**Accelerate diffusion, adoption, and/or commercialization of technologies**
Type of prize	Tech-based accomplishment	Tech. development to demonstrate technological feasibility	Tech. development to demonstrate increasing performance	Tech-based accomplishment to demonstrate commercial feasibility
Target for maturity of prize technologies	Low	Medium	Medium-High	High
Prize challenge	Challenging, new problem with unknown solutions	Develop new artifact/system to solve newly-defined problem	New performance requirements for existing technologies	Set schedule/cost conditions to accomplish a feat linked to specific users community/ commercial markets
Cash reward determination	Cash purse attractive for independent inventors, professionals	Cash purse attractive for smaller industry players	Cash purse to cover part of costs of incremental development	Cash purse to potentially close business case
Specific recommendations	Sequential competitions that build up on previous prizes can be used to attenuate programmatic risks.	Only link prize challenge to sizable markets if these are uncertain.	Set concrete, verifiable measures of improvement to find a fair winner.	Seek official endorsement of technology adopters or customers.

Source: own analysis.

Rules should be kept simple, unambiguous, and easy to understand. They have to remain unchanged after the competition has been announced to avoid discouraging participating teams. Program managers should work with industry experts, entrepreneurs, and would-be entrants to get further insights to create the proper set of rules. Moreover, contrary to other incentive mechanisms, prizes are flexible in terms of design and allow setting multiple parameters to, for example, test special regulatory frameworks. Similarly, though in less controllable fashion, competitions can operate as a test bed for unorthodox methods and radical technologies when prizes incorporate open-ended challenges and no requirements to build specific technologies. In any case, fair and transparent rules allow comparing competing approaches to R&D, technologies, and business strategies in a level playing field.

Prizes can encourage flexible approaches to problem solving if they do not pose restrictions to R&D organization, which suggests their implementation in cases that traditional instruments are too restrictive. A comparison between prizes and NASA's SBIR/STTR program in selected dimensions is illustrative (Table 8.6). The networked configuration of prize activities and collaborative efforts observed in the GLXP, for example, may be not generally allowed under SBIR/STTR programs due to the requirements of in-house execution and no partnership. Moreover, while the SBIR/STTR program funds certain R&D effort, specific technology maturity levels, and standard development lead times (12-24 months,) prizes allow setting these parameters discretionarily, based on the sponsor's needs.

Table 8.6: Prizes compared to NASA's SBIR/STTR programs (selected dimensions)

	SBIR/STTR	Prizes
Selection process	Competitive award with experts assessment (about 20-25 percent of proposals are awarded;) contractual relationship	Prize competition (generally winner-takes-all)
Type of participant entities	Small for-profit (in partnership with non-profit research organization in STTR)	Not restricted
Foreign participation	No	Possible
Entry process	Detailed proposal	Entry fee (may require proposal as well)
Technology area	Solicitation with topics and subtopics proposed by agencies; Focus by phase: Phase I, low TRL levels (proof-of-concept); Phase II, medium TRL levels (development); Phase III, high TRL levels (commercialization)	Prize challenge definition set by sponsor; May target different technology maturity levels
Development lead times	Varying by phase: 12-24 months	Not restricted
Reward	Varying by phase: $100-750K	Not restricted
Partnerships with foreign firms	No	Not restricted
R&D subcontracting	SBIR: Phase I <25 percent, Phase II <50 percent STTR: small business >=40 percent, research institution >= 30 percent	Not restricted
Technology ownership	Gov. has non-exclusive paid-up license for the technologies; if performer does not exercise right to patent, invention is made public or patented by government	Optional right to license, or request placing in public domain, or combination of them.

Source: own analysis.

Since prizes may induce collaborative efforts across geographical boundaries, rules have to consider the regulatory framework specific to the industry sector, particularly when prizes involve technologies that may have dual-use or be considered inherently military in nature. In those cases, U.S. citizens and organizations that enter in prize competitions to develop certain aerospace and defense technologies may need to abide by the International Traffic in Arms Regulations (ITAR.) Program managers should explore special eligibility requirements for prize entrants and competition rules that regulate the use or destination of prize technologies in those cases. In some instances, this type of regulations may give national teams an advantage when they are able to source technologies that foreign teams do not have access to.

The key role that IP rights play in fundraising and commercialization activities of entrants puts forward the question of whether entrants should be allowed to retain IP rights when program managers want to further disseminate or advance technologies with follow-up competitions. If prize sponsors are willing to further disseminate or advance prize technologies, they shall enter in agreements to negotiate in good faith to license the technologies or have preferential access to commercial services offered by entrants.

To announce prizes, program managers should watch industry and broader trends to anticipate favorable contexts and the potential influence of factors external to the competition. Program managers should take advantage of related public events and think strategically to increase the program's visibility and reach out not only to those that may eventually enter the competition, but also to broader audiences including policy-makers and the general public. Online social network platforms and other communication means can help to engage more individuals with diverse backgrounds and experience and, thus, enable a more innovative technology development process.

Prize sponsors should also consider some drawbacks of the use of prizes. Most importantly, there is the potential negative effect of the widespread or routine use of prizes on their incentive power. To prevent this, program managers may use a portfolio perspective and use prizes only as a complement of more traditional programs. Prizes can initiate new lines of research, for example, and contracts support further development of prize outputs. If a multi-prize program is designed, program managers can implement sequential competitions that build up on previous results and posit increasingly difficult challenges, simultaneous yet complementary global competitions, or similar yet regionally focused competitions.

The development/evolution of the prize competition, on the other hand, is generally difficult to anticipate, which raises concerns on the efficiency of the program spending from budgetary and societal standpoints. Prize managers cannot anticipate neither the approaches used to find the solution nor the levels of the R&D activity. Moreover, if entrants divert efforts from R&D considerably to seek funding, technological development may be constrained. In this case, prizes can induce a more focused R&D effort by providing seed funding or other forms of in-kind support such as access to special facilities or equipment for all entrants. Unfortunately, the very uncertainty that prize R&D processes involve impedes calculating an accurate estimate of the R&D costs and, thus, the optimal level of support. All this suggests that prizes should be considered as an alternative, experimental policy instrument to complement other traditional technology programs.

Prize R&D efforts may also be inefficient and originate activity that ultimately does not result in, for example, the introduction of technologies or the dissemination of the most appropriate methods. Uncertain methods of technology development in the pursuit of certain technological goals may also imply higher risks for individuals, the environment, and property. Therefore, program managers have to implement the necessary measures to limit liabilities. Moreover, the introduction of unorthodox approaches is an appealing idea in some circumstances, yet further work may be necessary to properly introduce and disseminate those methods as standard practices. Codification and documentation of procedures and methods, for example, may be necessary if teams are informal organizations that rely heavily upon trial-and-error or other informal approaches to R&D.

Finally, prize program evaluations require special considerations compared to other incentive mechanisms. The generally widely distributed R&D effort in prizes is difficult to measure and, therefore, the assessment of the overall impact of the program is more complex as well. Surveying prize entrants and partners to gather data on their activities may raise confidentiality concerns on their part and even have a negative effect on the ability of the prize to attract entrants. Moreover, program evaluations have to consider the dynamics of the competition in terms of entrants (new teams, drop outs, mergers) and significant variations in the number of members/volunteers that teams engage. Data gathering to evaluate programs is likely to depend on self-reporting instruments and thus require appropriate design to favor data reliability and avoid unnecessary bureaucracy.

8.5 Methodological considerations

This research has investigated prizes and the means by which they induce innovation using an empirical, multiple case-study methodology and multiple types of data sources. The iterative research process has—based on the analysis of previous research—introduced an innovation model applied to prizes, tested and revised the model with pilot case studies, analyzed the main case study, probed hypotheses, and revised theoretical aspects. The research was set out to answer four questions and probe four corresponding hypotheses that are deemed relevant from the point of view of both scientific inquiry and policy-making.

The analysis has been able to answer the research questions and make an important contribution to our knowledge of prizes. The hypotheses—created to reflect assumptions implicit in the prize literature—helped to frame a systematic data collection process for prize cases and triggered a more general yet fundamental discussion about the real effect of prizes. The probes allowed concluding that prizes do induce technological innovation under certain conditions (H4,) but the underlying effects of this phenomenon (implicit in H1, H2, and H3) are more complex than generally assumed. The analysis has unveiled other intervening factors than those hypothetically anticipated and allowed setting a basis for further investigation and refinement of our approaches to investigate prizes. Future research projects should develop hypotheses that incorporate those factors and probe, for example, the incentive power of certain incentives considered individually, the entrant-level determinants of R&D configurations, and the relationship between technical aspects of prize outputs and prize configurations.

That iterative approach demonstrated to be appropriate to investigate prizes when there is a lack of prior research. The test cases helped to refine the model and provide methodological insights to investigate the main case. The main case contributed significant empirical evidence to gain better understanding of the phenomenon. Overall, the three cases contributed insights to develop new building blocks for a theory of prizes. Further research, however, should investigate and compare two or more cases, and cases in different technological fields and broader contexts, rather than following that sequential approach. That will help to gain better understanding of the potential of the prize mechanism under more diverse circumstances.

The innovation model proposed by this research has some advantages over the traditional economic modeling of prize mechanisms. Other models have generally considered only the monetary incentive and the production of one innovation, and have not considered other diverse motivations, the indirect participation of, for example, partners and volunteers, and the development of technologies that do not necessarily focus on the prize target. In this regard, the most important contribution of this research is an alternative model of innovation in prizes that do consider those factors and, particularly, assumes that R&D performers are not necessarily profit-maximizing and have diverse decision-making processes, knowledge, and skills. Moreover, this new model allows comparing modern with historic cases to understand the influence of the context on competitions and comparing prizes with other instances of innovation. Improvements in this innovation model applied to prizes should include the refinement of the operationalization of research categories, the specification of other relationships between categories, and the investigation of new themes emerging from them.

The investigation of prizes without much prior empirical research required probing classifications of incentives and entrants to allow the operationalization of certain constructs. The classification of incentives into prize and technology incentives was appropriate for one of the first empirical research projects that investigates modern prizes. This research has shown how different types of incentives weigh on the decision of entrants to participate but has also highlighted the need to further address the topic in future research to assess the importance of each individual component of the set of incentives. On the other hand, this research has shown that entrants are very diverse and new classifications can be explored. The classification into conventional and unconventional is costly from the research standpoint, because it does not allow understanding all the diversity and complexity in variety of entrants. Considering the implementation of prizes, it is still useful for prize sponsors to know generally whether they will be able to engage individuals and organizations not familiar with the prize technologies. Yet, the priority goal-based classification—i.e. whether the entrant seeks to win the competition, start a new business, or other—may be more illuminating to understand strategies and the factors that can help to focus R&D efforts, despite its more complex operationalization.

Data on prize cases are generally scant. The information available on recent competitions has not been systematically collected and mostly contributed by anecdotal accounts and media coverage. Hence, this research sought to draw upon multiple types of data sources and data triangulation to increase its internal reliability. Visits and observation of team activities, in particular, have helped to gain a better understanding of entrants' organization and strategies, and also yielded valuable insights to better interpret data from questionnaires and documentary sources. This shows that real-time data from ongoing competitions can also be more insightful than historical accounts for the study of certain innovation topics in prizes.

Future research should seek to develop, among others, methods to quantify and qualify the magnitude of the collaborative effort that includes volunteers and partners. For this, researchers will possibly draw upon self-reporting methods to gather data about entrants and their activities and collaborators. For this, questionnaire design shall balance more and more detailed questions with simplicity and low bureaucracy to increase response rates. Potential data sources for future research also include the data generally collected by prize sponsors about the activities of teams. This project, for example, has had the collaboration of the X Prize Foundation for data gathering. Future projects should explore methods to gather data systematically without interfering with competitions.

Finally, this research has also shown that the winning entry is not necessarily the most important technological development in the context of prizes. Findings of significant activity during the competition (in both teams and their partners) supports the idea by which the most interesting effect of prizes is not necessarily the winning entry but also the activities and outputs of runner-ups, other entrants, and other entities that participate in competitions only indirectly.

CHAPTER 9

CONCLUSIONS

Inducement prizes–where cash rewards are given to motivate the attainment of targets—have been long used to stimulate individuals, groups, and communities to accomplish diverse types of goals. During the last fifty years, prizes proliferated in different formats and in many sectors as a widespread social process. Lately, prizes that reward the achievement of technological targets have increasingly attracted the attention of policy-makers, managers, philanthropists, and the media due to their potential to induce path-breaking innovations and accomplish related goals, such as economic recovery or the engagement of social groups to create innovation communities. Academic research, however, has barely investigated these prizes in spite of their long history, recent popularity, and notable potential.

This research has investigated technology prizes and the means by which they induce innovation or other effects related to technological development. The project was set out to engage four key aspects of prizes for which there have been significant knowledge gaps: the motivation of entrants, their R&D activities, their technology outputs, and the overall effect of prizes on innovation. Using an empirical, multiple case-study methodology and multiple types of data sources, this research investigated three cases of recent aerospace technology prizes: a main case study, the Google Lunar X Prize (GLXP) for robotic Moon exploration; and two pilot cases, the Ansari X Prize (AXP) for the first private reusable manned spacecraft and the Northrop Grumman Lunar Lander Challenge (NGLLC) for flights of reusable rocket-powered vehicles.

Prizes are an incentive and support mechanism for technological development and also an indirect mechanism to influence industry and public perceptions about S&T issues. Prizes can selectively target certain technologies, R&D performers and geographic areas, induce increasing levels of R&D activity and, under certain conditions, induce technological innovation as well. Prizes also leverage funding significantly due to their widespread, decentralized impact but involve higher programmatic risks than other more incentive traditional mechanisms such as R&D contracts and grants. Prizes can induce research, development, diffusion or commercialization of technologies, and diverse related effects. Prizes, however, are not always the best policy option and their successful implementation requires many parameters to be properly set.

Technology prizes offer varied incentives. *Prize incentives* are those created by the announcement and development of competitions and include the cash reward and other non-monetary benefits (e.g. reputation, visibility, opportunity to participate in technology development.) *Technology incentives* are those linked to the market value of the technologies involved in the competition. These incentives attract entrants with diverse characteristics. In modern technology prizes, non-monetary incentives, in particular, are more effective than other prize incentives to attract both unconventional entrants—individuals and organizations generally not involved with the prize technologies—and conventional entrants. The latter, however, generally use prizes as a means to produce technologies with market potential. The monetary reward is not as important as other prize incentives, yet it is still important to position the competition in the media and disseminate the idea of the prize.

Prizes can induce increasing R&D activities to target various technological goals, yet the evolution of prize competitions is generally difficult to anticipate. The overall organization of prize R&D activities depends on entrant-level factors such as entrants' goals, strategies, and resources, and is not directly influenced by prize design. The most remarkable characteristic of prize R&D activities is their interaction with fundraising efforts that, in some circumstances, may constrain the activities of entrants. Prizes can also selectively focus on the advancement of technologies at different levels of maturity, yet the quality of the technological outputs is difficult to anticipate and depends on entrant-level factors as well. The evidence shows that there is a weak relationship between type of entrants and prize technology outputs, and that stronger plausible explanations can be found in entrants' goals, the prize challenge definition, and state of the art of the prize technologies.

Finally, prizes can induce innovation over and above what would have occurred in a context in which only more traditional incentive mechanisms are implemented, yet their overall effect depends significantly on the characteristics of the prize entrants and the evolution of the context of the competition. The ability of prizes to induce innovation is larger when there are larger prize incentives, more significant technology gaps implicit in the prize challenge, and open-ended challenge definitions. Complementary incentives and support may be needed in some circumstances to make prizes work.

The lack of previous research and empirical evidence on prize cases required making important decisions in terms of methodologies, data gathering, and analysis for this project. Most importantly, there was the trade-off between the comprehensiveness of the study and the degree of detail and strength of insights provided by the evidence. The researcher decided to balance both depth and breath with the goal of explaining the entire innovation process induced by prizes and contributing empirically-grounded insights for theory building. In terms of data gathering, this research required creating new data gathering instruments and coordinating the collection of significant amounts of data from multiple sources. The analysis required an intense effort to be able to disentangle the effects induced by the prize from those related with the characteristics of entrants or the context of the competitions.

Further empirical research will substantiate our knowledge and prize theories. Future research should seek to develop better data sources and methods to quantify and qualify the magnitude of the collaborative effort that includes volunteers and partners. The approach followed by this project demonstrates that real-time data from ongoing competitions can be more insightful than historical accounts to study innovation in prizes. This is related with the notion that the most interesting effect of prizes is not necessarily the winning entry but also the activities and outputs of runner-ups, other entrants, and other entities that participate only indirectly. Though this research was not able to analyze the winning entry of the GLXP case, significant insights about the effect of the prize are obtained from the current technology outputs.

APPENDIX A

SUPPLEMENTARY TABLES

Table A.1: Ansari X-Prize entrants

#	Team name	Created	Entered the competition in[a]	Number of members	Location	Type of entrant[b]
1	Acceleration Engineering	N/A	1996	1	Bath, Michigan, USA	Unconventional (volunteer; created for the competition)
2	Advent Launch Services	N/A	1996	100	Houston, Texas, USA	Unconventional (created company after entering; mostly volunteers)
3	Aeronautics and Cosmonautics Romanian Association (ARCA)	1999	2002	8	Ramnicu Valcea, Romania	Unconventional (non-governmental organization created by students)
4	Armadillo Aerospace	2000	2002	6	Mesquite, Texas, USA	Unconventional (volunteer)
5	American Astronautics Corporation	N/A	2003	N/A	Oceanside, California, USA	Unconventional (company created for the competition)
6	Bristol Spaceplanes, Ltd	1991	1997	N/A	Bristol, England, UK	Unconventional (consulting company that re-directed its activities)
7	Canadian Arrow	N/A	2000	18	London, Ontario, Canada	Unconventional (volunteer team with no experience in aerospace industry)
8	The da Vinci Project	N/A	2000	14	Toronto, Ontario, Canada	Unconventional (volunteer)
9	Pablo de Leon & Associates	N/A	1997	6	Buenos Aires, Argentina	Unconventional (company created for the competition)
10	Discraft Corporation	N/A	1997	N/A	Portland, Oregon, USA	N/A
11	Flight Exploration	N/A	N/A	N/A	London, England, UK	N/A
12	Fundamental Technology Systems	N/A	2000	7	Orlando, Florida, USA	Unconventional (company that re-directed its activities)
13	HARC (High Altitute Research Corporation)	N/A	N/A	N/A	Huntsville, Alabama	N/A

Notes: a. Number of members is as of 2003 (otherwise indicated); b. Teams were classified into traditional and unconventional categories from the point of view of the similarity of their activities in relation to the prize challenge.

Source: different sources cited in the text and references and analysis of the author.

Table A.1: Ansari X-Prize entrants (Contd.)

#	Team name	Created	Entered the competition in[a]	Number of members	Location	Type of entrant[b]
14	IL Aerospace Technologies	N/A	2002	7	Zichron Ya'akov, Israel	Unconventional (company created for the competition)
15	Interorbital Systems	1996	2003	8	Mojave, California, USA	Traditional (aerospace company)
16	Kelly Space and Technology	N/A	N/A	N/A	San Bernadino, California, USA	Traditional (aerospace company)
17	Lone Star Space Access Corporation	N/A	N/A	N/A	Houston, Texas, USA	N/A
18	Micro-Space, Inc.	N/A	2003	6	Denver, Colorado, USA	Unconventional (company that re-directed its activities)
19	PanAero, Inc.	1997	1997	9	Fairfax, VA, USA	Unconventional (company created for the competition and other goals)
20	Pioneer Rocketplane, Inc. (now Rocketplane Kistler)	2001	N/A	N/A	Oklahoma City, OK	Traditional (company created in the spaceflight business)
21	Scaled Composites	N/A	2001	135 employees	Mojave, California, USA	Unconventional (aviation company)
22	Space Transport Corporation	2002	2003	N/A	N/A	Unconventional (company created for the competition)
23	Starchaser Industries	1998	1996	35	Cheshire, England, UK	Unconventional (company created for the competition)
24	Suborbital Corporation	N/A	N/A	N/A	Moscow, Russia	N/A
25	TGV Rockets	N/A	1999	6	Bethesda, Maryland, USA	Unconventional (company created for the competition)
26	Vanguard Spacecraft	N/A	2003	6	Bridgewater, Massachusetts, USA	Unconventional (company created for the competition)

Notes: a. Number of members is as of 2003 (otherwise indicated); b. Teams were classified into traditional and unconventional categories from the point of view of the similarity of their activities in relation to the prize challenge.

Source: different sources cited in the text and references and analysis of the author.

Table A.2: Data gathering summary for embedded cases in Ansari X Prize

Dim.	Categ.	Selected teams						
		Scaled Composites	**Armadillo Aerospace**	**Advent Launch Serv.**	**ARCA**	**Da Vinci Project**	**PanAero**	**Starchaser Industries**
Motiva tion	**Per-ceived incen-tives**	Sizable potential market; public exposure and reputation	Challenging goal, opportunity to learn	Prize money as potential funding for ongoing projects	Opportunity to achieve organizational goals	Self-fulfillment, personal goals	Potential reputation with investors	Company startup opportunity
	Per-ception of risk	Management of technology development risk	Risk of participation and trust in sponsor	N/A	N/A	N/A	N/A	Technology development risk and safety risk in technology testing

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.2: Data gathering summary for embedded cases in Ansari X Prize (Contd.)

Dim.	Categ.	Selected teams: Scaled Composites	Armadillo Aerospace	Advent Launch Serv.	ARCA	Da Vinci Project	PanAero	Starchaser Industries
R&D activities	**Design criteria**	Simplicity	Simplicity	Simplicity, cost, reliability	Simplicity, cost, reliability	Reliability, re-usability, and safety	Simplicity, cost, commercial-ization	Simplicity, easiness, safety, cost
	Design sources	Existing rocket technologies, lessons from past projects, and innovative designs	N/A	N/A	Existing technologies	Proposed unconventional air-based launch for existing rocket technologies	Proposed both use of existing technologies and more innovative approach	Existing technologies
	Tech-nology sources	In-house development, subcontracting, and off-the-shelf components	In-house manufacturing	Subcontracting	In-house manufacturing	In-house development, subcontracting, and off-the-shelf components	Off-the-shelf components	Off-the-shelf components

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.2: Data gathering summary for embedded cases in Ansari X Prize (Contd.)

Dim.	Categ.	Selected teams						
		Scaled Composites	**Armadillo Aerospace**	**Advent Launch Serv.**	**ARCA**	**Da Vinci Project**	**PanAero**	**Starchaser Industries**
R&D activities	**R&D organization**	Flat, entrepreneurial-culture company, fast prototypers org.; use of competition to source tech.	Small, entrepreneurial, fast prototypers organization	Traditional corporate organization (?)	N/A	Coordination of large pool of volunteers and consultants	Partnership of companies pursuing the space tourism market	N/A
	Re-sources-innovation effort	$30 million investment, significant funding from investors and significant pool of human resources	Fully self funded, small volunteer team, $1 million investment	Self funded team, significant number of volunteers	Small budget team	Large pool of volunteers and money from investors	Small, low budget team	Medium-size team
	Con-straints	Lack of experience with aerospace technologies	Lack of knowledge/skills for aerospace development	N/A	Lack of funding	Lack of funding	Lack of funding	Lack of funding

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.2: Data gathering summary for embedded cases in Ansari X Prize (Contd.)

Dim.	Categ.	Selected teams						
		Scaled Composites	**Armadillo Aerospace**	**Advent Launch Serv.**	**ARCA**	**Da Vinci Project**	**PanAero**	**Starchaser Industries**
Tech-nology output	**Tech-nology outputs**	Hybrid spacecraft design based on new configuration of existing technologies and new use of materials	Multiple tests of ongoing developments, introducing innovative concepts for operational features	Proposed new use of materials	First monopropellant composite materials fully reusable rocket engine	Tested scaled version of an alternative launch system	Conceptual design	Tested launch system
	Com-mercia-lization	Agreement to manufacture fleet of spacecrafts based on prize developments	Commercialization was not a goal	Commercialization was a target yet not achieved (?)	Commercialization was not a goal	Initial goal was not commercialization yet partnered with firm to enter the space tourism market	N/A	Pre-sold space flight to fund project

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.2: Data gathering summary for embedded cases in Ansari X Prize (Contd.)

Dim.	Categ.	Selected teams						
		Scaled Composites	**Armadillo Aerospace**	**Advent Launch Serv.**	**ARCA**	**Da Vinci Project**	**PanAero**	**Starchaser Industries**
Team's characteristics	**Type of team**	Unconventional (pre-existing aircraft design firm)	Unconventional (recently-created independent R&D team)	Unconventional (employee-owned corporation)	Unconventional (non-profit organization pursuing space activities, created by students)	Unconventional (independent R&D team that gathered many volunteers)	Unconventional (new aerospace engineering company)	Unconventional (space research foundation incorporated as a corporation to enter the competition)
	Experience / Background	Vast experience in innovative aircraft design	Diverse non-aerospace backgrounds	Extensive experience from NASA	Aeronautical engineering students	Aerospace support systems background	Extensive NASA experience	Aerospace experience
	Created	1982	2000	1996	1999	N/A	1997	1998
	Entered competition	2001	2002	1996	2002	2000	1997	1996
	Team members	135	6	12 (~100 volunteers)	8	14 (~500 volunteers)	9	35
	Location	Mojave, CA, USA	Mesquite, TX, USA	Houston, TX, USA	Ramnicu Valcea, Romania	Toronto, Canada	Fairfax, VA, USA	Cheshire, England

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.3: NGLLC entrants (2006-2009)

#	Team name	Created	Number of members[a]	Times partici-pated in NGLLC	Type of entrant[b]
1	Masten Space Systems	2004	5	3	Traditional (Rocketry and propulsion company)
2	Acuity Technologies	1992	5	3	Unconventional (develops, manufactures, and supports components and systems for unmanned vehicles, robotics, and automation; this is first rocketry project)
3	Micro-Space	Before 2004	3	2	Unconventional (company that re-directed its activities)
4	Armadillo Aerospace	2000	8	4	Unconventional (all volunteers until 2007?)
5	BonNova	N/A	6	3	Unconventional (company that re-directed activities and create a team specifically for the competition; it is a design firm focused on innovative invention and eng. for aerospace and all industries)
6	High Expectations Rocketry	N/A	4	1	Unconventional (group that re-directed its rocketry, engineering, and software activities to enter the competition)

Notes: a. Number of members is as of 2008 (or 2007 if data for 2008 were not found); b. Teams were classified into traditional and unconventional categories from the point of view of the similarity of their activities in relation to the prize challenge.

Source: different sources cited in the text and references and analysis of the author.

Table A.3: NGLLC entrants (2006-2009) (Contd.)

#	Team name	Created	Number of members[a]	Times partici-pated in NGLLC	Type of entrant[b]
7	Paragon Labs	2000	9	2	Unconventional (re-directed activities; now develops suborbital launch vehicles and VTOL technologies)
8	Speed Up	N/A	1	1	Unconventional (volunteer with support from a private company, Frontier Astronautics)
9	Phoenicia	N/A	5	1	Unconventional (volunteers; the team was created to compete for the prize)
10	Seraphim Works	N/A	N/A	1	N/A
11	TrueZer0	N/A	4	1	Unconventional (small company that re-direct its activities)
12	Unreasonable Rocket	N/A	4	3	Unconventional (volunteers)

Notes: a. Number of members is as of 2008 (or 2007 if data for 2008 were not found); b. Teams were classified into traditional and unconventional categories from the point of view of the similarity of their activities in relation to the prize challenge.

Source: different sources cited in the text and references and analysis of the author.

Table A.4: Data gathering summary for embedded cases in NGLLC

Dim.	Categ.	Selected teams				
		Armadillo Aerospace	**Masten Space Systems**	**BonNova**	**High Expectations Rocketry**	**Unreasonable Rocket**
Moti-vation	**Perceived incentives**	Prize money and reputation	Prize money and reputation	Challenging goal	Prize money and self-fulfillment	Recognition and self-fulfillment
	Percep-tion of risk	Risk of participation and trust in sponsor	Balance business risk	Personal commitment to risky competition	N/A	Probability assessment of risk of participation
R&D activi-ties	**Design criteria**	Simplicity, modularization, programmability	Reliability, low maintenance	Efficiency, low cost, and simplicity	Low cost	Low cost, simplicity
	Design sources	Existing technologies	Own know-how	Fiction and other industries as well	Lessons from other competitors	N/A
	Technol-ogy sources	In-house development and manufacturing	In-house manufacturing (preferred) and subcontracting	Off-the-shelf and in-house manufacturing		In-house manufacturing
	R&D or-ganiza-tion	Small, entrepreneurial, fast prototypers organization, learning-by-testing process	"Incremental test production" with software dev.-like iterations for modeling, analysis, and test	N/A	Relatively slow R&D process compared to other teams	Very simple R&D organization, learning-by-doing
	Resources -innova-tion effort	At least $3.5 million with support from wealthy leader and corporate sponsors	$2.5 million, own resources (?)	Small volunteer team	N/A	Very small, self-funded team
	Con-straints	Bureaucratic issues to obtain experimental permit (?)	N/A	Lack of time to be ready for competition day	Lack of time to be ready for competition day	N/A

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.4: Data gathering summary for embedded cases in NGLLC (Contd.)

Dim.	Categ.	Selected teams				
		Armadillo Aerospace	**Masten Space Systems**	**BonNova**	**High Expectations Rocketry**	**Unreasonable Rocket**
Tech-nol-ogy out-put	**Technol-ogy out-puts**	Reusability records, introduction of fast pace, modular development, sophisticated computer controls	New efficiency and speed standards	New patent-pending rocket engine components and standards in size and weight	N/A	Functional yet not fully performing technology
	Commer-cializa-tion	Commercialization goal may have influenced towards modular design	Designs targeted a specific market yet it was still not readily available for commercialization	Patent applications	N/A	Commercialization was not a goal but declared interest

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.4: Data gathering summary for embedded cases in NGLLC (Contd.)

Dim.	Categ.	Selected teams				
		Armadillo Aerospace	**Masten Space Systems**	**BonNova**	**High Expectations Rocketry**	**Unreasonable Rocket**
Team's characteristics	**Type of team**	Unconventional (independent small R&D team and later decided to join the prize)	Traditional (small startup, rocketry and propulsion company)	Unconventional (company that re-directed activities and create a team specifically for the competition)	Unconventional (group that re-directed its rocketry, engineering, and software activities to enter the competition)	Unconventional (small father and son team created to participate in this prize)
	Experience / Background	Gained specific engineering experience only after joining the AXP and several years of R&D	Only one member with aerospace experience and the rest with internet technology background	Leader participated in design of AXP's winning entry, yet very diverse backgrounds the rest	Diverse engineering experience and background	Engineering background yet no experience with rocket engines until competition
	Created	2000	2004	N/A	N/A	2007
	NGLLC participation	2006, 2007, 2008 (1st place level One), 2009 (2nd place level Two)	2006, 2007, 2009 (1st place level Two, 2nd place level One)	2007, 2008, 2009 (withdrawn)	2008	2007, 2008, 2009
	Team members	8	5	6	4	4
	Location	Mesquite, TX	Mojave, CA	Tarzana, CA	Moscow, ID	Solana Beach, CA

Notes: N/A indicates data not available. (?) indicates contradictory evidence.

Source: own analysis based on data described in the text.

Table A.5: GLXP entrants

Team name	Type of entity	Reported country in GLXP site	Created for GLXP	Entered GLXP	With-drawn
Odissey Moon	For-profit	Multi-natl./Isle of Man	No	Dec-07	
ARCA	Non-profit	Romania	No	Feb-08	
Chandah	Independent	USA	Yes	Feb-08	Jan-11
Astrobotic	For-profit	USA	Yes	Feb-08	
LUNARecon (Lunatrex)	For-profit	USA	No	Feb-08	Dec-09
SCSG	Independent	USA	Yes	Feb-08	Jun-08
Micro-space	For-profit	USA	No	Feb-08	Nov-10
Italia	N/A	Italia	Yes	Feb-08	
Frednet	Non-profit	Multi-national	Yes	Feb-08	
Quantum3	For-profit	USA	Yes	Feb-08	Feb-09
Selene	Independent	China, Germany	Yes	May-08	
Stellar	For-profit	USA	Yes	May-08	
Jurban	Part of larger org. (Non-profit)	USA	Yes	May-08	
Advaeros	For-profit	Multi-national	No	May-08	Nov-10
Independence X	Part of larger org. (Non-profit)	Malaysia	Yes	Sep-08	
Omega Envoy	Non-profit	USA	No	Oct-08	
Next Giant Leap	For-profit	USA	Yes	Dec-08	
Euroluna	Non-profit	Danish, Swiss, Italian	Yes	Dec-08	
Synergy Moon	N/A	Multi-national	Yes	Feb-09	
White Label Space	Non-profit	Multi-national	Yes	May-09	

Source: GLXP official website and questionnaire to GLXP teams.

Table A.5: GLXP teams (Contd.)

Team name	Type of entity	Reported country in GLXP site	Created for GLXP	Entered GLXP	With-drawn
Part Time Scientists	For-profit	Germany	Yes	Jun-09	
Selenokhod	For-profit	Russia	No	Sep-09	
C-Base Open Moon	Non-profit	Germany	Yes	Oct-09	
Barcelona Moon	For-profit	Spain	Yes	Apr-10	
Rocket City Space Pioneers	Part of larger org. (For-profit)	USA	Yes	Sep-10	
Moon Express	For-profit	USA	No	Oct-10	
Teams that entered after data gathering finished:					
Team Space IL	Non-profit	Israel	Yes	Jan-11	
Mystical Moon	N/A	Multi-national	Yes	Feb-11	
Team Puli	Independent	Hungary	Yes	Feb-11	
SpaceMETA team	Independent	Brazil	Yes	Feb-11	
Plan B	For-profit	Canada	No	Feb-11	
Penn State Lunar Lion Team	Non-profit	USA	Yes	Feb-11	
Angelicum	For-profit	Chile	No	Feb-11	
Team Indus	For-profit	India	Yes	Feb-11	
Team Phoenicia	For-profit	USA	No	Feb-11	

Source: GLXP official website and questionnaire to GLXP teams.

Table A.6: Additional reasons to participate in the GLXP given by questionnaire respondents

Type of motivation	Teams						Additional motivations given in questionnaire
	T6	T22	T26	T14	T13	T19	
Entertainment		●		●		◑	*"Have fun"; "Entertainment value"*
Opportunity to demonstrate technical capability	●						*"Proving capability of the open source community"*
Learning		●					*"Improve complex team management for other projects"*
Benefits to society		●			◑		*"Help spreading / raising interest within youth in science & technology"*
Opportunity to gather resources to pursue other types of projects		●					*"Help raising money from non space related companies for space projects"*
Religious			●				*"Opportunity to Showcase and Testify to the Lord Jesus Christ's Blessings, Provision and Assistance for His Followers who are involved in Innovative Technology!"*
Demonstrate technological concept				●			*"To validate a technical concept originally conceived in the mid-1960s"*
Opportunity to engage in aerospace development, hands-on experience					◑		*"Development research in the aerospace"*

References: ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: the table shows additional reasons to participate (i.e. not given as pre-defined options in questionnaire) as indicated by six teams.
Source: questionnaire applied to GLXP teams.

Table A.7: Top reasons to participate in the GLXP according to interviewed team members

Type of motivation	Importance of motivation for each team							Related team quotations (selected examples)
	T20	T13	T14	T11	T4	T6	T16	
Participation in challenging project	●			●			◑	*"…like doing something that is really difficult to do."*
Competition		●			◑			*"We are constantly stimulated by competition, which leads us to push our limits."*
Intrinsic motivation				◑	◑	◑		*"the team itself is a really proactive people. […] …people that are always doing something... […] …people that in anyway would do something."*
Commercialization of prize technologies	◔				◑		◑	*"We have great hopes though that we could grow customers on the commercial side…"*
Opportunity to gather resources to pursue <u>this type</u> of project				◑	◑			*"...only in the competition we can do this. If we do this in our spare time without the competition, for the companies has no value or it doesn't make sense for to spend money or energy or components."*
Professional reputation	●							*"…want to be recognized as a competitor, that's already very valuable to me."*
Opportunity to participate as an additional incentive to accomplish organizational goals		●						*"[The GLXP] fits with our own goals."*

References: ○ **Not important at all** ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: only reasons emphasized (positively or negatively) by interviewees are shown; when needed, the examples omit part of the text to maintain the anonymity of teams.

Source: interviews with GLXP teams.

Table A.7: Top reasons to participate in the GLXP according to interviewed team members (Contd.)

Type of motivation	Importance of motivation for each team							Related team quotations (selected examples)
	T20	T13	T14	T11	T4	T6	T16	
Demonstrate technological concept			●					*"…looked at the Google Lunar X Prize as a perfect way to demonstrate the […] concept"*
Demonstrate technological leadership					●			*"When you lead a team, the world expects you to win."*
Opportunity to engage in aerospace development, hands-on experience							●	*"…wanted to be a part of something real and be able to make something different."*
Learning	◔						◑	*"…for me it was mostly learning everything."*
Commercialization of expertise				◑				*"One thing that we thought about later on was that we could, if someone is interested, offering them our collaborative work."*
Networking						◑		*"The benefits that I have is that I'm getting in contact with a lot of interesting people."*
Prize money	○		○	◔	○	○	○	*"…we are not driven by the prize"*

References: ○ **Not important at all** ◔ **Somewhat important** ◑ **Important** ● **Very important**

Note: only reasons emphasized (positively or negatively) by interviewees are shown; when needed, the examples omit part of the text to maintain the anonymity of teams.

Source: interviews with GLXP teams.

Table A.8: Additional design criteria in GLXP projects as reported by interviewees

Design Criteria	Teams							Description
	T20	T13	T14	T11	T4	T6	T16	
Reusability	X				X		X	Design useful for multiple missions.
Optimiza-tion	X			X			X	Efficiency / Performance vs. Mission Accomplishment balance.
Perfor-mance				X	X		X	Meet requirements and minimize failure and maintenance among others.
Minimum tech. dev. effort	X				X			*"…do less engineering and buy cheaper components."* (T4, 2010)
"Simple and smart"	X			X				Creative, simple solutions that work efficiently; *"…getting us from A to B as fast as possible."* (T20, 2010)
Minimalism					X			Minimum capabilities required to accomplish mission.
Robustness					X			System that resists many mission days.
Scalability							X	*"…going to be useful in the future when we want to pursue larger missions…"* (T16, 2010)

Note: the table shows additional design criteria mentioned in interviews yet not offered as options in questionnaire.

Source: interviews to GLXP team members.

Table A.9: Coding summary for GLXP team interviews

Dimension: Motivation **Category: Perceived incentives**

Team	**Coded data**
T10	Opportunity to engage in a unique (international, competitive, dynamic,) challenging project taking advantage of strong background and be recognized for that; prize money is not very important; team seek to learn and eventually may try to earn money from commercialization. of technology. or expertise.
T13	Opportunity to engage in a unique, challenging project as an additional incentive to achieve related organizational goals; similar experience with prizes help decision to enter.
T14	Use the opportunity to demonstrate capabilities of proprietary tech. for landers (pending patents filed when entering the competition;) prize money is considered to cover expenses. Withdrawn after considering own goals not aligned with sponsor's.
T11	Overall, prize money is not an incentive; the challenging engineering goal is the most attractive; the competition offers the elements (reputation before 3rd parties, focus, competitive environment) to make this type of project doable; intrinsic motivation is strong, proactive team members. Seek to win and commercialize proven expertise after that. Learning is a plus yet not a goal.
T4	Seek to demonstrate technological leadership and build commercial enterprise at the same time; perception of potentially sizable new markets to exploit; the competition offers the elements (reputation before 3rd parties, focus, competitive environment) to make this type of project doable. Winning the competition is a key component in the team's strategy.
T6	Opportunity to participate in an event linked to potential commercial opportunities that can be pursued using publicity, personal reputation, or networks given by participation.
T16	Opportunity to engage with space tech. dev. and gain professional reputation and experience; the team analyzes potential markets for the technologies they develop. Challenging engineering goal also motivates.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: Motivation **Category: Perceived risk**

Team	**Coded data**
T10	Technical risks assessed; seeks to diversify mission risks by engaging sponsors and partners; project risk is managed by allocating most complex tasks to most trusted partners.
T13	Deviate from organizational goals of higher priority.
T14	N/A
T11	Technical risks assessed; seeks to diversify mission risks by engaging sponsors and partners.
T4	Technical risks assessed and managed; new tech. configurations aimed at mitigating risk in mission's critical points.
T6	There are no risks in participation. Technical and programmatic risks not considered yet.
T16	Technical risks assessed and managed using NASA-like procedures; seeks to diversify mission risks by engaging sponsors and partners.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities   Category: Design criteria

Team	Coded data
T10	Min. tech. dev. effort; cheap and quick; simple and smart designs reduce no. of components; std. proc. for rocket motor design; "not fancy things, just something that works;" some efficiency and prfm. loss tolerated; start from scratch to design a custom sys. that can be used for other missions; commercial. does not affect design; lack of access to some tech. (e.g. to enable night survival) forces certain mission design.
T13	N/A
T14	Core tech. is based on technologies developed since the 1960s by the founders; seek to demonstrate use of spinning lander concept.
T11	Simple and smart are the key criteria; simplicity of the mission to accomplish allows significant simplification of tech. dev., even with small budget (the latter considered to be equivalent to prize money) and time constraint; electronics redundancy to assure performance.
T4	Less engineering dev. and increasing use of existing cheaper components influences design characteristics and evolution; creative solutions are used otherwise; minimalist, customized design constrained by launch capabilities; robustness; budget expands to match required design rather to adjust to prize money; seek performance for continuing activity after prize.
T6	Cheap, low tech., new approaches brought from non-aerospace backgrounds.
T16	High performance and optimized designs to match slim margins of mass and budget (the latter considered to be equivalent to the prize money); compatibility with commercially available components; low cost; lander with simplified, conventional design that reduces moving parts and increases reliability; designs with commercial orientation (e.g. scalability to allow use in future missions.)

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities   Category: Design sources

Team	**Coded data**
T10	Significant, multidisciplinary knowledge and experience available from previous work; research into previous missions; external expert advice (wide network available); available yet old space agency's doc. (NASA) for rocket design; other ref. material available in-house or published online or provided by companies; designs by other teams are not an important source; inputs from members with comm. background.
T13	Developed own tech. based on Ansari X Prize experience and new design based on organizational needs.
T14	Significant knowledge and experience available from previous work; for main subsystems (power, telemetry, propulsion) using own designs based on previous experience (speeds up things considerably); new landing radar under preliminary design.
T11	Extensive network of partners and manuf.; feedback from project presentations at diff. venues; multi-disciplinary work groups with non-aerospace participants; own creativity applied to existing tech. solutions and mission boundaries (i.e. prize req.); feedback from external experts (aerospace agency); feedback from team's website; doc. from space agencies (NASA); “there is not much to learn from other teams”
T4	Significant insights from trial and error; previous aerospace and robotics experience; creative solutions to problems learnt from agency’s missions; collaborations with other academic departments; requirements resulting from sourcing existing technologies.
T6	Different insights contributed by non-aerospace team members. (team have not progressed significantly in terms of outputs)
T16	Previous projects by agencies; commercially readily available components; significant communication with prize teams from other competitions (NGLLC); industry companies; external experts; designs by other teams are not an important source.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities   Category: Technology sources

Team	**Coded data**
T10	Use of off-the-shelf and modified components and manuf. Partners, incl. launcher and break stage; in-house lander's descent motor based on standard designs; rest of lander built with support of main corp. partner; rover built by univ. partner; other local firms build models and mockups; electronic controllers and actuators sourced from firms abroad; software, electr. sourced from foreign partners; commercial, non-aerospace electronic components; test services for rocket motors available from foreign lab; natl. partner provides structural elements in special mat.; comm. subsystem by foreign univ. partner; negotiation and sponsorship opp. used to source tech.
T13	Launcher and transfer vehicle developed in-house (uses tech. already developed for Ansari X Prize); seeks propulsion systems and avionics from third-parties.
T14	Launcher and upper stage are existing, proven commercial solutions (SpaceX and ATK). (team didn't make any additional progress before withdrawn)
T11	Extensive network of partners provides tech. for each subsystem; launcher is available commercial solution; lander and rover assembled with support of univ. partners and sourced parts by partners (in-house manufacturing capabilities are not required for the chosen organizational structure).
T4	Partners provide technologies for various subsystems; "friend companies" also contribute (anywhere between 5-20% of costs may be covered with this type of contributions); launcher and upper stages from existing solutions (SpaceX and ATK); rest of subsystems is customized and built in-house or by other companies; lander's rocket is surplus part from NASA's program; commercially available, non-aerospace electronic components.
T6	Seeks to source existing commercially available technologies for all subsystems except the lander; use design equipment from universities.
T16	Launcher is commercially available solution (SpaceX); upper stage will be built using existing standard commercially available rocket motor; extensive use of compatible off-the-shelf components (in-house manufacturing capabilities are limited) and equipment; rover and lander assembled with support of univ. partners.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities   Category: Organization of R&D

Team	Coded data
T10	Prize team with space agency-like elements in internal organization; flexible organizational approach, no hierarchies, non-profit coordination and execution by network of corporate partners; international division of work with formal comm.; readily available access to pro. network and significant knowledge from previous projects; direct engagement resulting from smaller multi-disciplinary teams (which may in turn slow down devs.); R&D approach strongly dependent on external funding; there is specialization in some subsystems but also members working on multiple aspects (e.g. lander dev.); standard dev. procedures; own design and outsourced manuf.; test facilities provided by local and foreign partners; "no one person understands the whole system."
T13	Trial and error approach to R&D. Centralized, in-house production. Some subsystems developed by partners.
T14	Quick turnaround based on subcontracting production and launch. Delegation of production to partners.
T11	International division of work, sub-teams; fresh, multi-disciplinary non-aerospace approach to problem-solving; low cost dev. structure (thanks to formal and informal connections with univ. facilities and equipment); agile organization yet top-bottom approach allows delegation, facilitates control by core team, and speed ups dev.; direct comm. channels and optimized workflow allow internal idea sourcing without bureaucracy; rapid prototyping and testing; manuf. of components and subsystems sourced from wide network of partners; use of software tools to coordinate virtual meetings and work groups; open sharing of information; org. structure evolves significantly to maintain flexibility as the team grows (strong focus on org. matters.)
T4	Flat organization with strong academic components; leading univ. is main R&D center, multi-disciplinary inter-departmental collaborations; sub-groups; decentralized R&D is also undertaken by network of "friend companies"; forced, very near term, complete conceptual system design that is optimized in further dev.; "craft culture": focus on trial and error, iterative prototyping and testing cycles evolve design ("real success comes from failing fast and failing often"), simulation only supports that process; creative problem-solving instances result from lack of resources to acquire commercially available technologies or need to adapt sourced components; emphasis on informal, face to face comm.
T6	Informal and decentralized organization; "The groups are the places where the life is taking place. [...] They work from their homes."; no access to network of univ. or corporate partners; weak organization of communication and work flows.
T16	Flat, cost effective organization with decentralized sub-groups; small core team with knowledge about all aspects (this speeds up dev. and gets to accomplishments); local division of dev. work between univ. partners but members engaged in multiple tasks (which requires combined skills); internal telecomm. to coordinate work, few face to face meetings (this may cause mistakes); flat organization with academic components; access to network of corporate partners and former prize teams; access to specialized test and assembly facilities; rapid prototyping and analysis based on actual test results (and not simulation).

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities   Category: R&D effort

Team	Coded data
T10	$50 million mission; no money raised yet; design phase at the moment; volunteer team effort; lack of funding does not affect design criteria but forces internal re-organization of work (towards fundraising) and plans to rely upon partners to develop and test; need to speed up forces reduction of engineering effort which is planned to be sourced from partners; significant organizational and co-ordination effort; GLXP is the only project of the team.
T13	Significant engineering effort in all phases of the mission; testing of unconventional solutions; GLXP is one of the projects of the team.
T14	$25 million mission; volunteer effort with limited, out-of-pocket spending before withdrawn (6-7 months of participation with own funding); manufacturing and assembly planned to be delegated to partner company; some planned fund raising to coordinate effort and pay for certain equipment; GLXP is the only project of the team.
T11	Significant work performed by students, part at univ. facilities; significant work on other aspects of participation (fundraising, internal organization, public relations, feedback gathering); full-time fundraising and PR effort; part-time engineering work with few exceptions; sponsorship and partnership contributions applied to dev. effort exclusively; presentations help to gather new human resources; quick prototyping turnaround; short-cycle iterative design, modeling, and testing; GLXP is the only project of the team.
T4	$90 million mission; significant full-time work on fundraising and commercialization of prize technologies and related services; significant human, knowledge resources and facilities available from univ.; most significant dev. work on spacecraft landing and rover; GLXP is one of the projects of the team.
T6	Small effort not backed by any company or univ.; effort is mostly done to find partners and gather other resources; model devs. with promotional purposes; GLXP is the only project of the team.
T16	<$30 million mission; design phase at the moment; significant volunteer effort; important test facilities available to the team, yet not all the necessary manufacturing equipment; most significant dev. effort in on lander and communications; GLXP is the only project of the team.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: R&D activities **Category: Constraints**

Team	**Coded data**
T10	Need to speed up forces to combine tasks (e.g. prepare working models that serve multiple purposes) and reduce to only those strictly necessary; lack of access to certain componentry forces changes in mission approach and systems design; all possible dev. work done internally until funding is raised.
T13	N/A
T14	Requirements of rules for high-definition video system conflicted with own developments.
T11	Rules were a constraint at the beginning, now are generally conducive rather than restrictive, in spite of having some rules with difficult interpretation; some rules affect systems design and mission approach; prize deadline is not a concern.
T4	Funding is the big challenge.
T6	Lack of access to networks in the aerospace sector; funding; rules are not conducive with regard to some aspects of organization.
T16	Funding is main potential constraint; prize deadline is not a problem with full funding, but time advantage of other teams is a concern; rules are "reasonable"; students-team profile makes difficult to get partners.

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: Technology outputs **Category: Technology outputs**

Team	Coded data
T10	Design phase; no testing so far; no significant innovation achieved; new dev. in terms of rocket engine expected to be commercialized; seeks to develop new system and platform for planetary exploration with partners.
T13	Only GLXP team that successfully tested launcher, telemetry, control and command flight systems, and data transmission systems.
T14	Team withdrew before actual dev.; designs were in progress but main conceptual dev. was already proven in multiple missions before entering the competition. Key technologies are patented or patent-pending.
T11	Design and testing of rover, lander, and communications system; multiple new devs. of subsystems for different parts of the mission (e.g. transfer, communications, rover, and organization.) Designs do not significantly affected by potential commercialization of services (only some payload space reserved;) IP on new technologies and processes or rights on scientific data are exchanged with partners only when need to source technologies or funding.
T4	Development and testing phases; contract for launcher already made; “60% is common denominator and 40% is always unique and special”; some devs. are forced by the rules (sometimes reducing efficiency of the system); rover design and testing; lander design. Technologies are licensed from main R&D center at univ.
T6	Very early phase of the project; no significant tech. outputs. Commercialization of technologies is not main interest; sub-groups would retain IP of devs.; in early stage, seeks funding from merchandising.
T16	Initial phase of dev.; camera under design; suspension system test and built, lander prototypes being built, rover under dev. and testing. Scalable configuration to offer different payload size ranges in eventual commercialization. In general, seeks to develop products and process that can be transferred to commercial fabrication; interested in patenting technologies, yet significant devs. will be shared; some rights are given away to fund project (NASA and other contracts.)

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: Team characteristics **Category: Experience/background**

Team	**Coded data**
T10	Core team with extensive space agency and aerospace industry (large company) experience; participated in innovative aerospace projects for tech. demonstration; collaborators with amateur rocketry experience. [Conventional]
T13	Team created by students to promote space activities; past prize experience. [Unconventional]
T14	Core team with extensive aerospace industry experience in large companies. [Conventional]
T11	Core team with mostly IT/software and diverse science backgrounds; significant proportion of students; key members with business and space agency experience. [Unconventional]
T4	Multi-disciplinary engineering backgrounds and business and prize experience; previous (own) work on designing lunar projects. [Unconventional]
T6	Diverse backgrounds (including Physics, IT, Design, and Arts) and small business experience. [Unconventional]
T16	Core team comprises mostly aerospace students. [Unconventional]

Source: own analysis.

Table A.9: Coding summary for GLXP team interviews (Contd.)

Dimension: Team characteristics **Category: Strategy/goals**

Team	Coded data
T10	Engineering challenge approach, not business approach to the prize; seeks to create sponsorship opportunity, branding and advertising platform; network of tech. partners may eventually commercialize devs.; collaborators may continue further devs. on subsystems (lander rocket motor) to commercialize as well; commercial payload probable but not considered yet. Core team seeks professional reputation/publicity. Other workgroups seek commercialization.
T13	Team established to increase the level of aerospace activities in its country and the desire to promote innovative research projects. No intention to commercialize technologies.
T14	The main goal is demonstrating that a proprietary technological concept works.
T11	The main goal is participation and technical accomplishment, focus on winning the competition; inspiring students and the general public; some members seek to create new enterprise based on prize technologies. Seeks to create sponsorship opportunity; seeks to eventually commercialize expertise, consulting services.
T4	Demonstrate technological leadership and create space commercial enterprise. Seeks to sell payload capability to finance dev. to reduce need of investors; target future NASA contracts and diverse commercial customers; when mission accomplished, will sell services related to Moon presence.
T6	Core team seeks professional reputation/publicity/networking; some workgroups with focus on winning the competition.
T16	Learning, further space activities beyond the prize; commercialization is evaluated. Commercial opportunities arising; may change to a for-profit form in the future to commercialize.

Source: own analysis.

Table A.10: Overall assessment of selected historic prizes

	Longitude Prize	Orteig Prize	Kremer Prize
Year	1714-1765	1919-1927	1959-1977
Type of prize	Technology-based achievement, unknown solution		
Sponsor	British Parliament	Raymond Orteig (businessman)	Henry Kremer (industrialist)
Purpose	Develop a new method to measure longitude at sea	First transatlantic flight	First successful controlled human-powered flight
Cash purse[a]	Up to £ 20,000	$25,000	About $100,000
Challenge was about...	Developing a new method	Accomplishing a feat that required the right balance of technology/skills	Complete a human-powered flight within timeframe in designated course (this certainly demanded building a new type of aircraft at that time)
Context	Significant industry need; catastrophic accidents at sea due to lack of proper instruments	Ten years of aviation rivalry and competitions; increasing interest in aviation	Ultra lightweight materials enabled new techniques of construction
Entrants	Independent inventors	Recognized and independent aviators	Independent inventors
Induced activity	Creativity, precision, invention	Flight skills, technology adaptation, courage	Flight skills, engineering effort
Technology output	Unsuccessful development of very diverse methods, diverse technologies. **Winning entry**: New precision mechanisms (e.g. circular balances, bi-metallic strips, caged roller bearings)	Multiple attempts with diverse configurations of current-day technologies. **Winning entry**: current-day, adapted aircraft (i.e. solo flight, lighter plane, no security equipment)	Multiple attempts with diverse configurations. **Winning entry**: Use of ultra-lightweight materials
Overall effect	Introduction of a novel method (chronometer) to measure longitude	Demonstration of existing capabilities to accomplish the feat	New approach to accomplish the feat (i.e. ultra-light plane with large wing area at very slow speeds)

Note: a. historic value.
Source: own analysis and literature cited in text.

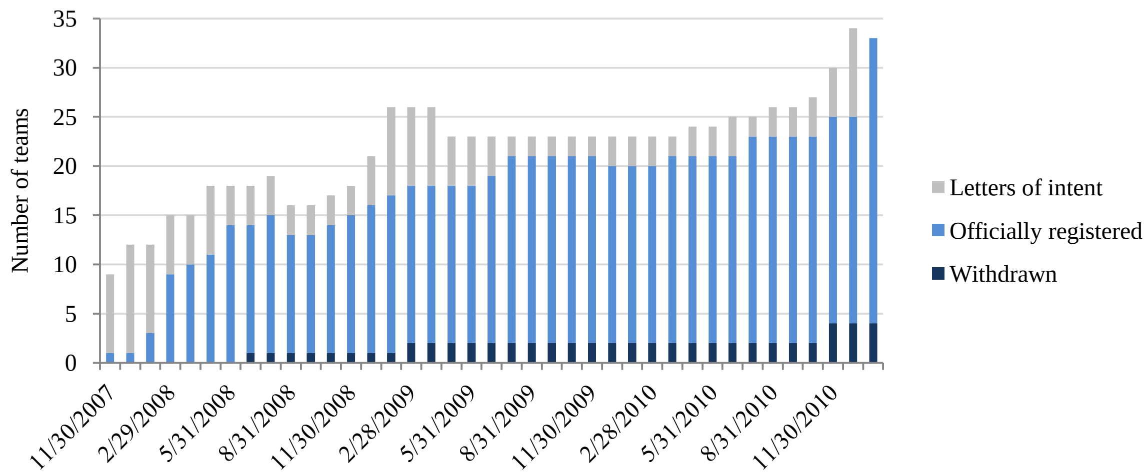
Table A.11: Overall assessment of selected modern prizes

	Ansari X Prize	DARPA Challenges	NGLLC	GLXP
Year	1996-2004	2004, 2005, 2007	2006-2009	2007-present
Type of prize	Prizes for technology demonstration, unknown solution	Prizes for technology demonstration, well-defined problems with existing solutions		Technology-based achievement, well-defined problem with existing solutions
Sponsor (organizer)	Ansari Family (XPF)	DARPA	NASA, Northrop Grumman (XPF)	Google (XPF)
Purpose	Demonstrate private space industry capabilities	Development of autonomous road vehicles	Comm. development of VTOL vehicles	Commercial development of lunar technologies
Cash purse	$10 million	Up to $3.5 million	Up to $2 million	Up to $30 million
Challenge was about...	Building a vehicle and accomplishing a feat under certain operational conditions	Building a vehicle and demonstrating technological efficiency in a designated course	Building a vehicle and demonstrating technological efficiency	Accomplishing a feat under certain schedule/funding conditions
Context	Some evidence of potential of space tourism market	Congress request for tech. dev. for DoD that is also related with potential civil use as well	Emerging new space sector and new NASA programs for tech. dev.	New players in aerospace, new race between countries and trend towards commercialization
Entrants	New and existing companies, independent teams	Universities, companies	Independent teams	New and existing companies, independent teams, universities, non-profit orgs.
Induced activity	Engineering effort, new tech. dev.	Engineering effort, improvements	Engineering effort, improvements	Engineering, tech. implementation /business development
Technology Output	Varied conceptual approaches **Winning entry**: New application of materials, new configuration/conceptual approach	Diverse vehicles, diff. range of autonomous capabilities **Winning entry**: New software and configurations on generally existing sensors and LIDAR systems	Converging, more efficient VTOL technologies **Winning entry**: New controls and rocket engine components	Generally, existing launch technologies and mostly existing components with new business development approaches; some novel concepts under development.
Overall effect	Demonstration of existing industry capabilities to accomplish the feat	Advanced navigation technologies that enabled first time autonomous vehicle operation in traffic	Advancement of VTOL technologies for better performance	Commercial implementation of existing technologies?

Source: own analysis and literature cited in text.

APPENDIX B

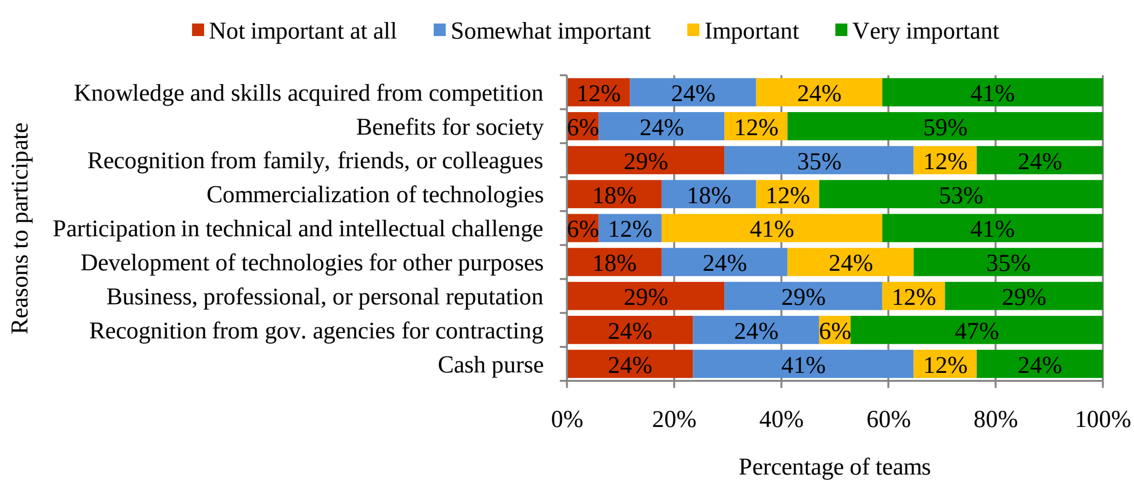
SUPPLEMENTARY FIGURES



Note: the chart shows the cumulative number of teams since the prize announcement.

Source: X Prize Foundation.

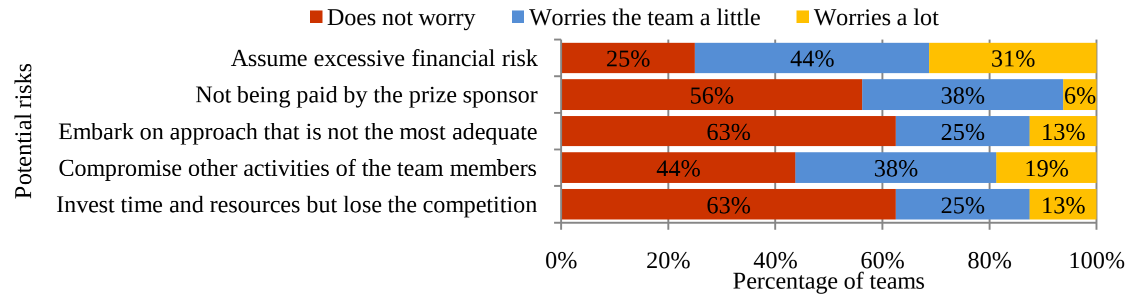
Figure B.1: Number of official GLXP teams, letters of intent to compete, and withdrawn teams (2007-present)



Note: N=17 cases; questionnaire's labels indicating motivations are shorten in the figure to facilitate presentation of data.

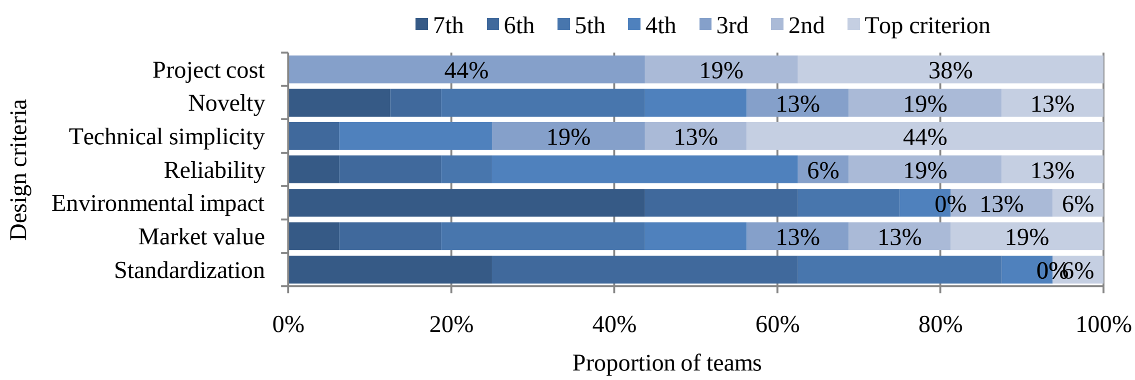
Source: questionnaire applied to GLXP teams.

Figure B.2: Reasons to participate in the GLXP



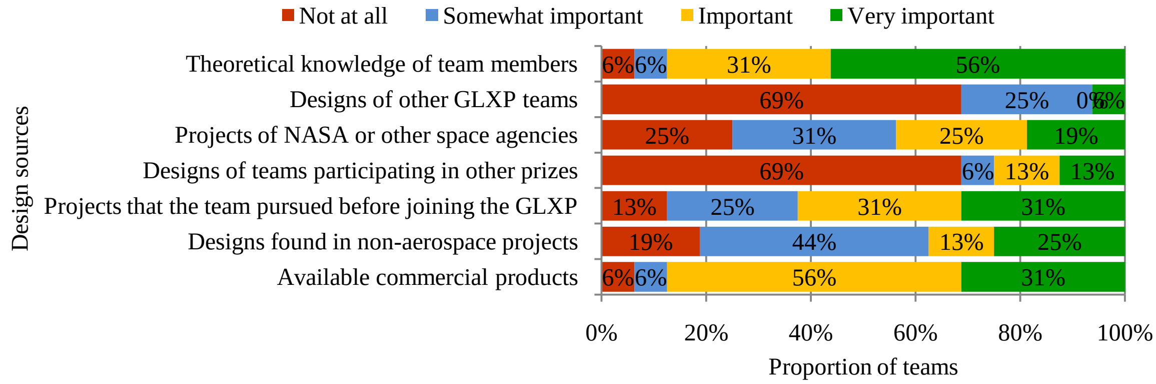
Note: N=16 cases; assessment of risks made by questionnaire respondents in relation to given options.
Source: questionnaire applied to GLXP teams.

Figure B.3: Risks perceived from participation in the GLXP



Note: N=16 cases.
Source: questionnaire applied to GLXP teams.

Figure B.4: Design criteria used by GLXP teams



Note: N=16 cases.

Source: questionnaire applied to GLXP teams.

Figure B.5: Sources of inspiration for design in the GLXP

APPENDIX C

QUESTIONNAIRE APPLIED TO GLXP TEAMS

How do prizes induce innovation?
Learning from aerospace competitions

This questionnaire is part of a research project that investigates technology prizes and the means by which they induce innovation. While there is no direct benefit to you, it is anticipated that the project will contribute significantly to our understanding of prizes to inform the design of more efficient technology and innovation policies and public and private prizes. The questionnaire should take about 30 minutes. We will also be contacting some of the participants that fill out the questionnaire and ask if they would like to be in a follow up interview. There is no obligation to be in the follow up interview. There are no risks to being in this study. The data collected in this study will be kept private to the extent allowed by law. The information provided by you will be kept in a secured, limited access location. Your participation in this study is voluntary. You do not have to be in this study if you don't want to be. You have the right to change your mind and leave the study at any time without giving any reason and without penalty. If you have any questions about the study, you may contact the Principal Investigator, Dr. Philip Shapira at +1 (404) 894-6111 (email: pshapira@gatech.edu). If you have any questions about your rights in participating in this research study, you may contact Ms. Melanie Clark of the Office of Research Compliance, Georgia Institute of Technology, Atlanta, GA 30318 USA, Telephone: +1 (404) 894-6942. We appreciate your cooperation in making this project a success.

- Questionnaire questions refer to your team and its participation in the Google Lunar X-Prize (GLXP).
- However, this project does not look at any prize competitor in particular but at prizes in general.
- Neither this research project nor any of its researchers is affiliated with any GLXP team.
- The questionnaire should be responded to by your team's GLXP project leader.
- Part of the data collected through this questionnaire (yet not the complete set of responses) may be published or referred to in workshops, conferences, or scientific publications before the GLXP competition deadline (December 31, 2012). If that is the case, this project will notify teams that returned completed questionnaires and share such publications or references with them.
- More information and updates about this project can be found at www.prizeresearch.org

Please return this questionnaire in the enclosed postage-paid envelope within 15 days to:
Luciano Kay
School of Public Policy
Georgia Institute of Technology
201 DM Smith Building
685 Cherry Street
Atlanta, GA 30332 - 0345
USA

Please, use the included International Reply Coupons to pay for postage from non-US countries.

Questions about this questionnaire?
Telephone: +1 (404) 345-0689
e-mail: luciano.kay@gatech.edu

THANK YOU FOR YOUR HELP

THE TEAM

1. When did the team effectively start working on the GLXP project?

Month _________ Year _________

2. Was your team exclusively created to participate in the GLXP?

☐ Yes → *Please skip to Question 4*

☐ No

3. How many years of work experience does your team, *as a group*, have with aerospace technologies?

_________ years

4. Which of the following organizational types better describes your team?

☐ For-profit organization (e.g. company)

☐ Non-profit organization (e.g. foundation)

☐ Independent, informally organized team (e.g. group of colleagues)

☐ Team part of a larger organization (e.g. part of a university, company, or similar) (please, specify which organization): ____

5. Where is the main facility or office that the team uses to work on or coordinate the GLXP project?

City ______________________________ Country _____________________

PRIZE PARTICIPATION

6. How important are the following reasons for your team to participate in the GLXP? If your team has other reasons, please specify them in the blank space provided after option i).

Reasons to participate in the GLXP	Not important at all	Somewhat important	Important	Very important
a. Knowledge and skills acquired from practice and competition	☐	☐	☐	☐
b. Benefits that technology development may bring for society	☐	☐	☐	☐
c. Recognition from family, friends, or colleagues	☐	☐	☐	☐
d. Commercialization of technologies developed for the GLXP prize	☐	☐	☐	☐
e. Participation in a real technical and intellectual challenge	☐	☐	☐	☐
f. Development of technologies for other activities of the team or its members	☐	☐	☐	☐
g. Business, professional, or personal reputation	☐	☐	☐	☐
h. Recognition from NASA or other gov. agencies for potential future contracts	☐	☐	☐	☐
i. Cash purse	☐	☐	☐	☐
j. Other (please specify):	☐	☐	☐	☐
k. Other (please specify):	☐	☐	☐	☐

7. To what extent these potential risks of participating in prizes worry the team?

Potential risks of participating in prizes	Does not worry the team	Worries the team a little	Worries the team a lot
a. Assume excessive financial risk	☐	☐	☐
b. Not being paid by the prize sponsor in spite of first achieving the prize target	☐	☐	☐
c. Embark on a technological approach that is not the most adequate for the competition	☐	☐	☐
d. Compromise other personal or professional activities of the team members	☐	☐	☐
e. Invest time and resources but lose the competition anyway	☐	☐	☐

8. To what extent the following factors constrain or challenge your team in the GLXP competition?

Factors faced in the GLXP	Constrain or challenge your team?		
	Not at all	*To some extent*	*To great extent*
a. Limited resources to develop or acquire technologies	☐	☐	☐
b. Limited time to achieve the prize target	☐	☐	☐
c. Unclear rules or technical requirements for the prize target	☐	☐	☐
d. Time advantage that first-to-enter teams have	☐	☐	☐
e. Competitive strategies of other teams	☐	☐	☐
f. Inadequate technical knowledge or experience in team members	☐	☐	☐

SYSTEMS DESIGN AND DEVELOPMENT

9. For the technologies that the team is developing for the GLXP, please indicate the priority given to each of the following design criteria. Please, rank on a scale from 1 to 7: highest priority=1, lowest priority=7. *Please do not give the same ranking to more than one criterion.*

____ Project cost (seek to reduce project cost as much as possible)

____ Novelty (seek characteristics not currently found in industry)

____ Technical simplicity (seek to reduce the number of parts or mechanisms)

____ Reliability (seek redundancy or failure prevention)

____ Environmental impact (reduce environmental impact as much as possible)

____ Market value (seek to increase the potential commercial value)

____ Standardization (seek compliance with industry standards)

10. How important are these sources of inspiration for the designs that the team pursues for the GLXP project?

Sources of inspiration	Not important at all	Somewhat important	Important	Very important
a. Theoretical knowledge that team members already had	☐	☐	☐	☐
b. Designs of other GLXP teams	☐	☐	☐	☐
c. Projects of NASA or other space agencies	☐	☐	☐	☐
d. Designs of teams participating in other prizes	☐	☐	☐	☐
e. Projects that the team or its members pursued before joining the GLXP	☐	☐	☐	☐
f. Designs found in non-aerospace projects	☐	☐	☐	☐
g. Available commercial products	☐	☐	☐	☐

11. The prize challenge can be achieved by manufacturing completely new systems and components ("from scratch") and/or acquiring, adapting, or copying existing technologies.

Overall, how new are the technologies that your team employs (or plan to employ) for the GLXP?

☐ Completely new

☐ Somewhat new

☐ Not new at all

12. In particular, how new are the technologies that your team employs (or plan to employ) in each of these subsystems for the GLXP project?

Subsystems for the GLXP project	How new are your team's technologies? *Not new at all*	*Somewhat new*	*Completely new*
a. Earth-to-Moon transfer vehicle	☐	☐	☐
b. Lunar lander	☐	☐	☐
c. Lunar rover	☐	☐	☐
d. Photo/video system	☐	☐	☐
e. Control/navigation hardware and software	☐	☐	☐
f. Communications between Moon and Earth	☐	☐	☐
g. Ground support system	☐	☐	☐

*If you responded **Completely new** to all options, please skip to Question 14*

13. What are the reasons to use existing technologies in the GLXP project? Please, rank on a scale from 1 to 4: most important=1, least important=4. *Please do not give the same ranking to more than one reason.*

____ Reduce project costs

____ Speed up technology development

____ Facilitate commercialization of technological developments

____ Increase technology reliability in the project

14. Please, indicate what percentage of your team's complete GLXP project systems is planned to be contracted to others or "commercial off the shelf":

Technology source	0%	Less than 20%	Between 20% and 50%	More than 50%
a. Contracted to others	☐	☐	☐	☐
b. "Commercial off-the-shelf"	☐	☐	☐	☐

15. Please, indicate whether the team regularly exchanges information or points of view on its project with the following people / organizations:

People / organizations	Exchange information? *Yes*	*No*
a. Providers or contractors	☐	☐
b. Family and friends	☐	☐
c. Academic researchers	☐	☐
d. Consultants	☐	☐
e. Members of other teams in the GLXP	☐	☐
f. Colleagues with experience in prize competitions	☐	☐

*If you respond **No** to all options, please skip to Question 17*

16. What are the main topics of the information exchange mentioned in the previous question? Please, rank on a scale from 1 to 4: most important=1, least important=4. *Please do not give the same ranking to more than one topic.*

____ Solutions to technical problems

____ Commercial opportunities

____ Overall strategies to win the prize

____ Team contribution to industry or society

17. Please, indicate which of the following better describes how the team has organized its activities for the GLXP project since joining the competition. *Please tick only one option.*

☐ Team members are organized as only one work group that regularly meets in the same location to work on the project

☐ Team members are organized into different work groups and regularly meet in the same location to work on the project

☐ Team members are organized into different work groups that work on the project from different locations

☐ Team members work remotely and only meet in the same place for some specific tasks

18. To what extent the team has responded (or planned to respond) with these actions when facing *a lack of funding* or *the need to speed up technology development* in the GLXP competition?

Actions	...when facing a lack of funding?			...when facing the need to speed up tech development?		
	Not at all	To some extent	To great extent	Not at all	To some extent	To great extent
a. Designed simplified new technologies…	☐	☐	☐	☐	☐	☐
b. Relied more upon existing or standard technologies…	☐	☐	☐	☐	☐	☐
c. Sought additional funding from investors…	☐	☐	☐	☐	☐	☐
d. Partnered with other organizations…	☐	☐	☐	☐	☐	☐
e. Designed technologies that can be commercialized…	☐	☐	☐	☐	☐	☐
f. Skipped risk analysis or test phases…	☐	☐	☐	☐	☐	☐
g. Thought on abandoning the competition…	☐	☐	☐	☐	☐	☐

PRIZE DEVELOPMENTS

19. Assuming that achieving the prize target is equivalent to 100% and considering the team's plans for the GLXP project: *What percentage of the project has been already completed by the team?*

☐ Less than 20%

☐ Between 20% and 50%

☐ More than 50%

20. Could you please indicate the scheduled completion date for your team's GLXP project?

Month _________ Year _________

21. While working on the GLXP project: Has the team achieved significant innovations which are useful for the GLXP project or other projects?

☐ Yes

☐ No → *Please skip to Question 23*

22. (If Yes) Please, indicate which types of significant innovations were achieved, how they were achieved, and whether they are useful for the GLXP project and/or other projects of the team or its members. *Please, indicate all types that apply.*

Types of innovations	Achieved type of innovation?		How was it achieved?		Usefulness of the innovation		
	No	Yes	Planned	By chance	Only for GLXP	Only for other projects	For GLXP and other projects
a. New products or components	☐	☐ →	☐	☐	☐	☐	☐
b. New ways to organize technology design and development	☐	☐ →	☐	☐	☐	☐	☐
c. New use for existing materials, products, or components	☐	☐ →	☐	☐	☐	☐	☐
d. Other type (please, specify): _______________	☐	☐ →	☐	☐	☐	☐	☐

- 5 -

23. To what extent your team's GLXP project relates to projects that *the team or its members* had when deciding to join the competition or before that?

☐ Very great extent
☐ To some extent
☐ A small extent
☐ Not at all → *Please skip to Question 25*

24. Which of the following better describes the relation between the GLXP project and the projects that *the team or its members* had when joining the competition or before that? *Please, tick only one option.*

The GLXP project is…

☐ …the restart of discontinued project(s)
☐ …the continuation of ongoing project(s)
☐ …the expansion of ongoing project(s)
☐ …the unification of ongoing projects
☐ …the application of results or knowledge from other project(s)

25. If the GLXP did not exist: How likely would be for *the team or its members* (individually or as part of a larger organization) to work on a project related to unmanned exploration of the Moon?

☐ Very likely
☐ Likely
☐ Not likely
☐ Do not know

TEAM MEMBERS

26. How many people were on the team at the moment of its creation and are on it today?

Team people	Number of people when just created	Number of people today
a. Full-time member *(they spend 80% or more of their time working in the GLXP project)*		
b. Part-time member (*permanently with the team, but share time with other job or activity*)		
c. Volunteers or collaborators (*with the team only when it is necessary–maybe remotely*)		

27. How many team members (full- or part-time) have undertaken the following activities?

Activities	Number of team members
a. Researched (academically) in aerospace/aviation/satellite comm. technologies	
b. Designed or developed technologies as an aerospace/aviation/satellite comm. company employee	
c. Worked for NASA or other Space Agency	
d. Worked in rocketry or related activity as independent professional	
e. Participated in other technology prize competitions	

28. How many team members (full- or part-time) have reached the following education levels?

Education level	Number of team members
a. High school	
b. College / Bachelor	
c. Masters	
d. Ph.D.	

29. For those team members (full- or part-time) that reached college or higher education levels: how many have the following backgrounds?

Backgrounds	Number of team members
a. Engineering	
b. Physics/Chemistry/Math	
c. Computer Science/IT	
d. Other	

30. To better understand the composition of the teams participating in the GLXP competition, please can you indicate how many current team members (full- or part-time) are:

	Number of team members
a. Female	
b. Students	

31. Are any of the team members (full- or part-time) exclusively dedicated to business development or commercialization of the technologies developed for the GLXP?

☐ Yes

☐ No

32. Are these future activities among the plans of the team <u>or</u> its members for when the GLXP is finished?

Future activities	Is part of the plans of the team or its members?		
	Don't know	*No*	*Yes*
a. Seek opportunities to commercialize the technologies developed for the GLXP	☐	☐	☐
b. Seek opportunities to continue research in aerospace/aviation/satellite comm.	☐	☐	☐
c. Retire from aerospace/aviation/satellite comm. career or projects	☐	☐	☐
d. Seek other prize to compete	☐	☐	☐

33. CONTACT DATA: Please, provide us with your name and contact data in case that some clarifications are needed or some feedback is provided to the team.

Name of your team: ______________________________

Your name: ____________________________________

E-mail: ____

Phone: ____

Mailing address: Address ____

City, State, ZIP code ____

Country ____

APPENDIX D

GUIDING QUESTIONS FOR INTERVIEW WITH GLXP TEAM LEADERS

How do prizes induce innovation?
Learning from aerospace competitions

Interview questions for Team Leader

Please, respond in relation to the participation of your team in the Google Lunar X Prize:

1. Why did you decide to create the team and enter the competition?

2. To what extent participating in the prize is related to other (e.g. personal, professional) goals of the team or its members?

3. What is the most significant risk that you perceive from participating in this competition?

4. How did the team come up with the overall systems design or approach pursued for this competition?

5. What part of this competition (e.g. Earth-Moon transfer, communications, Moon landing) requires the most significant R&D effort to win? Could you please describe how your team undertakes such effort?

6. What are the main differences/similarities between your team's and the traditional aerospace industry's organization of R&D activities?

7. What are the benefits/disadvantages that participation in the competition brings to technology development in your team?

8. Could you please describe the technology achievements and innovations of your team in terms of its mission goals? **If innovations were achieved**: Would the team or its members come up with those innovations if the competition did not exist? Why?

9. Does the team plan to commercialize any of the technologies developed for this competition? **If yes**: To what extent commercialization targets affect systems design and R&D activities? **If no**: what technological achievements would your team openly share with other organizations or individuals?

APPENDIX E

OTHER OUTPUTS OF THIS RESEARCH PROJECT

Peer review journals:

Kay, L. "The effect of inducement prizes on innovation: evidence from the Ansari X Prize and the Northrop Grumman Lunar Lander Challenge." R&D Management. *Accepted for publication, forthcoming*.

Working papers and presentations:

Kay, L. (2010). "Modeling incentives, R&D activities, and outcomes in innovation inducement prizes." Workshop on Original Policy Research, School of Public Policy, Georgia Institute of Technology. March 12, 2010.

Kay, L. (2010). "Technology R&D in the context of innovation inducement prizes Insights from the Google Lunar X Prize." Workshop on Original Policy Research, School of Public Policy, Georgia Institute of Technology. October 22, 2010.

Professional reports:

Kay, L. (2011). "Managing Innovation Prizes in Government." The IBM Center for the Business of Government.

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