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Grand Innovation Prizes: A theoretical, normative, and empirical evaluation

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ABSTRACT

This paper provides a systematic examination of the use of a Grand Innovation Prize (GIP) in action – the Progressive Automotive Insurance X PRIZE – a $10 million prize for a highly efficient vehicle. Following a mechanism design approach we define three key dimensions for GIP evaluation: objectives, design, and performance, where prize design includes *ex ante* specifications, *ex ante* incentives, qualification rules, and award governance. Within this framework we compare observations of GIPs from three domains – empirical reality, theory, and policy – to better understand their function as an incentive mechanism for encouraging new solutions to large-scale social challenges. Combining data from direct observation, personal interviews, and surveys, together with analysis of extant theory and policy documents on GIPs, our results highlight three points of divergence: first, over the complexity of defining prize specifications; secondly, over the nature and role of incentives, particularly patents; thirdly, the overlooked challenges associated with prize governance. Our approach identifies a clear roadmap for future theory and policy around GIPs.

1. Introduction

Solving grand social challenges requires the development of fundamentally new innovations and, possibly, entirely new innovation incentives. Appropriate incentive design must confront at two distinct issues. First, as their name implies, "grand" challenges often involve fundamental breakthroughs that rely on harnessing unusual stakeholders across unexpected bodies of expertise. Second, the social nature of many grand challenges forces policymakers to think beyond existing market incentives to attract the attention of sufficiently diverse and committed a range of innovators to yield solutions. Consequently, traditional incentive mechanisms – procurement and patents – often fail to induce innovators to tackle grand missions: patents do not provide adequate incentives for challenges subject to market failure, and procurement-oriented approaches constrain both the set of possible innovators and the range of approaches they consider.

Given these limitations, the resurgence of interest in an alternative mechanism – prizes – is hardly surprising. Prize mechanisms fall broadly into two types (although a sharp dividing line does not exist). First we define Grand Innovation Prizes GIPs). These are large monetary prizes awarded to the xinnovator(s) providing the *best* or *first* solution to a pre-determined set of *significant* new performance goals with no path to success known *ex ante* and believed to require significant commitment and a breakthrough solution (see Kay, 2011). Second, we distinguish GIPs from smaller-scale competitions and challenges for well-defined (albeit difficult) problems that often require only limited time commitment (see Brunt et al., 2008) or involve matching or adapting existing solutions to problems - for example, many of those posted on InnoCentive, TopCoder and elsewhere (see Jeppesen and Lakhani, 2006; Boudreau et al., 2011).

Contemporary interest in GIPs has been particularly intense in the United States. Galvanized by compelling narratives of historical prizes (Sobel, 1995; Siegel, 2009), a community of activists across the public and private sectors increasingly champion GIPs. The X PRIZE Foundation has also led efforts to implement and define GIPs through their X PRIZE initiatives.[2] In government, the 2010 America COMPETES Reauthorization Act authorized Federal agencies to pursue prizes – both GIPs and smaller competitions – for a range of problems (OSTP, 2009; Zients, 2010; Lane and Bertuzzi, 2011). Several international initiatives have also explored GIPs particularly in global health (Kremer, 1998, 2002; Willetts, 2010).

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[2] See Diamandis (accessed from http://www.xprize.org/prize-development on 14.10.11).

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Despite policy directives and private action to deploy this innovation mechanism, systematic analysis of GIPs remains limited (Williams, 2012). Relative to the extensive body of theoretical research considering the design of patents (e.g. Nordhaus, 1969; Merges and Nelson, 1990; Scotchmer, 2004) or procurement contracts (e.g. Laffont and Tirole, 1992) little economic theory explicitly considers the properties of innovation prizes, or how prizes operate in comparison to other incentive mechanisms (see Wright, 1983; Shavell and van Ypersele, 2001; Scotchmer, 2004). The most significant gap is the lack of empirical studies of contemporary GIPs (such as those offered by the X PRIZE Foundation). There exist reasonable accounts of historical cases (e.g. Sobel, 1995). However, the study by Brunt et al. (2008) of prizes and medals offered by the Royal Agricultural Society and Kay's recent detailed analysis of prizes for space innovation including the Northrop Grumman Lunar Lander Challenge (Kay, 2011) provide the only empirical analyses of GIPs to date. While these papers start to detail how GIPs work in practice, the lack of empirics remains worrisome as popular advocacy grows.

To bridge this gap, this paper draws on an in-depth study of the $10 million Progressive Insurance Automotive X PRIZE (PIAXP). We leverage detailed information from the teams, organizers and judges involved in the prize to test theoretical and normative claims against the facts on the ground. To enrich our analysis, we explicitly compare theoretical arguments regarding GIPs, positions taken by GIP advocates, and the empirical reality of the PIAXP. To do so, we develop a simple framework that defines three dimensions over which to evaluate prizes: objectives, design, and performance. Rather than an exhaustive assessment of the entire GIP landscape, our evaluation offers a window into how the claims made by prize theorists and advocates compare with a Grand Innovation Prize in practice. We have five key findings:

- GIPs are used to meet more complex and multi-faceted goals than anticipated in theoretical or policy analysis. Education, attention and community building can be as important as the technical solutions themselves.
- While theorists design prizes with the object of producing efficient levels of effort towards a goal, advocates and practitioners aim to maximize effort.
- The design of the *ex ante* technical specification for GIPS is complex and specifications that ensure "appropriate" solutions are hard to predict *ex ante*.
- *Ex ante* incentives are more nuanced than recognized by theorists or prize advocates. Retained IP ownership is often a complement not a substitute to the award.
- Prize governance is of critical importance: "thin" institutional arrangements leave prize organizers vulnerable to disputes over the structure or fairness of GIP awards.

These findings have received little attention in the theoretical literature and are often assumed away by prize advocates. They suggest important divergences that have policy implications particularly as the government moves forward with prize implementation. Moreover, they suggest several paths for future empirical analysis.

Our paper proceeds as follows. Section 2 provides a brief history of the use of GIPs in incentivizing solutions to mission-oriented problems. In Section 3, we outline our framework as a context within which to evaluate the objectives, design, and performance of prizes. Section 4 describes the methodology for our comparative theory, policy and empirical analysis, focusing on the empirical methods used in the study of the PIAXP. Section 5 structures our findings around the evaluative framework comparing theory, policy–advocacy and the empirical reality of PIAXP. A final section briefly concludes.

2. A short history of Grand Innovation Prizes

As this special issue highlights, society confronts a range of daunting challenges; public health to food security, energy, and defense. These are simultaneously extremely costly when they go unsolved and yet remain highly intractable. In many cases, the solution of these grand challenges depends on the development of macro innovations for which the solution (as well as the solution path) is difficult to establish *ex ante*. The very nature of these grand challenges and their solutions implies that traditional innovation mechanisms likely fall short (Mokyr, 1999). On the one hand, procurement contracts limit the scope of experimentation and are rarely able to induce the macro innovations required. At the same time, many grand challenges are the consequence of significant market failure; market-based incentive mechanisms thus have limited value. Alternative approaches are required to encourage innovations to address grand social challenges. The question is therefore: what mechanisms can ensure that significant effort, creativity and experimentation are plausibly focused on the challenges at hand? Faced with this question, it is perhaps not surprising that policymakers have gone "back to the future" and turned their attention towards prizes and challenges of all types but most centrally on Grand Innovation Prizes – prizes for innovations that met significant challenges.

2.1. Historical perspectives

As early as the thirteenth century, governments established incentive systems to encourage innovations to address their most pressing needs. In this context, GIPs have a storied history as a tool of innovation policy to induce solutions to national challenges (see the detailed catalogue in Knowledge Ecology International, 2008). By the sixteenth century, governments and private actors provided inventors with significant *ex post* monetary rewards for breakthrough innovations; the British Parliament rewarded Jenner for his vaccine inoculation and Gatehead for the lifeboat (MacLeod, 2007). The eighteenth century saw the more systematic use of *ex ante* Grand Innovation Prizes. Following unsuccessful longitude prizes in Spain (1567) and the Netherlands (1627), the British promulgated the Longitude Act – a monetary reward of £20,000 (equivalent to $12 M today) for a method to calculate longitude at sea – with the objective of solving one of its most significant problems, navigation.[3]

While longitude is certainly the most storied GIP, it was not the only attempt to use a large innovation prize to focus inventive activity. The French were particularly assiduous in offering grand prizes for national challenges (as well as a range of smaller prizes) throughout the 18th and 19th century. Via royal decree or the French Academy of Sciences, GIPs were instituted in areas from Food preservation (1795) to Agricultural pests (Davis and Davis, 2004; Knowledge Ecology International, 2008; Wright, 1983). And from 1839 the (British) Royal Agricultural Society sponsored (smaller) prizes and medals for a range of innovations in agricultural instruments used in tillage, harvesting and crop preparation (Brunt et al., 2008).

Despite these initiatives, Grand Innovation Prizes gradually fell out of favour during the 19th century to be replaced by mechanisms such as patents, procurement, or market-based rewards based on first mover advantages and complementary asset control (Teece, 1986; Chandler, 1990; Murmann, 2003). While the decline of prizes has not been fully explained, one impetus was presaged

[3] The Longitude Act noted that "The Discovery of the Longitude is of such Consequence to Great Britain for the safety of the Navy and Merchant Ships as well as for the improvement of Trade. . .".

by controversies in the Longitude Prize; the difficulty in designing prizes which credibly commit to rewarding qualified winners however unexpected the design or the innovator (Davis and Davis, 2004; Siegel, 2009). Rising costs of innovation were also likely a driver as independent inventors in a prize system struggled to fund research (in advance of an award). In response, governments shifted to *ex ante* funding of individuals through grants (Crosland and Galvez, 1989; Alder, 2002; Galison and Hevly, 1992), while the rise of industrial research allowed companies to fund innovation from profits derived in part from patent monopolies (Birr, 1979; Rosenbloom and Kantrow, 1982; Reich, 1985).

2.2. Contemporary innovation prizes

Innovation prizes made a brief return to prominence at the start of the 20th century with a series of privately sponsored prizes for aviation. Outside this anomaly however, formal GIPs only re-emerged over the past 15 years as a legitimate innovation incentive mechanism. This resurgence was in part initiated by the success of the 1996 $10 million Ansari X PRIZE (see Kay, 2011 for a detailed analysis). A privately offered prize launched by Peter Diamandis through the X PRIZE Foundation, it rewarded the first private space vehicle to launch a reusable manned spaceship into space twice in 2 weeks. 26 teams to spend over $100 million and in 2004, Spaceship One (funded by Microsoft co-founder Paul Allen) was declared the winner.

The attention and investment garnered by the Ansari Prize galvanized government and private interest in GIPs (e.g. Love and Hubbard, 2007). In 1999, U.S. government interest was formally recognized in the National Academy of Engineering report "Concerning Federally Sponsored Inducement Prizes in Engineering and Science" (NAE, 1999). A range of GIPs across mission-oriented agencies followed: the 2004 Defense Advanced Research Project Agency (DARPA) Grand Challenge was a $1 million prize for an autonomous land vehicle which could complete a 150 mile course without human intervention. NASA launched three GIPs in 2006 including its Tether Challenge. Government interest was paralleled, and at times foreshadowed, by private sector GIPs including further prizes by the X PRIZE Foundation and the Prize4Life Foundation ALS Biomarker Prize (as well as a number of smaller competitions for social challenges).[4]

In the U.S. government, these trends were transformed from isolated experiments to a broader policy initiative by regulations from the Obama administration that sought to accelerate the adoption of prizes of all types as an innovation tool. The 2005 Medical Innovation Fund Prize Act provided prize-based incentives for new medicines. By 2007, the Department of Energy had a mandate to "carry out a program to competitively award cash prizes. . .to advance. . .hydrogen energy technologies".[5] Following the release of the President's Strategy for American Innovation in September 2009, the Office of Management and Budget issued a memorandum encouraging all U.S. government agencies to promote and harness innovation through prizes and challenges. This was formalized in the 2010 America Competes Act (Bershteyn and VanRoekel, 2011). In 2011, the Office of Science and Technology Policy stated "in the months to come, the Obama Administration will work closely with key agencies to leverage the new authority for ambitious prizes in areas of national priority" (White House, 2011).

[4] The US $20,000 InnoCentive challenge for "A Safe and Economical Synthetic Route for PA-824 a Tuberculosis Drug" was announced in 2007 (see www.innocentive.com for details). Prize4life Prizes and Programs accessed from http://www.prize4life.org/page/prizes/biomarker_prize (last accessed 09.10.11).

[5] Medical Innovation Prize Act 2005, H.R. 417. Energy Independence and Security Act H.R. 6, §654.

Despite growing deployment of the GIP incentive mechanism for major challenges, progress is hampered by the lack of an analytical framework to ensure that GIPs are effective. Historical lessons suggest that prizes can be hard to design and a well functioning prize economy hard to maintain. Absent a framework within which to evaluate prizes, scholars such as ourselves and policymakers will be unable to systematically evaluate the performance of individual GIPs, determine how future prizes could be improved, and assess how to build an institutional landscape to support a well-functioning prize economy.

3. Evaluating Grand Innovation Prizes

3.1. Evaluation framework

This section outlines a tractable yet systematic framework for evaluating Grand Innovation Prizes from the perspective of all stakeholders. We are not the first to evaluate prizes as a mechanism for encouraging innovation. Our approach, however, is distinct. Since the work of Wright (1983), the analysis of innovation prizes explicitly compares them with other mechanisms, identifying the conditions under which prizes are the preferred innovation incentive (see Gallini and Scotchmer, 2002; Nordhaus, 1969; Kremer and Williams, 2010; Williams, 2012).

One difficulty with this approach is the lack of agreed upon dimensions along which to analyze each incentive mechanism. Another is that, as modelled, prize incentives are somewhat idealized (particularly relative to patents). To overcome these issues and deepen our empirical evaluation of GIPs we develop a framework that lies between the highly formalized approaches followed in the mechanism design literature (pioneered by Hurwicz (1973) and used to compare prizes and patents in Hopenhayn et al. (2006) and Chari et al. (2011) and prior empirical work that provides considerable empirical data (see Kay, 2011, in particular) but no clear approach to undertaking comparative analysis. In developing this framework we aimed to be comprehensive and generalizable but also capture the essence of the prize we are evaluating. Our approach is to decompose GIPs into a set of three dimensions that together characterize a framework for prize analysis: objectives, design, and performance.

(1) **Prize objectives**: Dimension 1 focuses on the objective of the innovation mechanism, in this case the objective of a GIP. For what specific innovation objectives is the prize designed? This is a critical feature of any incentive mechanism and can be thought of as its objective function, whether it is to maximize social surplus or some other attribute.

(2) **Prize design**: Dimension 2 outlines the prize design-attributes characterizing the "rules of the game" under which the incentive mechanism is played. Two elements emphasize the *ex ante* definition of a "winning" solution and incentives required to induce effort towards that solution. Two additional elements define who is qualified to participate and how winning is adjudicated. Together, these elements specify the way in which the GIP mechanism "works":

(2-a) ***Ex ante* technical specification**: This element specifies the terms of a winning solution. In other words, what is defined about the technical parameters of the innovation objectives *ex ante*? If we were to compare prizes to patents, the *ex ante* specification of a patent is of course limited: it must only meet rules of novelty, non-obviousness and usefulness. Typically prizes have a more precise technical specification. Nonetheless, this must be defined and understood.

(2-b) ***Ex ante* incentive specification**: This element specifies the incentives for participating in the GIP; what is assumed and what is specified *ex ante* about the incentives? In the case of a patent, the incentives are monopoly rights to exclude others from producing your idea (as defined in your patent). In the case of a prize, the incentives are precisely specified in terms of a financial reward. They may also include other non-monetary incentives, as well as, in some designs, IP rights to the solution.

(2-c) **Qualification and staging**: Element three defines how many participants are allowed to be engaged in the prize, how they are qualified and selected and what stages, if any, participants go through in order to reach the final prize deliberations. There is no particular equivalent in patenting although procurement mechanisms tend to have similarly complex rules around qualification to play the procurement game.

(2-d) **Award governance**: The fourth element relates to how the award is actually selected and the governance of prize allocation. In the case of patents, awards of property rights are (today) made by a national patent office with governance and recourse through patent interference during patent prosecution and later in the Courts. Likewise, award governance mechanisms for prizes must be specified and described.

(3) **Prize performance**: Our last element of prize evaluation relates to the performance of a prize. On what criteria do we define a successful or unsuccessful incentive mechanism? Of course one way of doing this is to return to the initial objective function and measure that. However intermediate metrics of performance are useful to consider. As with the patent system, we would include the amount of innovative effort engendered, the diversity of that effort and the development and disclosure of new knowledge by all parties.

4. Empirical case study

In the remainder of this paper we use our framework to make sense of a case study of a single GIP – the Progressive Insurance Automotive X PRIZE (PIAXP). With so little systematic evidence of contemporary GIPs we have chosen to focus in-depth on a single GIP rather than continue to rely on overused anecdotes. However, our principal aim is to understand the convergence *and* divergence among the theoretical analysis, normative advocacy, and the empirical reality of the PIAXP. Absent our evaluative framework, our three-way comparison would be messy and achieving analytic traction would be challenging. Our analysis and results (see Section 5) are therefore presented according the framework's dimensions. It should be noted that our comparison – theory, policy and empirical reality – follows a complementary (but unusual) path to more traditional innovation analysis: rather than focus on comparative institutional analysis of how "ideal" versions of different innovation incentive mechanisms might work, we instead compare the idealized theoretical understanding of a prize, with the view put forth by policymakers and compare that explicitly to empirical reality.

4.1. Empirical data – Progressive Automotive Insurance X PRIZE

Our selection of the PIAXP as the source of our empirical data is grounded in the assumption that the PIAXP is typical of contemporary Grand Innovation Prizes in design and implementation. We make this claim because while other GIP designs exist, the approach developed by the X PRIZE Foundation is emerging as a canonical design and prizes in the X PRIZE "tradition" seem to be increasingly common.

Founded in 1996, the X PRIZE Foundation was started by Dr. Peter Diamandis to "bring about radical breakthroughs for the benefit of humanity by creating and managing prizes that drive innovators to solve some of the greatest challenges facing the world today" (interview with Diamandis, 2010). He followed the Ansari X PRIZE with a series of Prizes and Challenges: "An X PRIZE is an award of $10 million or more given to the first team to achieve a specific goal, set by the X PRIZE Foundation, which has the potential to positively impact individuals around the world." Each of the X PRIZEs share a similar architecture, scale and scope.

4.2. Prize description

The basic design of the PIAXP followed prior X PRIZE Foundation designs and was similar to other GIPs, e.g., the DARPA Grand Challenge. PIAXP was launched in 2006 and known as the Automotive X PRIZE until March 2008, when Progressive Insurance was announced as title sponsor of the $10 million prize. The U.S. Department of Energy announced a $3.5 M national education program in conjunction with the PIAXP.[6]

The broad purpose of the PIAXP was to provide incentives to "teams from around the world to focus on a single goal [of building] viable, super fuel-efficient vehicles that give people more car choices and make a difference in their lives".[7] The initial prize proposal called for two divisions – Mainstream and Alternative – with the "same requirements for fuel economy and emissions, but different design constraints" (AXP Draft Competition Guidelines Version 6.0, April 2007, p. 4).[8] A "winner-take-all" design awarded $5 million per division to the team with the fastest vehicle with fuel efficiency in excess of 100 miles-per-gallon equivalent (MPGe) around a course. Qualification was a simple "Letter of Intent", with a "Design Judging" Stage winnowing the teams by examining "credible, initial plans for a production capable vehicle or product that could meet the performance criteria of the prize". Teams meeting these requirements would, subject safety guidelines, participate in the first of two "dramatic long-distance" races – a Qualification Race which, if successfully completed (and after crash test results) would secure admission into a Final Race (AXP Draft Competition Guidelines Version 6.0, April 2007) (see Table 1).

In the period from the PIAXP announcement until close of registration (August 2008), 111 teams formally registered with 136 vehicles. At each subsequent stage teams and vehicles were eliminated (or withdrew) (see Table 2).

About 97 teams (108 vehicles) entered the Design Judging Stage. Just prior to a Las Vegas event (November 2009) when PIAXP undertook technical inspections and safety performance tests, unsafe vehicles were eliminated. At this point, 43 out of 97 teams (56 of 108 vehicles) won the right to move into the "race stage" of the prize. Of these, 31 teams (33 vehicles) actually chose to continue participating in PIAXP.

4.3. Data gathering

With permission from the X PRIZE Foundation to participate in all PIAXP events and interact with participating teams, we had unique access to gather data in real time. The period of empirical exploration extended from November 2009 until January 2011 (including the September 2010 winner's announcement).

[6] Accessed from http://www.progressiveautoxprize.org/education on 14.10.11.

[7] Accessed from http://www.progressive.com/progressive-insurance/autoxprize.aspx on 09.05.11.

[8] Mainstream class: 4+ passenger vehicles with 4+ wheels meeting conventional expectations for size and capability; Alternative class: 2+ passengers, no requirement on number of wheels, designed for innovative ideas that push forward today's conventions about automotive transportation.

Table 1
Stages of the PIAXP competition (Based on PIAXP Competition Guidelines 1.3, 2009).

Registration/acceptance:
Teams will be accepted for the Progressive Insurance Automotive X PRIZE competition based on preliminary information about their entry.

Design judging
Accepted teams will then provide evidence that their vehicle or vehicle modification designs are production-capable, in the form of detailed Data Submissions that will be judged on a pass/fail basis. . .. Those that pass will be invited to bring their vehicle(s) to the competition events. An initial series of technical reports, technical inspections, and active safety performance tests will eliminate unsafe vehicles.

Races
Shake-down
The Stage Race is a high-mileage race comprising stages with courses that will reflect known consumer driving patterns, incorporating a variety of realistic and performance-illustrating driving conditions, terrains, and trip profiles. Vehicles will race over closed track facilities. Vehicles must obey all simulated traffic regulations, including speed limits. The Stage Race will enable fair, technology-neutral comparisons of vehicles while maximizing public impact. Following a 2–3 week hiatus after the initial race stages that will serve as a shake-down period, a "knockout" qualifying event will be held to admit vehicles to the final race stages.

Knock-out
To advance, vehicles must pass a full set of active safety performance tests, demonstrate Tier 2, Bin 10 criteria emissions, and demonstrate at least 67 MPGe (i.e., two-thirds of the 100 MPGe target) over a road course based on a composite of the Urban Dynamometer Drive Schedule (UDDS) and the Highway Fuel Economy Driving Schedule (HWFET) test cycles. The knockout event will be conducted at a suitable test track or proving ground, and may be open to the public and the media at selected periods.

Finals
After the "knockout" event, there will be at least a 2-week hiatus to allow the surviving teams to apply what they have learned during the shake-down stages and knockout event before the final stage. To complete the Progressive Insurance Automotive X PRIZE Stage Race successfully, vehicles must maintain a minimum average speed (maximum allowable time) while meeting Progressive Insurance Automotive X PRIZE requirements for fuel economy and emissions – determined by averaging the dynamometer test results with the overall scoring-stage averages.

Validation
At the end of the final stage, there will then be a coast-down stage followed by the chassis dynamometer stage that will conclude the competition events. For those vehicles that successfully complete all of the Stage Race requirements, placement (ranking) will be based on the total of the stage completion times. Time penalties will be applied for infractions and equipment failures.

Winners
Final ranking will be determined by the adjusted total time – i.e., the fastest vehicles are the winners.

During data collection we sought to build comprehensive insights into PIAXP from the perspective of teams (including their resource commitments, motivation, technical approaches employed and outcomes), organizers and sponsors. The specific questions guiding our data collection were sharpened by our goal of understanding how each the dimensions of prize design worked in practice. In the spirit of prior studies of innovation processes (e.g. Clark and Fujimoto, 1990; MacCormack, 2001), we followed several paths of data gathering:

- analysis of documents, press commentary and blogs associated with PIAXP,
- qualitative data based on interviews and direct observations at key events,
- survey data from teams at different stages of the competition.

The documentary record (from the Foundation) provided a particularly critical backdrop for interviews and observations. All the teams were asked by PIAXP organizers to participate in our interviews and answer survey questions. It was also made clear to teams that our research was independent, that team-specific information was confidential, and that our research was not funded by the X PRIZE Foundation. While attending PIAXP events and building familiarity with participating teams, our research team conducted in-depth qualitative interviews with every team that participated in the final stages of the PIAXP (~30 teams), as well as interviews with key X PRIZE staff: director of Team Development and Relations, VP of Prize Operations; those designing the judging and prize structure; and the Founder of the X PRIZE Foundation. We also gathered survey data from the teams (of which only a small fraction is presented in this paper). Our first survey was sent in December 2009 to the 43 qualified PIAXP teams that completed Design Judging (and the 68 teams who failed) with a response rate of 81% and 41% respectively (52% overall).

5. Results – a comparative evaluation of theoretical, normative policy and empirical perspectives

Our analysis was guided by the framework presented above and our results are presented accordingly (paying particular attention to the four crucial components of prize design). Of course, we use only one GIP – the Progressive Automotive X PRIZE – as our empirical comparison versus theoretical and policy views. In addition, while we found many differences among the three perspectives, we emphasize and provide support for only one or two most striking distinctions.

5.1. Prize objectives

From the perspective of a theoretical economist, the objective of innovation prizes is to ensure that the marginal benefit of additional effort focused on the prize goal is equal to the marginal cost. In other words, in meeting grand social challenges, the theoretical objective of the prize is to allocate innovative effort to social problems only to the extent it is economically efficient to do so. Advocates of the prize economy emphasize a different calculus: to maximize prize-related activity. According to all but the most "economically minded" advocates, GIP objectives should be to allocate effort to a challenge as long as marginal benefits are greater than zero. In other words, advocates do not explicitly count the cost of participant effort when considering the scope of a prize and therefore do not view cost-benefit balancing as a core objective. Evidence from PIAXP closely accords with this perspective: the Foundation paid no attention to levels of participation and the balancing of participant costs with benefits. Instead, they emphasized the broad benefits of running an Automotive X PRIZE. Indeed, the guidelines

Table 2
Stages of the PIAXP competition with number of teams and vehicles breakdown of entries by PIAXP competition stage.

No. of vehicles	Registered	Entered and passed design judging	Entered shakedown	Entered knock-out	Entered finals/validation	Winners
Mainstream	80	31 passed	12	8	2	1 of 2
Alternative – Tandem	56	25 passed	8	7	5	1 of 2
Alternative – side-by-side			13	13	8	1 of 5
Vehicle total	136	108 entered → 56 passed	33	28	15 of which 9 finally competed	3
Team total	111	43 passed	31	26	13 of which 9 finally competed	3

are clear in articulating the key objective as attracting investment to the prize with no discussion of the appropriate level of investment that would balance prize benefits and costs.

Current theoretical perspectives on prizes also clearly outline the conditions under which prizes are likely to be effective relative to alternative incentive mechanisms: first and foremost, when their objectives are focused on problems and challenges for which there is adequate information to enable a "social planner" to define the properties of a solution, but with little understanding about who has the information to develop such a solution (Wright, 1983). Furthermore, prizes will be useful when there is no "upside" to the development of a particular solution, i.e., if the prize constitutes the full value of the solution, as is the case for social challenges where markets are poorly functioning (Kremer, 1998, 2002; Abramowicz, 2003; Wei, 2007). This contrasts to a patent, where there exist many settings in which demand may be unclear *ex ante* but innovators recognize potential ex post market signals (Scotchmer, 2004).

Prize advocates take a broader perspective of the range of problems likely to yield to prize incentives. For example, policy proposals highlight the broad objectives of prizes to "address national goals and opportunities" (National Research Council, 2007, p. 16). Moreover, the normative policy approach considers prizes to be essential across wide-ranging objectives; bringing attention to a problem, leading education, participation, and shaping prestige. For example, a National Academy of Engineering report (NAE, 1999) argues that prizes should "identify and engage nontraditional participants and unorthodox approaches" (NAE, 1999, p. 8) in such as way as to push innovators across traditional disciplinary boundaries. Harking back to eighteenth century Britain, when scientific displays were widely consumed by the public, the report argues that "through publicity and public demonstrations, such as displays of competing aerial robotic systems, inducement prize contests may fire the imaginations of both contest observers and participants" (NAE, 1999, p. 8). Prize advocates also argue that prizes "...may attract young people to study or pursue careers in engineering or science, and may also inspire support from the public and policymakers for research or technology objectives" (NAE, 1999).[9]

Evidence from the PIAXP suggests that the actual prize economy accords more closely with prize advocacy than prize theory. From the start, the Foundation's focus on the PIAXP was not focused explicitly on market failure in the automotive industry. Instead, it emphasized "inspir[ing] the formation of new industries and revitalising markets that are currently stuck due to existing failures, or [eliminating] a commonly held belief that a solution is not possible" (interview with Diamandis, December 2010). With regards to the energy sector, the Foundation wanted to "revolutionize the automotive industry" (interview with PIAXP organizer, April 2010) through what the Foundation viewed as the need to "inspire a new generation of viable, super-efficient vehicles... that help break our addiction to oil and stem the effects of climate change" (PIAXP Press Release 2007). This grand vision was elaborated during an interview with Diamandis in which he emphasized:

> "it's not about a single vehicle. It is really about a new generation of vehicles and very importantly changing the public mindset of the kind of cars that they can drive." (interview with Peter Diamandis, December 2010)

In translating these broad aims into more precise objectives, the approach taken by PIAXP ties to the multi-faceted set of objectives laid out for GIPs by policy advocates. The PIAXP organizers determined that their prize needed to meet ten objectives:[10]

- Be simple to understand and easy to communicate.
- Benefit the world – this is a global challenge.
- Result in real cars available for purchase, not concept cars.
- Remain independent, fair, non-partisan, and technology-neutral.
- Provide clear technical boundaries (i.e., for fuel-efficiency, emissions, safety, manufacturability, performance, capacity, etc.).
- Offer a "level playing field" that attracts both existing automobile manufacturers and newcomers.
- Attract a balanced array of private investment, donors, sponsors, and partners to help competitors succeed (e.g., manufacturing assistance, testing resources, etc.).
- Make heroes out of the competitors and winner(s) through unprecedented exposure, media coverage and a significant cash award.
- Educate the public on key issues.

The Department of Energy emphasized similar objectives, sponsoring PIAXP because "they believe in incentivizing innovation through competition to reshape the automotive industry" (PIAXP Press Release 2009c). For the prize sponsor – Progressive Insurance – sponsorship met a related but distinctive set of objectives (which have yet to be fully examined). Their public statement regarding their objectives notes: "Progressive supported this competition and funded the prize purse because we want to help make people's lives better by giving them more choices in safe, super fuel-efficient vehicles".[11]

In summary, we find a sharp divergence between prize theory on the one hand and advocacy and empirical reality on the other with regards Prize Objectives. Two differences are particularly noteworthy. First, while prize theorists emphasize that the objective of a prize should be to induce effort up to the level where the marginal cost of innovation equals the marginal benefits of the solution, the calculus in the prize economy is more closely focused on maximising effort. Second, both prize organizers and other advocates emphasize prize objectives that transcend simply solving problems and challenges that are subject to market failures. They intend to stimulate education, participation, public attention, and the reputational benefits (to participants, sponsors and organizers) that follow.

5.2. Prize design

The second key dimension of GIPs is the prize design, including the four elements crucial in determining how contests stimulate innovation: *ex ante* specifications, *ex ante* incentives, qualification and staging, and award governance. We focus on how the empirical reality compares to prevailing theoretical and policy expectations.

5.2.1. Ex ante technical specifications

Two key issues arise when examining *ex ante* technical specifications across perspectives. First, the meaning associated with specification; second, the challenges of effective specification; and third, the degree to which goal "creep" arises due to unexpected changes during the prize process.

Prize theory assumes that a "single, discrete invention goal" can be defined and established (Wright, 1983, p. 700). Indeed, a key conceptual definition of an innovation prize (whether grand

[9] The NAE report then develops five additional objectives (NAE, 1999, p.9): Stimulate stalled or nascent technology, stretch existing technologies by demonstrating their usefulness, foster technology diffusion, address neglected or seemingly intractable problems, and build social capital.

[10] From http://www.progressiveautoxprize.org/prize-details, last accessed on 14.10.11.

[11] From http://www.progressive.com/progressive-insurance/autoxprize.aspx, last accessed on 17.10.11.

or smaller in scope) is that it is "a payment funded out of general revenue that is made to a researcher *conditional on delivering a specified invention* [emphasis added]" (Gallini and Scotchmer, 2002, p. 2). The emphasis on specification requires the social planner to select the appropriate level or "stretch" of prize and clarify its definition. The policy view is also clear that technical specifications are necessary to prize design: Kalil (2006) emphasizes the importance of a "specific objective and clear definition of the victory conditions" (Kalil, 2006). However, where theory assumes that the form of the solution should by definition be easily defined, from the policy perspective prize definition (and the engagement in specification that goes with the definitional process) is *itself* is a key value of a GIP, i.e., *prize specification is an objective of a GIP as well as an input into the GIP design*. For example, the OMB argues that "under the right circumstances, [prizes] may allow the government to *establish* an important goal" (Zients, 2010, p. 2). In the same way that mission-oriented research programs such as Kennedy's Moonshot or the recent Human Genome Project provided a technical specification and a guiding vision for grants and procurement programs, so prize specification offers sponsors the opportunity to define their vision of a challenge: "It is one thing to articulate the thought that one or more goals of national significance may make an interesting prize topic. It is another thing to express that thought in the form of the accomplishment of an object that would help reach the national goal in a way that would be new, different and a substantial advance over what can presently be accomplished" (NRC, 2007, p. 34).

The view that prize specification is a meaningful goal of the prize design process was shared by the Foundation. Early on the development of PIAXP, the Foundation's design specifications committee requested feedback from the public and potential participants on a preliminary draft of the prize guidelines released at the New York Auto show in April 2007:

> *AXP is a new prize that is currently under development by the X PRIZE Foundation. Prior to making a final decision on launching the prize, we are entering a sixty-day public comment period on the Guidelines contained in this document. Our goal in doing so is to obtain valuable feedback that will help us to create final, detailed prize rules and inform the launch decision." (PIAXP Guidelines 2008).*

According to Prize advisors, the committee received "over 1000 comments or so" from the crowd, thus providing opportunities for a meaningful challenge to be constructed by a variety of actors in the prize economy. It also allowed the Foundation to better understand the kinds of challenges the public would be interested and capable of solving.

Theorists and policymakers alike give little attention to issues of how *ex ante* specification should be accomplished. Prize policy provides (some) heuristics to enable prize designers to determine the appropriate scope and difficulty of prizes, arguing that by "setting performance objectives perceived to be *within the range of possibility* of a significant number of contestants" prizes broaden the set of ideas and approaches (NAE, 1999, p. 8). However, legislation around prize design has little to say regarding the process of developing specifications (COMPETES Act H.R. 5116–8 Section 24). At best, the COMPETES Act requires that the government "share best practices and assist agencies in developing guidelines for issuing prize competitions" (COMPETES Act, H.R. 5116–8 Section 24 (n)). Compared to the "thin" treatment of technical specification setting provided by theory and the lack of guidance from prize advocates, empirical evidence from the PIAXP and the historical record highlight the challenges of specification.

The PIAXP were guided in developing their specifications by the multifaceted objectives they sought. To meet the goal of demonstrating a breakthrough in transportation, their metrics had to promote both significant technological developments in multiple vehicles and be "simple to understand and easy to communicate", "remain independent, fair, non-partisan, and technology-neutral and" offer a "level playing field" that attract[ed] both existing automobile manufacturers and newcomers" and enable an exciting prize.[12] As a Senior Advisor to the X PRIZE Foundation pointed out:

> *"balancing the judging criteria- technical and practical- to promote high efficiency while [setting a challenge that could be completed in] a realistic timeframe with limited resources. . . was the hardest thing" (interview with X PRIZE Senior Advisor, April 2010).*

The core specification was a vehicle that could meet an efficiency standard of 100 MPGe[13] with CO_2 emissions equivalent to <200 g/mi through various urban and highway challenges. By proposing a new metric to enable a comparison among a number of alternative fuel vehicles, the Foundation used the opportunity to publically define and articulate a metric in an area otherwise beset with confusion. But the precise level of this metric – 100 MPGe – reflected a more complex set of objectives. As on organizer explained "100 is far more compelling than 108." And, according to one of the advisors,

> *"we wanted a number that was difficult to achieve – we were committed to try to test vehicles in a typical way people drive cars – 100 mpge was agreed by experts as being achievable but tough! We want it to be achievable as we wanted somebody to win – we didn't want it to be easy. During the original meeting we proposed 500MGGe but quickly moved on!" (Interview with Dorgelo, April 2010).*

However, the Foundation "didn't want PIAXP to be purely fuel economy competition":

> *"a competition also focused on performance to meet needs of consumers. . . There are lots of competitions to make hyper hyper-efficient cars- but often they look like rolling coffins. We wanted to leave room for consumer desirability and performance in this vehicle as it has a better chance of racing the market. We wanted a focus on consumer desirability" (Interview with Dorgelo, April 2010).*

As a result, PIAXP was defined as a prize for vehicles that win a long-distance race for "clean, production-capable vehicles that exceed 100 MPGe" with "production-capable" (a more complex specification to define) to be judged by an expert panel on four criteria (see Table 3).

Further criteria were also included, in part to meet the objectives of drawing attention to the competition and having the prize associated with high profile media events that made "heroes" out of the winners. In particular, the prize was to be associated with a series of races: in the later guidelines this included three (not two) races – first a Stage Race "comprising stages with courses that will reflect known consumer driving patterns, incorporating a variety of realistic and performance-illustrating driving conditions, terrains, and trip profiles" (PIAXP Guidelines 2009b), second, a Knock-out Qualifying event in which vehicles would "demonstrate at least 67 MPGe (i.e., two-thirds of the 100 MPGe target) over a road course based on . . .the Highway Fuel Economy Driving Schedule (HWFET) test cycles" (PIAXP Guidelines 2009b). Remaining vehicles would

[12] Last accessed from http://www.progressiveautoxprize.org/prize-details on 17.10.11.

[13] The definition of Miles per Gallon equivalent (MPGe) required new and creative work on the part of the X PRIZE Foundation in the design of the prize. At the time of the prize inception, no such metric was available. MPGe was defined as "a pump-to-wheels energy efficiency measure that expresses fuel economy . . .based on the energy equivalence of all fuel(s) consumed".

Table 3
Production-capable criteria for PIAXP judging.

Safety, emissions	Vehicles must be designed so that a production vehicle would likely be able to meet U.S. safety standards (FMVSS) and U.S. emissions standards (Tier II, Bin 5)	Vehicles must be designed to meet safety regulations in the U.S. and other markets
• Manufacturability, cost	Vehicles must be capable of being manufactured in quantities of 10,000 per year, with vehicle production costs within levels consistent with historical examples of comparable vehicles	Vehicle cost at a production rate of 10,000 units per year must be within levels that the market is likely to bear
• Features	Vehicles must be desirable, addressing the most important features and factors consumers consider when purchasing an automobile	Vehicles must be desirable, addressing the most important features and factors consumers consider when purchasing an automobile
• Business Plan	There must be a credible plan to manufacture, sell, and service 10,000 vehicles (or conversions) per year by 2014; The plan must show that the national fuel infrastructure will support the vehicles, especially if any non-standard fuels or fueling-methods are to be used	Teams must articulate clear and viable business cases for bringing their vehicles to market

proceed to a Final Stage Race, where "final ranking will be determined by the adjusted total time – i.e., the fastest vehicles are the winners" (PIAXP Guidelines 2009b). As is obvious, by incorporating a variety of criteria, minimum standards rather than maximum standards, and the constraint of exciting "races", the specifications were extremely complex and fraught with ambiguity of a type not anticipated in either the theoretical or normative literature.

Beyond illustrating the challenges associated with effective *ex ante* specification design under conditions with complex objectives, the experience of the PIAXP also underscores the problem of committing to a *static* set of prize rules – an issue not considered in either theory or policy. In the first design iteration, the prize was designed to award the first team to meet all the technical specifications and win the race. After input and comment it was decided to split the competition into two divisions – a Mainstream division for four passengers and four wheeled vehicles and an Alternative division intended as an outlet for innovative ideas that push forward today's conventions about automotive transportation. By October 2008 it was announced that the PIAXP would include a Demonstration Division to recognize the fact that "actual, high-volume production vehicles involve more and substantially harder engineering challenges and tradeoffs than developmental vehicles that are merely production-capable" (PIAXP Guidelines 2009a). In 2010, the Demonstration Division was removed. Rule changes also arose in January 2009 – the active period of the competition: in Version 1.2 the PIAXP noted "we have relaxed the vehicle requirements in several areas such as: no top speed requirement (replaced by a highway-capable requirement), reduced acceleration requirements, no eco-feedback indicator" (PIAXP Guidelines 2009a).

Taken together, these examples underscore several core distinctions between the reality of prizes on the ground and the more normative and theoretical perspectives. In particular, prize specifications are hard to define and finalize. With complex objectives, specifications become extremely complex. In addition, and exacerbated by this level of complexity, it is hard to predict *ex ante* which rules will be problematic to the functioning of the GIP. As such, rather than being set *ex ante*, the specifications emerge. As we will examine (see Section 5.2.4, below) this leads to additional challenges in the design of prize governance and in the judging process.

5.2.2. Ex ante incentives

Ex ante incentives are critically important to successful GIPs. Indeed, theory has given growing attention to a variety of increasingly complex mechanisms that can be used to set prizes at the optimal level (Kremer, 1998). In contrast, the policy view uses a more simple heuristic formulation to select the appropriate prize level. Empirical reality from examining prizes such as the PIAXP shows that the prize purse is set with little attention to the economic benefits and costs of the innovation. Instead, organizers highlight a broader set of factors in setting the award amount and in shaping the incentives for innovative effort. However three distinctions arise when understanding incentives from the perspective of theory, advocacy and on-the-ground reality: first prize organizers and policymakers have a different calculus as they consider the monetary value of the prize. Second, compared to theory they generally consider IP to be a complement to, not a substitute for, prizes. Third, they consider incentives to be much more complex and multi-faceted.

The core theoretical starting point in designing incentives is the assumption that the prize incentive is entirely determined by the monetary prize value. As argued by Gallini and Scotchmer (2002), "a firm's willingness to accelerate invention at a higher total cost depends on the "prize" it will receive, conditional on delivering the product. Thus, the size of the prize determines the rate of investment" (p. 7). As a consequence, prize design theorists highlight the importance of setting the award to ensure that the marginal benefits of innovation towards the prize goal equal the marginal costs of participation. In simplest theoretical treatment, the prize amount is thus set equal to the full social value of the innovation as determined by the prize sponsor (Wright, 1983).[14] Alternatively, prizes may be set by considering the cost of participation, and, in some theoretical treatments, prize incentive designs use auction-based arrangements to reveal the benefit of solving a problem for a set of interested parties (Kremer, 1998; Kremer and Zwane, 2002).[15] Regardless of the approach, two elements of prize incentive design are central to the theoretical perspective: (1) the tight link between award size and effort and (2) the incentives that ensure effort *only* up to the point where it is not dissipative.

The government's approach to prize design has been strongly influenced by the tenets of prize theory – coupling the prize award and *ex ante* incentives, and linking prize size to considerations either of the social benefits of prizes or of the costs of participation. However, the policy approach takes a more heuristic turn. On the benefits side, for example, the Medical Innovation Prize

[14] Under conditions where a prize sponsor has private information about the value of a particular innovative solution (or private preferences about its value) prizes theoretically serve the same inducement function as patents (Kremer, 1998; De Laat, 1996; Scotchmer, 2004).

[15] By asking for-profit corporations to actually provide the prize purse for the X-Prize competitions the Foundation is implicitly auctioning off particular prizes to those parties who most highly value the solutions (or the process).

Act lists a variety of factors to consider when determining prize size, each of which speak to calculating the potential benefits of a solution. Conversely, the NAE report suggests focusing on the costs of participation when setting prize awards, noting that "the closer the objectives of the competition lie to the perceived market opportunities and existing capabilities of potential competitors, the lower the cost of competing and the smaller the prize will need to be" (NAE, 1999, p. 11). Likewise, in an approach more akin to procurement, the NAE argues that "the prize [purse] should be commensurate with the effort required and goals sought" (NAE, 1999, p. 11) and should be larger if the challenge solution involves high risk "beyond the current technological horizon, or otherwise neglected technologies or societal challenges" (NAE, 1999, p. 11). In sharp contrast to prize theory, however, advocates in government and elsewhere do not discuss the possibility that prizes could be too large and induce too much inefficient and potentially duplicative effort towards particular goals. Therefore, consistent with our discussion of objectives, under conditions where all additional effort is deemed valuable and benefits and costs are not clearly balanced, larger prizes will always be thought of as beneficial.

The empirical reality of GIPs as produced by the X PRIZE Foundation – and many prize organizers – differs sharply from theoretical views and, to some extent, from policy perspectives. They neither attempt to balance the costs and benefits of participation, nor do they try to value the potential social benefits of a prize solution. Some, like Peter Diamandis, are guided by history. In setting the first X PRIZE purse at $10 M, Diamandis was inspired by the large sums at stake in the Orteig Prize, the $25,000 reward that inspired Charles Lindbergh to venture across the Atlantic in his aircraft, the Spirit of St. Louis, in 1927 to become the first aviator to fly non-stop from New York to Paris. Consistent with objectives of garnering attention and building the reputation of participants and organizers, prize hosts emphasize the ability of a prize of a given magnitude to grab attention and generate media and innovator interest. Of course the publicity benefits of a large prize can be a double-edged sword: the Foundation had hoped to attract innovators from large established companies as well as entrepreneurs and "garage" innovators to the PIAXP. As the publicity grew however, none of the large auto companies participated, in spite of extensive efforts to solicit their interest (the major aerospace corporations did not participate in the Ansari XPRIZE either). A member of the PIAXP team reflected:

> *We were told that the GMs of the world no way they would risk being embarrassed unfairly by comparisons with developmental vehicles. Because they have such an emphasis on comfort and consumer comfort- they are to going to perform as well as new vehicles- last 100,000 miles- result in an unfair comparison- public do not understand those details" (interview with PIAXP organizer, April 2010).*

The second major divide between practice, policy, and theory of prizes lies in the area of intellectual property (IP) rights. In theory, prizes are always seen as a substitute for patents, but in practice they are viewed as a *complement*. This is consistent with the notion that the total package of prize incentives be maximized and set to build attention and interest rather than set at a level to induce the "right" amount of participation. The Foundation allows participants to keep the IP rights to their solutions:

> *We have a standard for any X PRIZE that we have no interest in taking IP from teams with the exception of media rights to tell the story of the competition. It is not in our best interest to claim IP. We are really trying to build markets and change an industry and to do that we need to allow teams to pursue their businesses in whatever way makes sense to them- we are very hands off on that. We have broad protection of teams in terms of judging process (Interview with PIAXP organizer, April 2010).*

This perspective diverges sharply from prize theory in which prizes are modelled as an alternative to IP ownership and IP rights do not serve as an element in the overall *ex ante* provision of incentives in prize design. Indeed, much of the raison d'être of the prize incentive mechanism is to avoid the deadweight loss of the patent monopoly (see Wright, 1983; Kremer, 1998). The historical record suggests a mixed set of choices regarding the relationship between GIPs and IP rights,[16] but today's prize advocacy is closer to practice in regarding IP rights as part of the overall collection of incentives provided to prize winners (and participants). In fact, several prize guidance documents (including Kalil, 2006) advise *against* exchanging the prize purse for intellectual property, based on the argument that the prize purse for a viable GIP often has to be extremely large, and IP ownership can offset the need for such a large purse (and induce effort on the part of possible non-winners).

The third sharp dividing line separating (in this instance) prize policy and practice from theory relates to the broader perspective on the types of incentives motivating participation in innovation prizes. While theory has focused on only monetary rewards, the PIAXP organizers hold the view that prize benefits (and therefore *ex ante* incentives) are multi-faceted:

> *Benefits do vary between competitors – one of them is exposure to new customers and assistance in building their brand, exposure to potential investors and sponsors and a validation that the business model they are going after is credible. . ..There is also awareness building of their vehicles amongst general public and investors and general sponsors. There is also in any start-up organization, having been in them myself – deadlines are really beneficial for driving breakthroughs. Teams may or may not acknowledge that rule but the fact is there is a schedule for the competition – that there is an end date- is a very motivating fact for getting work done – especially in a start up organization. Competitions also provide access to preferred providers of software or access to parts. . ..not necessarily financial but with parts, assistance or the like- that type of networking is very beneficial for our teams (Interview with PIAXP organizer, April 2010).*

Thus prize organizers consider incentives as extending beyond the money and IP rights to encompass media attention, reputation and education. While broadly consistent with academic literature highlighting incentives for innovation – such as career benefits and quality signaling (Lerner and Tirole, 2002) as well as fun and community building (von Hippel and von Krough, 2006) – this view has not been incorporated into prize theory.

The foundation has incurred considerable costs in the provision of the broader set of inducements. Indeed, while not observable in the cost of the prize purse, an under-appreciated feature of GIPs is the cost of running activities that produce benefits such as education, fun, attention etc. Education is a particularly critical but costly-to-provide incentive. According to one of the organizers, PIAXP "helped teams find funding and develop their business in a variety of ways, including educational presentations, webinars on sponsorship generation, and a "how-to deck" on marketing" (Interview with PIAXP organizer, April 2010). Our preliminary evidence suggests that teams indeed value the educational opportunities provided as this comment from a team member illustrates:

> *"the feedback is very helpful – we have some pretty good minds at our company but building a highway capable vehicle is a new*

[16] The 1795 for the Encouragement of Industry Prize to enhance the preservation of food was won in 1809 by Nicolas Francois Appert who was forced to publish his approach and his cannery was subject to intense competition from imitators (Knowledge Ecology International, 2008, p. 6). In the area of food and agriculture, the Napoleon III prize for a process to manufacture a butter substitute was awarded together with a patent (Knowledge Ecology International, 2008, p. 7).

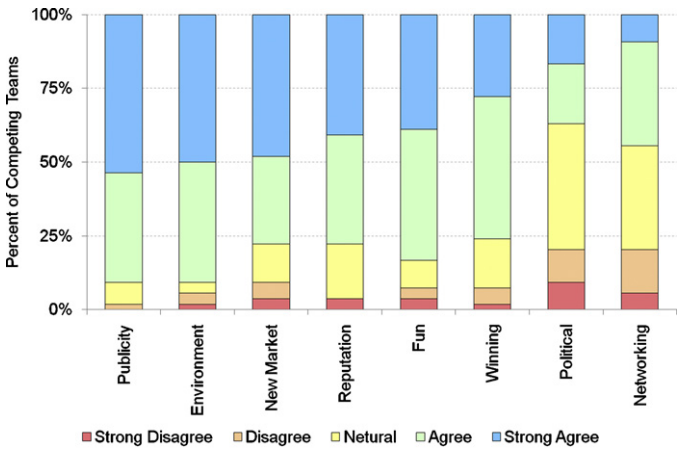

Fig. 1. Graph measures the teams' strength of agreement with different types of team motivators for choosing to compete in PIAXP (based on respondents all of whom successfully completed the early Design Judging stage of the PIAXP).

order of magnitude for our company – X PRIZE is giving us a lot of direction and feedback we probably won't have in house – X PRIZE has helped tremendously – not just with technical knowledge but also social media" (Interview with PIAXP competitor, July 2010).

Our survey results also suggest that a number of incentives are of significance to participants – consistent with recent empirical evidence from small-scale innovation prizes (Lakhani et al., 2007) – as illustrated in Fig. 1.

While the graph shows that a full 75% of the respondent teams agree (or strongly agree) that winning the prize motivates participation in the PIAXP, the most preferred rationale was publicity, helping the environment (which interviews suggest is interpreted as having a passion for the cause of building cleaner vehicles) and having fun. All of these ranked above winning the prize as agreed-upon motivators. Of course, for almost 70% of teams winning the prize was also important!

Taken together, the evidence suggests three points of divergence in understanding *ex ante* incentives for GIPs. First, while the focus of theory is on setting the level of the prize to induce the efficient amount of effort, most (although not all) prize advocates and organizers consider setting the purse to maximize effort. Moreover, in making this calculation, theorists carefully balance costs and benefits and policymakers use heuristics focused on benefit or costs levels, while prize organizers use a different calculus based on factors such as attention. Second, while theory sees IP rights as a substitute for prizes and an alternative incentive mechanism, policy advocates and prize organizers often use IP as a complement, thus boosting the "value" of the prize and inducing further development beyond the prize period. Third, prize organizers and advocates consider *ex ante* incentives well beyond the monetary award and the IP: they focus on fun, education, attention (and the reputation benefits that accrue). While publicity and reputation are linked to the prize purse, they are also closely coupled to (costly) marketing efforts, the excitement engendered by the prize and the validation provided by competing. This has significant implications for other aspects of prize design.

5.2.3. Qualification and staging

The third critical element of prize design involves determining the qualifications for participation and the structure for staging elimination rounds. In considering these issues, theory stands sharply at odds with advocacy and empirics: as highlighted in the discussion of prize objectives, theory is concerned with optimizing levels of participation in prizes, viewing duplication of effort as wasteful. In contrast, advocates and those active in the prize economy promote widespread participation through low barriers to qualification in order to maximize effort and involvement.

In models of innovation prizes (and procurement), qualification is used as a key mechanism to reduce the number of participants in any given innovative activity, ensuring efficient use of resources, reducing costs associated with selecting among different solutions, and guaranteeing the "right" innovators participate in the prize. While a range of qualification mechanisms have been modelled, of particular note are designs in which innovators pay to enter a GIP or bid in an auction for the right to compete (Wright, 1983). Such designs attempt to elicit information about the most qualified entrants and also limit the number of those entrants to efficient levels. Beyond limiting entry into a prize, it is also possible to stage participation through a series of "knock-out" rounds. Several theoretical models propose the staging of procurement (Laffont and Tirole, 1992), and suggest that a staged design is also appropriate for innovation prizes (Gandal and Scotchmer, 1993). The underlying logic of staging is simple: through a series of stages, the number of innovators can be reduced with low-cost validation of intermediate steps (towards the final objective), leaving remaining innovators to allocate additional resources to their prize efforts. Of course, each additional stage (prior to the final stage) re-introduces a number of design factors as noted, including the *ex ante* specification of technical requirements (see Section 5.2.1) and governance (see Section 5.2.4).

In contrast to theoretical perspectives, government policy approaches to GIPs focus on the importance of not selecting innovators *ex ante*. The National Academies report explicitly in arguing that the "primary reason for offering a prize is to attract different parties to contribute to a recognized societal or scientific objective" (NRC, 2007, p. 20) and strongly recommends that contests encourage participation from "a wide range of types of contestants, including those not ordinarily active in the research grant and contract world" (NRC, 2007, p. 46). The desire to encourage "unusual suspects" leads Kalil and others to emphasize the benefits of prizes design with limited "qualification" rules and low administrative requirements compared to other mechanisms. He states that "prizes can attract teams with fresh ideas who would never do business with the federal government because of procurement regulations, e.g., accounting and reporting requirements) that they may find burdensome" (Kalil, 2006, p. 7). This generally precludes prize designs with arduous qualifications and certainly militates against pay-to-play types of arrangements. The National Academies report explicitly recommends against charging fees at "initial registration, especially since one purpose of the prize program will be to encourage the widest possible participation including teams with limited resources" (NRC, 2007, p. 30).[17] With regards to staging, policy is less explicit and advocates large single stage prizes that garner attention. The NA suggests that "potential participating teams demonstrate their competence through a preliminary contest or demonstration" (NRC, 2007, p. 37). They argue for intermediate staging in instances that "involved access to and use of sophisticated federally owned measurement and testing equipment or facilities. . ..or resources that increased significantly with the number of contestants" (NRC, 2007, p. 37) citing the DARPA Challenge and the expense of using military resources to support a final competition too many participants.

[17] One additional aspect of participation criteria highlighted in prize policy is eligibility of entry. In a move that effectively limited any non-United States participation in prizes run under the Competes Act, Section 24 (g) specifies that to be eligible, "an individual or entity – . . . shall be incorporated in and maintain a primary place of business in the United States, and in the case of an individual, whether participating singly or in a group, shall be a citizen or permanent resident of the United States.

The evidence from the PIAXP and other GIPs suggests a structure more akin to the prevailing policy vision of prizes than theoretical pay-to-play qualification stages. However, the PIAXP experience also emphasizes the need for staged designs, given the high costs of education, testing, judging, etc. Thus, in its staged approach, prizes on the ground are closer to the staged competitions proposed in theory. The PIAXP evidence also highlights the attendant difficulties associated with staged designs.

After wide-ranging deliberations and public comment, the PIAXP designed five meaningful stages with a very low requirement bar set for initial registration. *Registration* for the Prize ran March 2006 to August 2008, with teams only signing a letter of intent. Teams then provided information for the *Design Judging Stage*, including data demonstrating that their vehicles were production capable. Based on this Stage, unsafe vehicles were eliminated. Remaining teams were invited to an event in Las Vegas in November 2009. Qualified teams went to Michigan in April 2010 for the start of the on-track performance events. These were organized in cooperation with the Michigan Economic Development Corporation (MEDC) and the Michigan International Speedway (MIS). The competition was then organized into a series of competition stages aimed at evaluating the efficiency, safety and performance of each competition vehicle under real world conditions. During the *Shake-down Stage*, the purpose was to conduct safety inspections and on-track dynamic safety evaluations of competition vehicles. Teams submitted their cars to on-the-ground challenges for the purpose of shaking out problem areas and preparing their vehicles for the Knockout Qualifying Stage that followed, all without risk of elimination by the judges. Vehicles were tested on braking speed, lane change ability, acceleration and refuelling/recharging time, etc. Prior to the *Knockout Stage*, to narrow the field of competitors PIAXP re-conducted inspections and certified readiness. In order to pass this, teams had to demonstrate that their vehicles could achieve 67 MPGe while also meeting expectations for range, emissions, and real world performance. Achieving emissions thresholds proved a significant hurdle for teams in this stage. The *Final Stage* was designed to identify the top finalists in each class. The Final Validation Stage was the final technical event, with the top finalists in the Mainstream and Alternative classes undergoing dynamometer testing under controlled laboratory conditions at certified labs to verify technical performance results. The results of this testing, combined with the speed, efficiency and emissions results from the earlier events, determined the winners of the PIAXP.

The evidence from PIAXP suggests that staging can be an extremely valuable approach to balancing the benefits of broad and diverse collaboration (through low entry barriers) against the costs of effective validation and testing, which requires the use of costly equipment under complex conditions. The degree to which the various PIAXP stages led to a reduction in the actual participants – versus their use as opportunities to build publicity, community and opportunities for education – can be seen in the levels of filtering and narrowing of the competitors between stages. As illustrated in Table 2, the PIAXP Registration attracted 111 teams with 136 vehicles, including 80 Mainstream vehicles and 56 Alternative vehicles (2+ passengers, no requirement on number of wheels). Of the 136 registered vehicles that were eligible for the Design Judging Stage, 108 actually submitted their materials, suggesting some "self triaging" Of the remaining registrants, 56 were qualified and passed into the next round in November 2010. Only 33 of these participants actually participated in the Shakedown in April 2010, and 28 made it to the Knock-out Stage in June 2010 (a very limited triage at this stage). Only 15 moved to the finals in July 2010, and 9 reached validation in August 2010. At the completion of the finals 3 winners were announced: one in the mainstream category, one in the alternative-tandem category, and one in the side-by-side category.

Another lesson derived from our findings emphasizes the importance of the staged design in "activating" prize incentives, beyond the prize purse (see Section 5.2.2). In particular, features such as media coverage, education and community-building are more usefully accomplished during the various events that "staging" allows. For example, one start-up entrepreneur (representative of many participants) described the value of various activities over the course of stages that could not have happened in the context of a one-stage design:

> *"X PRIZE is not tangible to our business, it is core. We're a new company. Safety- we have it in the spades, but we don't have a history for consumers to base their assessment of our vehicle's reliability or durability. X PRIZE gave us the opportunity for third-party validation of the claim of being the most energy efficient. So, coming here and being tested by Consumer's Union and the DoE and being sponsored by Progressive, it has the sense of credibility that we are doing, what we said we were doing. The most valuable outcome would be to see reports of our performance from the likes of a consumer union, where they say it is credible, solid and high performance" (Interview with PIAXP competitor, July 2010).*

An additional benefit of the staged design that has not been noted in either theory or in policy links to opportunities for education. One team member put the value of staging this way:

> *"it gave us a very rigid timetable- no room for error. As very small, lean company, that is challenging. If your Ford or GM and you are on a strict deadline- you throw more people on the project. We don't have those numbers which forces us to be smarter- we have to be as efficient in our thinking and in our design and development actions as we are in the execution of the car. When engineers are left up t o their own devices, they can iterate themselves into oblivion – you have to hold yourself to a certain timetable" (Interview with PIAXP competitor, July 2010).*

It is easy to underestimate another value of the staged structure: discipline. Many participants noted the value of the timetable and argued that the PIAXP structure helped them to be more timely, effective and innovative. By providing specific activities and education around defined stages, the X PRIZE was able to provide a clear and compelling timetable for action. These benefits suggest that while policymakers desire for one-stage "big bang" prizes is seemingly desirable, empirical reality suggests that low qualification barriers and opportunities for staging, can provide a compelling if costly prize design that accords with some aspects of prize theory.

5.2.4. Award governance

The final element of prize design concerns the process of judging, selecting winners, and awarding prizes. Formal prize theory has given little, if any, attention to the structure of governance arrangements and the institutional issues associated with credibly committing to awarding the prize. (Notably, Kremer (2002) provides an assessment of these issues for global health.) In most theoretical treatments, it is assumed that if a solution is forthcoming that meets the *ex ante* criteria, then prize awards will be allocated. The storied history of Longitude and the challenges faced by clockmaker John Harrison as he sought to collect his prize (Sobel, 1995) highlight the naiveté of the theoretical perspective. Of course, by extending insights from the political economy of intellectual property (Landes and Posner, 2004), it is reasonable to assume that a range of political forces are likely to influence judging and prize awards. Indeed, Davis (among others) has recently argued that prizes are an incentive mechanism likely to be vulnerable to high degrees of manipulation and capture (Davis and Davis, 2004). Nonetheless, theories of prize design have yet to anticipate the implications of weak governance.

Likewise, while current policy advocacy recognizes the import of governance, the literature provides only cursory guidance regarding it might be structured. For example, the NA (2007) report emphasizes that "contests should be designed [to] minimise the role of subjective judgements and controversy of outcomes" (NRC, 2007, p. 5). Kalil also advises that with ambiguous specifications it would be difficult to determine the winner, which may "lead to litigation about the final outcome" (Kalil, 2006, p. 20). In other words, if the criteria are too broad, "deciding which entrant is superior would become a contentious and subjective process" (Newell and Wilson, 2005, p. 27). As a practical matter, the need for governance is translated into prize-specific policy recommendations rather than broad, institution-building initiatives. The language of the MIPF Act specifies the creation of a 13-member Board of Trustees to serve as a permanent part of the executive branch, which is responsible for awarding prize payments.[18] Likewise, the National Academies suggests the need for "expert panels to judge the representations of competing teams", particularly in cases where some "degree of expert judgement" (NRC, 2007, p. 38) is required. However, it recommends that, at least for prizes sponsored by the National Science Foundation, the decision of the NSF director should be final.

The PIAXP experience emphasises two key problems regarding governance in action: the difficulty of establishing legitimate governance that is robust in the face of complex rules and the challenge of governance under conditions in which rules were changing. Specifically, the complexities of prize governance are illustrated by the difficulties faced by PIAXP throughout the competition. Overall, a number of teams expressed their frustration over rules that were unclear, inconsistent, and, as they perceived, potentially biased. One of the first accusations came as the result of the (potentially beneficial) wide-ranging discussion of prize rules, which led to charges of conflict of interest. The PIAXP countered with the following commentary in the third version of their prize guidelines:

> *We recognize that some contributors may end up competing, or perhaps advising those who compete, but that is an unavoidable result of engaging with so many experts who have real-world knowledge of the automotive industry. We believe that the Guidelines published here are balanced and credible, and that this would not have been possible without seeking as much feedback as possible from diverse parties, without regard for future possible conflicts. . ..Our process has been open, and we do not hide our involvement with any party* (PIAXP Guidelines 2009b).

PIAXP also replaced their Prize Development Advisory Board with a new, conflict-free Prize Administration Advisory Board. Beyond the notion that some individuals had tried to shape the rules according to their own strengths, participants felt that the rules were often unclear and lacking in clear criteria. Illustrating this frustration, one participating team noted:

> *"The test has been clear that you need to reach the 100 MPGe goal, but it hasn't been clear that if you do so what then. Who will win then? So I don't know. What's the number?" (Interview with PIAXP competitor, July 2010)*

This challenge arose in part because of the Foundation's desire to promote multiple competition objectives through the challenge statement and the prize design; as noted above, the PIAXP committee grappled with establishing clear technical criteria whilst also accelerating vehicle technologies, promoting business development and maintaining diversity and equity between the competition rounds within a specific timeframe. (For example, they did not want to knock out the less experienced teams early in the competition because they wanted to give these teams an opportunity to grow and develop.) However, the committee's policies inadvertently undermined the legitimacy of the governance process and the institutional infrastructure around which the prize was premised.

Beyond the governance challenges that arose from a lack of clarity in process and rules, the PIAXP also had to deal with rule changes that arise because of unforeseen problems or the desire to be "fair" to all participants. Unfortunately, as one team noted, "the rules for the events have been changing all the time". For example, in late 2009 entrants complained that the vehicles were too diverse to be compared using the same technical specifications. Therefore, through consultation with experts and teams, PIAXP devised two separate classes of Alternative vehicles, based on the architecture of the vehicle design. The $5 million Alternative purse would be split between the two winners of the Alternative Class – the fastest vehicle with side-by-side seating, and the fastest-vehicle with tandem seating. While the announcement (PIAXP Guidelines 2009b) was welcomed as being a better mode of evaluation, it also gave the impression that the rules were a moving target. From the perspective of the PIAXP, the flexibility in the rules benefited many teams who might otherwise have been eliminated from various stages; instead, these teams were given feedback and opportunities to improve. Describing the decisions to allow teams to move ahead, even if they had not met the rules of the stage (as laid out in the Guidelines), a PIAXP organizer argued:

> *The earlier rounds were also more lenient towards teams. Rather than eliminating teams for not hitting milestones, they provided detailed feedback, technical support and time to improve between rounds (in the earlier stages). Furthermore, workshops and webinars were offered upfront to provide additional support to teams that were not well versed in running a business.*

However it also rendered the judging and staging process less credible and opened up the possibility for complaints over governance and due-process. Several teams commented on the difficulties that arose because of these issues:

> *"[We are] competing for real money in real events. But you don't know what they are until you get there. . . There has to be a goal. And the goal here is really fuzzy. You have to go on trust and be willing to gamble because you just don't know. The truth is, you don't. The rules have changed many times."*

> *"Flexibility in the rules has it's advantages, especially during the earlier rounds to allow less experienced teams to catch up, however it resulted in the rules being unclear and potentially bias" and "actually, I think there's been quite a bit slipping in the rules for some things. I don't know why. But it seems to me that their rules aren't that strict. You can go under the fence somewhere" (Interview with PIAXP competitor, July 2010).*

The challenges to governance that arose throughout PIAXP are consistent with the problems faced by the Longitude Prize and the variety of innovators in prizes who make significant innovative efforts, only to find themselves disqualified from a competition or in a situation with changing rules. This is an issue that must be tackled directly by the organizers of any GIP. Furthermore, it should be recognized that these issues increase with the size of the prize purse (when more is at stake) and with the complexity of the prize specifications. The difficulties of the PIAXP illustrate the significant challenges that GIP incentive mechanisms pose and the possibilities

[18] (1) [t]he Administrator of the Centers for Medicare & Medicaid Services (2) [t]he Commissioner of Food and Drugs[;] (3) [t]he Director of the National Institutes of Health (4) [t]he Director of the Centers for Disease Control and Prevention and (5) [n]ine members appointed by the President, with the advice and consent of the Senate" (MIPF Act Section 6–7, 2005).

for capture, subversion or the appearance of bias. They suggest that much more thought should be given to the development of broader institutions to govern the emerging prize economy – a topic yet to be tackled by either theorists or policymakers.

6. Conclusions

Recognizing the need to fill the gap between theory and practice in Grand Innovation Prizes with a richer understanding of the empirical facts on the ground as well as accounting for the divergence between prize theory, advocacy and the realities of running Grand Innovation Prizes, we analysed the Progressive Automotive Insurance X PRIZE. To do so effectively, we explicitly developed and used a framework that relies on three dimensions of prize analysis: objectives, design, and performance, to shape our analysis. This furthers the study of innovation prizes as real-world incentive mechanisms not simply theoretical or policy ideals.

As we have shown, the empirical reality departs substantially from the ideal form of a prize, as described in the economic literature and advocated in policy-making documents. The contrast is particularly acute with respect to four areas.

First, contrary to the dominant theoretical perspective, which assumes GIPs have a single, ultimate objective – to promote innovative effort – we find that GIPs blend a myriad of complex goals, including attention, education, awareness, credibility and demonstrating the viability of alternatives. Paradoxically, our results suggest that prizes can be successful even when they do not yield a "winner" by traditional standards. Conversely, prizes in which a winner is identified and a prize awarded may still fail to achieve some of their most important design objectives.

Second, we find the types of problems that provide the target for GIPs are not easily specified in terms of a single, universal technical goal or metric. The reality is not nearly as clear or simple as either theorists or advocates have assumed. The complex nature of the mission (e.g., a highly energy efficient vehicle that is both safe to drive and can be manufactured economically), and the systemic nature of the innovations required to solve the stated problem, requires that multiple dimensions of performance be assessed. Some of these dimensions can neither be quantified nor anticipated, while others may change as the competition unfolds. Common metrics used today (e.g., miles per gallon) may be driven by current technical choices (i.e., gasoline engines), and translating them to work for new approaches (e.g., hydrogen fuel cells) may not be easily achieved. If done poorly, this will bias competitions in favour of certain technical choices and away from others. PIAXP demonstrates that contemporary GIPs are complex departures from smaller prizes examined by prior researchers, where the competitions involved individuals vying to solve relatively narrow problems (e.g., Lakhani et al., 2007). In those studies, the objective functions for solution providers are much more easily specified, as are the accompanying test procedures and mechanisms for governing and managing the process.

Third, we find a clear divergence between theoretical treatments of the incentive effect of a prize purse and the reality of why participants compete. Critically, there are a variety of non-prize incentives that are just as (if not more) salient to participants, many of which can be realized *regardless* of whether a team "wins" or not. Some of these broader incentives – publicity, attention, credibility, access to funds and testing facilities – are financial in nature, but not captured by the size of the purse. Others – such as community building – are social in nature and are difficult to measure in terms of the utility they generate for participants. Prior work has tended to view situations where prize participants collectively "spend" substantially more than the prize purse (i.e., in terms of resources) as evidence that prizes are inefficient in terms of inducing the correct allocation of inventive effort. Our observations however, provide an alternative explanation for why this may not be the case. Participants might, in fact, be responding rationally to a broader range of incentives than has been assumed in prior work.

Fourth, our work highlights the critical and underappreciated role of prize governance and management, a topic that is notably absent in the theoretical literature. We find that the mechanisms for governance and management must be designed explicitly to suit the particular prize being developed, a costly and time-consuming activity. Furthermore, given the difficulties in specifying *ex ante* all that can happen, rule modifications and adaptations along the way are to be expected, and these must be handled in a way that respects the rights and opinions of those participants who are already committed to the effort.

In combination, our results suggest that GIPS cannot be viewed as a simple incentive mechanism through which governments and others stimulate innovation where markets have failed. Rather they are best viewed as a novel type of organization, where a complex array of incentives are considered and managed in order to assure that successful innovation occurs. Our study has been useful in illuminating the particular challenges of an emblematic GIP, the PIAXP. Although variations will exist in how GIPs are organized and implemented, the results we have been able to capture validate the overall framework of analysis that we have deployed in studying GIPs. The close examination of the objectives, design, and performance will be useful in evaluating the burgeoning array of Grand Innovation Prizes. We hope and expect that such analyses will both enrich theoretical discussions of the topic and offer guidance to advocates as they attempt to spur innovative solutions to problems that lie beyond traditional incentive mechanisms.

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