

1. Introduction

Prizes have long been used by public and private sponsors to elicit effort from individuals and organizations and attain diverse goals, including scientific discovery and technology development. Since at least the 18th century, for example, prizes have been used to encourage basic research by compensating research results with monetary rewards or medals (MacLeod, 1971; Crosland and Galvez, 1989; Brunt et al., 2008). This is the case of popular prizes such as the Nobel Prizes, which function as an incentive for scientists to achieve breakthroughs. There are also prizes offered *ex-ante* for the achievement of a certain technological target. These prizes typically offer a fixed, sometimes sizable monetary reward to the first entrant that achieves a prize challenge or to the entrant that progresses the farthest in a competition. This kind of prize may have been decisive to develop early innovations such as the marine chronometer and induce the initial development of the aviation industry in the 20th century (Davis and Davis, 2004; Maryniak, 2005; Mokyr, 2009). One of the most popular prizes of this kind has been the Orteig Prize for the first aviator to fly nonstop between New York and Paris (won in 1927 by Charles Lindbergh). During the last fifty years countless prizes have been offered in many fields attracting contenders and audiences with diverse interests (Best, 2008). But it has been a handful of successful global innovation prizes recently launched in the USA that revitalized the interest in this topic since the 1990s. These recent competitions include government prizes such as the \$3.5 million DARPA Urban Challenge to develop autonomous robotic vehicles, and private sector prizes such as the \$10 million Ansari X Prize for the first private reusable manned spacecraft and the \$1 million Netflix Prize to improve Netflix Inc.'s movie recommendation system. Also older success stories such as that of the influential Orteig Prize were rediscovered in the 1990s and inspired the design of some of these modern prizes. The dynamism and broadly disseminated advances of those modern competitions suggested exciting opportunities in the use of prizes to exploit widely distributed knowledge and induce collaborative efforts to address critical issues, including technological innovation. In the USA this attracted the attention of policy makers and sparked further discussion between government stakeholders and some scholars (see, for

example, NAE, 1999; NRC, 2007; Stine, 2009) which ultimately led to the enactment of new legislation to authorize federal agencies to use prizes broadly to accomplish their missions. Innovation prizes then made their way into the portfolio of policy instruments and their immediate implementation by USA government agencies such as the National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency (DARPA). More generally not only policy makers but also 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. Increasing numbers of proposals have also been put forward to implement prizes in fields as diverse as agriculture, medicine and nanotechnology to seek solutions to very challenging problems (see prize proposals by, for example, Horrobin, 1986; Kremer, 2000; Masters, 2003; Anastas and Zimmerman, 2007; Charlton, 2007).

To date, however, despite the long history of prizes as incentives for science and technology, their recent popularity and increasing policy interest, there has been little empirically based scientific knowledge on how to design, manage and evaluate innovation prizes. Prizes have generally appeared marginally in studies as variations of more traditional incentive mechanisms in the portfolio of policy options, but increasing interest by Science and Technology (S&T) policy scholars anticipates a better future for prize research. New prize-focused research programs investigate specific cases of historic and modern prizes empirically. This new empirical evidence will help to substantiate our knowledge on prizes which has generally been based on theoretical economic approaches (see, for example, Wright, 1983; de Laat, 1997; Shavell and van Ypersele, 1999; Newell and Wilson, 2005) and only to some extent on case studies that draw on anecdotal accounts or historical analysis (see, for example, Crosland and Galvez, 1989; Davis and Davis, 2004; Saar, 2006). Scholars have also participated in forums and workshops to inform the design of concrete prize initiatives and in communities of practice that focus on government prizes and disseminate case studies, prize announcements and related information (e.g. the USA Challenges Listserv).

Motivated by the increasing interest in prizes to attain diverse goals, this book seeks to close some significant knowledge gaps that call for further investigation on the design, implementation and evaluation of innovation prizes. The book presents the results of an empirical investigation of 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 research

and development (R&D) activities, the prize technologies and the overall effect of prizes on technological innovation. The investigation used a 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.

The book draws on prize literature insights and more general innovation literature, and addresses four main questions that are not only deemed relevant from the viewpoint of scientific inquiry but are also considered to have significant implications for policy making to design effective and more efficient 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 technologies 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 be able to address these questions and probe corresponding propositions, the investigation 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 the 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 the retrospective study of two prize competitions of recent completion, the AXP and NGLLC. Second a refined version of the model is applied to investigate the main case study, the ongoing GLXP, and elaborate implications for theory, policies and future research.

The three case studies are among the most significant and popular modern prize experiences. The GLXP is a \$30 million multi-year global competition organized by the X Prize Foundation (XPF) 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 it is an opportunity to gather valuable real-time data from ongoing R&D activities in a high-tech competition; it is interrelated with the strategic aerospace and defense industry sectors; and it has global reach, which offers the opportunity to observe the broadest impact of prizes. This is also an interesting case because the accomplishment of missions with goals similar to the GLXP may have other significant non-technological implications such as those related with geopolitical affairs (not specifically analyzed here). 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 USA firm Scaled Composites won this prize in 2004. The NGLLC, part of NASA's 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 USA teams between 2006 and 2009. The USA firms Masten Space Systems and Armadillo Aerospace shared the prize money.

The analysis of these three case studies unveils the dynamics of these prizes and contributes a better understanding of the potential effects of prizes on innovation. Moreover, the book presents evidence of the complexity of the prize phenomenon and the uniqueness and specific features of each competition, revealing a big number of factors that influence the development of prizes and their ultimate outcomes. In the investigation of the ongoing GLXP, the book, however, does not seek to assess the performance of individual prize entrants and does not reveal sensitive information that might affect the strategies of competing teams. More generally, the investigation 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 prize research.

The book is organized as follows. Chapter 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. Chapter 3 reviews the literature that is relevant to each of the four research questions and posits four corresponding hypothetical explanations. Chapter 4 discusses methodological aspects, introduces the innovation model to study prizes and describes the data and data gathering process. Chapter 5 presents the analysis and findings of the AXP and NGLLC case studies and presents considerations for model improvement and further research. Chapter 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. Chapter 7 discusses case study findings and probes the anticipated effect of prizes. This chapter 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. Chapter 8 seeks to contribute new building blocks for the development of prize theory and presents policy and methodological considerations based on the findings of the three case studies. Chapter 9 makes some concluding remarks. The book also includes an Appendix with other useful data to understand the case studies.