FROM LONGITUDE TO ALTITUDE: INDUCEMENT PRIZE CONTESTS AS INSTRUMENTS OF PUBLIC POLICY IN SCIENCE AND TECHNOLOGY

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I. INTRODUCTION

On a foggy October night in 1707, a fleet of Royal Navy warships ran aground on the Isles of Scilly, some twenty miles southwest of England.[1] Believing themselves to be safely west of any navigational hazards, two thousand sailors discovered too late that they had fatally misjudged their position.[2] Although the search for an accurate method to determine longitude had bedeviled Europe for several centuries, the "sudden loss of so many lives, so many ships, and so much honor all at once" elevated the discovery of a solution to a top national priority in England.[3] In 1714, Parliament issued the Longitude Act,[4] promising as much as £20,000[5] for a "Practicable and Useful" method of determining longitude at sea; fifty-nine years later, clockmaker John Harrison claimed the prize.[6]

Nearly three centuries after the fleet's tragic demise, another accident, also fatal but far removed from longitude's terrestrial reach, struck a nation deeply. Just four days after its crew observed a moment's silence in memory of the *Challenger* astronauts, the space shuttle *Columbia* disintegrated upon reentry, killing all on board.[7] Although

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1. DAVA SOBEL, LONGITUDE: THE TRUE STORY OF A LONE GENIUS WHO SOLVED THE GREATEST SCIENTIFIC PROBLEM OF HIS TIME 12 (1995).

2. *Id*. at 11–12. The fleet's commanding officer, Admiral Sir Clowdisley Shovell, was one of only two men to wash ashore alive, though he was subsequently murdered on the beach by a local woman. *Id*. at 13.

3. *Id*. at 7–8, 16.

4. An Act for Providing a Publick Reward for Such Person or Persons as Shall Discover the Longitude at Sea, 1714, 12 Ann., c. 15 (Eng.) [hereinafter Longitude Act].

5. The Longitude Act authorized three prizes: £10,000 for a method to determine longitude to an accuracy of "One Degree of a great Circle, or Sixty Geographical Miles"; £15,000 for a method accurate to within two-thirds degree; and £20,000 for a method accurate to within one-half degree. *Id*.; *see also* SOBEL, *supra* note 1, at 53.

6. SOBEL, *supra* note 1, at 9–10. Harrison first presented his entry for consideration in 1737. *See id*. at 81–84.

7. *E.g.*, *Remains Thought to be from Columbia Crew*, CNN.COM, http://www.cnn.com/2003/TECH/space/02/01/shuttle.columbia/index.html (last visited Sept. 30, 2006).

Americans soon returned to space,[8] no manned space missions originated from the United States for more than seventeen months.[9] The June 21, 2004, launch of *SpaceShipOne*, the first privately financed manned spacecraft, marked a historic return to space from American soil.[10] Less than four months later, *SpaceShipOne* returned to space twice in two weeks to capture the $10 million Ansari X Prize, founded in 1996 to promote the space tourism industry through competition among non-government participants.[11]

The Longitude Act and the Ansari X Prize offer compelling—and competing—visions for technological innovation. Each contest's promise of a monetary reward spurred competition among a broad range of participants and ideas, all in pursuit of a common technological goal. Yet, despite providing a common impetus for innovation, these contests reflect divergent policy preferences. The Longitude Act—offered, administered, and awarded by government and its agents and open to all—demonstrates the potential efficacy of using prize contests as public policy instruments. The Ansari X Prize—offered, administered, and awarded by the private sector and open only to private-sector participants—establishes that purely private efforts also can advance technology effectively. The tension between public and private efforts and incentives constitutes a fundamental theme of this Note.

Also central to this Note are the implications of alignment between public policy and technology goals. Where public policy and technology goals are aligned, inducement prize contests can complement and coexist with government action to create great potential for innovation. Where public policy and technology goals conflict, however, the intrusion of government may stifle or marginalize potential innovations despite the existence of private inducement prize contests. Accordingly, government must weigh carefully the implications of intervention in considering whether to offer or oppose inducement prizes for technological or scientific innovation.

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8. Astronaut Ed Lu began his mission to the International Space Station on April 25, 2003, leaving from the Baikonur Cosmodrome in Kazakhstan. Jim Banke, *Fresh Crew Heads to Space Station in Tribute to Columbia*, SPACE.COM, Apr. 26, 2003, http://www.space.com/missionlaunches/soyuz_launch_030425.html.

9. *See* 2004 Space Launch Log, SPACE.COM, http://www.space.com/missionlaunches/launches/2004_launch_log.html (last visited Sept. 30, 2006); 2003 Space Launch Log, SPACE.COM, http://www.space.com/missionlaunches/launches/2003_launch_log.html (last visited Sept. 30, 2006).

10. Leonard David, *SpaceShipOne Makes History with First Manned Private Spaceflight*, SPACE.COM, June 21, 2004, http://www.space.com/missionlaunches/SS1_press_040621.html. *SpaceShipOne* now hangs in the Smithsonian's National Air and Space Museum's Milestones of Flight gallery. Press Release, National Air and Space Museum, SpaceShipOne Joins the Icons of Flight on Display at Smithsonian's National Air and Space Museum (Oct. 5, 2005), http://www.nasm.si.edu/events/pressroom/releaseDetail.cfm?releaseID=138.

11. Press Release, Scaled Composites, LLC, SpaceShipOne Captures X-Prize (Oct. 4, 2004), http://www.scaled.com/projects/tierone/041004_spaceshipone_x-prize_flight_2.html; *see* X Prize Found., What is the ANSARI X PRIZE?, http://www.ansarixprize.org/about/what_is_the_xprize.php (last visited Sept. 30, 2006) [hereinafter X Prize Found., What is the ANSARI X PRIZE?]; *see also infra* Part III.A.2.

This Note proposes to assess the role of government with respect to inducement prize contests and their underlying technologies. Part II offers an overview of inducement prizes, including descriptions of basic attributes, sponsorship and administration, and comparative advantages relative to other instruments of public policy in science and technology. Part III examines, via case studies, differences in the public policy treatments of underlying technologies advanced by selected inducement prizes.[12] Pursuant to such examination, Part III analyzes factors involved in the decisions whether to use inducement prizes as instruments of science and technology policy and what measures to pursue to advance or retard innovation in underlying technologies given the existence of relevant inducement prize contests. Finally, Part IV suggests conditions under which government might use inducement prizes as instruments of public policy and provides guidelines for how government might address disputed or disfavored technologies advanced by inducement prize contests.

II. BACKGROUND

In 1999, the National Academy of Engineering ("NAE") convened a workshop "to assess the potential value of federally sponsored prizes and contests in advancing science and technology in the public interest."[13] Forty-one participants from government, industry, and academe[14] assembled to consider the history, design, administration, and impact of prizes and contests as well as their potential value to addressing the aims of government agencies and society in general.[15] Workshop participants also considered the legislative, administrative, and legal ramifications of using prizes and contests as instruments of public policy in science and technology.[16] This Note takes as its starting point the findings and summary conclusions of that conference as stated in the report released by the workshop's steering committee.

12. Technologies discussed in these case studies include defense-related autonomous robotics, *see infra* Part III.A.1; commercial human spaceflight, *see infra* Part III.A.2; molecular nanotechnology, *see infra* Part III.B.1; and engineered negligible senescence, *see infra* Part III.B.2.

13. NAT'L ACAD. OF ENG'G, CONCERNING FEDERALLY SPONSORED INDUCEMENT PRIZES IN ENGINEERING AND SCIENCE v (1999) [hereinafter NAE REPORT].

14. The full roster of participants appears in an appendix to the NAE Report. *See id.* at B-1 to B-3.

15. *Id.* at v.

16. *Id.*

A. Basic Attributes of Inducement Prize Contests

1. Definitions and Distinctions of Inducement Prize Contests

Inducement prize contests are "competitions designed to foster progress toward or achievement of a specific objective by offering a named prize or award."[17] Such contests, which stimulate additional effort in pursuit of a specific goal, differ markedly from recognition prize contests, which acknowledge past achievement.[18] Contestants for recognition prizes usually are nominated by their peers, with winners chosen according to criteria that may or may not be public.[19] Recognition prize contests are thus retrospective and typically lack incentives for contestants to make additional efforts to improve their chances of winning.[20]

By contrast, inducement prize contestants must compete actively and openly; to win the prize, they must invest additional efforts in furtherance of the contest's specific objective.[21] Essentially, sponsors or administrators of these *ex ante* contests "define[] a problem to be solved, a reward for solving it, and the terms of the contest."[22] Further, administrators of inducement prize contests designate winners according to clearly defined criteria.[23] Although awarding the prize is only necessary upon completion of the goal,[24] some argue that there also is value in the contestants' collective failure.[25] Thus, even though "the losers work for nothing," inducement prize contests encourage activity.[26] Regardless of whether there is a winner, the contest outcome also "can shed light on the state of technology maturation."[27]

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17. *Id.* at 1.

18. *Id.* at 4. Among the most prestigious recognition prizes are the Nobel prizes. *Id.* Typical of recognition prizes, "[t]he Nobels are mostly a reward for past performance; sometimes, they are given decades after the achievements." Daniel Akst, *Do Good! Win a Prize!*, N.Y. TIMES, Oct. 17, 2004, § 3, at 6.

19. NAE REPORT, *supra* note 13, at 4.

20. *Id.*

21. *Id.*

22. Lee Davis & Jerome Davis, How Effective Are Prizes as Incentives to Innovation? Evidence from Three 20th Century Contests, Paper Presented at the DRUID Summer Conference 2004 on Industrial Dynamics, Innovation and Development (June 16, 2004) 4, *available at* http://www.druid.dk/ocs/viewpaper.php?id=114&cf=1.

23. NAE REPORT, *supra* note 13, at 4.

24. Akst, *supra* note 18; *see also* Brian D. Wright, *The Economics of Invention Incentives: Patents, Prizes, and Research Contracts*, 73 AM. ECON. REV. 691, 696 (1983) ("If a prize is chosen, it is awarded whenever success is achieved.").

25. *See, e.g.*, *NASA Contests and Prizes: How Can They Help Advance Space Exploration?: Hearing Before the Subcomm. on Space and Aeronautics of the H. Comm. on Science*, 108th Cong. 34, 41 (2004) [hereinafter *NASA Prizes Hearing*] (written statement of Molly K. Macauley, Senior Fellow, Resources for the Future).

26. Akst, *supra* note 18.

27. *NASA Prizes Hearing*, *supra* note 25, at 34 (written statement of Molly K. Macauley, Senior Fellow, Resources for the Future).

Inducement prize contests can be divided further into best-entry contests and goal-oriented contests.[28] Whereas the former reward the best solution to a given problem within a given time period, the latter may remain open until a contestant achieves the stated goal.[29] The privately funded Loebner Prize, awarded annually for the contestant computer that responds to questions most indistinguishably from a human, offers a representative example of a best-entry contest;[30] the Ansari X Prize, awarded to the first contestant to launch a privately financed manned spacecraft into suborbital space twice within a two-week period, offers a representative example of a goal-oriented contest.[31] Relative to best-entry prize contests, goal-oriented prize contests usually require more objective and less complex judging processes to determine winners.[32]

2. *Purposes and Objectives of Inducement Prize Contests*

The NAE Report identifies several generic purposes of inducement prize contests; though extensive, the list that follows is by no means exhaustive.[33] The purposes of inducement prize contests typically reflect a blend of scientific, technological, and societal objectives.

A primary purpose of inducement prizes is to attract a broad variety of involvement in scientific or technological challenges through

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28. *See id.* "Goal-oriented" is used interchangeably with "defined-objective" to mean a contest with a specific stated goal to be achieved by prize contestants. NAE REPORT, *supra* note 13, at 10–11.

29. NAE REPORT, *supra* note 13, at 10.

30. *Id.*; *see also* Loebner Prize Home Page, http://www.loebner.net/Prizef/loebner-prize.html (last visited Sept. 8, 2006). Since 1989, contest founder Hugh Loebner has spent more than $200,000 and volunteered a thousand hours "to hasten the arrival of intelligent machines." John Sundman, *Artificial Stupidity*, SALON.COM, Feb. 26, 2003, http://www.salon.com/tech/feature/2003/02/26/loebner_part_one/index.html. The following excerpt from an exchange between Jabberwacky, the 2004 runner-up, and a contest judge illustrates a recent state of the technology:

JUDGE: . . . Do you know something you call tell me about Oklahoma?
PROGRAM: Cold there. Do you know something about Novgorod?
JUDGE: I think Novgorod is in Russia. Am I right?
PROGRAM: No, it equals 8.
JUDGE: Oh. I thought Nova Scotia was closer to 8 than Novgorod. What is close to 10?
PROGRAM: Have you been tp [sic] mars [sic]. [sic]
JUDGE: Never, but I would like to be [sic] to Mars some day. Mars is soooo far away from here!
PROGRAM: Talk to Snoop Dogg.
JUDGE: Has Snoop been to Mars?
PROGRAM: I don't know, but I would like to think so.

Carpenter Jabberwacky, http://www.loebner.net/Prizef/2004_Contest/Jabberwocky.html (last visited Sept. 8, 2006) (timestamps omitted). Not surprisingly, no judge mistook a contestant computer for a human. Loebner Prize 2004 Results, http://loebner.net/Prizef/2004_Contest/loebner-prize-2004.html (last visited Sept. 30, 2006).

31. X Prize Found., About the X Prize Foundation, http://www.xprizefoundation.com/about_us/default.asp (last visited Sept. 30, 2006) [hereinafter About the X Prize Found.].

32. NAE REPORT, *supra* note 13, at 11.

33. Indeed, the objectives listed in the NAE Report are only those "that the workshop steering committee considered particularly worthy of consideration." *Id.* at 8.

identification and engagement of nontraditional participants and ideas.[34] As X Prize Foundation chairman and president Peter Diamandis notes,

> None of the traditional [NASA] contractors have [sic] demonstrated any interest in the X PRIZE competition. . . .
>
> The current contracting methods have spoiled the incumbents. They are paid for paper designs and are paid in cost-plus contracts *whether they deliver or not*.
>
> But luckily, it is not the traditional contractors who we seek to attract with these competitions. They lack the ability to take the risks involved in achieving breakthroughs and to achieve low-cost solutions.[35]

Inducement prize contests enable and encourage wider participation, in part, by lowering barriers to entry, especially relative to other instruments of public policy such as traditional government research grants or procurement contracts.[36] Prize contests achieve this lowering of entry barriers by reducing costs and other regulatory and bureaucratic obstacles by, for example, imposing few oversight requirements.[37] In theory, effectively calibrating an inducement prize to the level of effort required to achieve the contest's stated goal should cause capable contestants to self-identify.[38] The prospect and prestige of winning an open competition also may contribute to the ability of inducement prize contests to broaden the pool of potential contributors and ideas.[39] Although some participants may savor the thrill of competition itself,[40] the reputation motivator is essentially economic, as contestants may justify their participation by the potential increase in marketplace credibility that they believe winning would provide.[41] Empirical examples of this market-centric reputation effect abound,[42] perhaps none so heralded as the commercial licensing of *SpaceShipOne* technology to the Virgin Group.[43] Finally, contest design and structure

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34. *Id*. at 8, 14.

35. *NASA Prizes Hearing*, *supra* note 25, at 29 (written statement of Peter H. Diamandis, Chairman and CEO, X Prize Foundation) (emphasis added).

36. NAE REPORT, *supra* note 13, at 6, 8.

37. *See NASA Prizes Hearing*, *supra* note 25, at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

38. *See* NAE REPORT, *supra* note 13, at 6.

39. *NASA Prizes Hearing*, *supra* note 25, at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

40. *Id*. at 31 (oral statement of Molly K. Macauley, Senior Fellow, Resources for the Future).

41. *Id*. at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

42. *See, e.g.*, Davis & Davis, *supra* note 22, at 20.

43. The deal, announced just days before *SpaceShipOne*'s first qualifying flight for the Ansari X Prize, could be worth more than $21 million. Press Release, Scaled Composites, LLC, Virgin Group Sign Deal with Paul G. Allen's Mojave Aerospace: Licensing the Technology to Develop the World's First Commercial Space Tourism Operator (Sept. 27, 2004), http://www.scaled.com/projects/tierone/092704_scaled_paul_allen_virgin_galactic.htm. Virgin Galactic—"the most exciting development in the story of modern space history"—plans to make visiting the final frontier affordable by the end of the decade. *See generally* Virgin Galactic, http://www.virgingalactic.com/en/ (last visited Sept. 30, 2006).

can also play a part in encouraging a diverse range of participants and ideas. For example, RoboCup, an initiative to promote artificial intelligence and robotics research "by providing a standard problem [soccer] where [a] wide range of technologies can be integrated and examined,"[44] is open to all; past contestants have included high school students, graduate students, postdoctoral students, faculty, and researchers based in both not-for-profit and for-profit organizations.[45]

A major secondary purpose of inducement prize contests is to educate and inspire the public.[46] Beyond inviting the participation of contestants, inducement prize contests also can inspire complementary action by third parties.[47] Moved third parties might include policymakers, as illustrated by the opening remarks to a July 15, 2004, hearing before the House Subcommittee on Space and Aeronautics:

> Space entrepreneurs are anxious for polices that encourage further commercial activities and for future opportunities in space transportation. . . .
>
> The good efforts of . . . the X Prize have given us the historic opportunity to do space in a smarter way. In particular, the organizers of the X Prize contest never wavered in their belief that non-traditional players, someday, would make a tremendous impact on space transportation.
>
> . . . [*SpaceShipOne* is] a compelling example that a revamped national space program fueled by inspired, market-based creativity and innovation holds promise for America in the exploration and utilization of space.[48]
>
> . . . .
>
> There is no question that the recent success of *SpaceShipOne* in reaching the edge of space has generated a lot of excitement. . . .
>
> The development of a healthy commercial space sector is important to the future of this country, and it is something that I have long supported.[49]

More broadly, inducement prize contests can educate and inspire the public—and thereby build popular support—by offering better

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44. RoboCup Official Site, http://www.robocup.org (last visited Sept. 30, 2006). The RoboCup project's ultimate goal is: "By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, comply with the official rule [sic] of the FIFA, against the winner of the most recent World Cup." The RoboCup Federation, RoboCup: Objective, http://www.robocup.org/overview/22.html (last visited Sept. 30, 2006).

45. *See* NAE REPORT, *supra* note 13, at 8, 19 n.18.

46. *Id*. at 8.

47. *Id*. at 7.

48. *NASA Prizes Hearing*, *supra* note 25, at 13 (statement of Rep. Dana Rohrabacher, Chairman, House Subcomm. on Space and Aeronautics).

49. *Id*. at 13, 15 (statement of Rep. Nick Lampson, Ranking Member, House Subcomm. on Space and Aeronautics).

insight into underlying technologies than comparable work funded by other means.[50] In addition, a compelling prize topic or underlying technology, communicated via publicity or public demonstration, can enhance an inducement prize contest's inspirational effect, particularly on contest observers.[51] As Diamandis explains, "[A] key to [the] success [of the Ansari X Prize] was the romance and excitement involved with the prize topic. Sub-orbital space flight included the human element, the potential to create heroes and a personal message to every viewer of the competition, that message being 'You can go next!'"[52] Such celebrations of scientific or technological achievement and the triumphs of individual contestants create popular appeal, while demonstrations of the feasibility and commercial potential of particular technologies may also inspire public support.[53]

The NAE workshop identified several ancillary purposes that inducement prize contests might serve. Such contests might be used to promote emerging or "stalled" technologies or to "stretch" existing technologies by exhibiting their utility.[54] Additionally, inducement prize contests can aid technology diffusion.[55] Further, inducement prize contests also can confront overlooked or seemingly unsolvable societal problems.[56] Finally, inducement prize contests may enhance the collaborative capabilities and incentives of individuals and groups.[57]

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50. *See* NAE REPORT, *supra* note 13, at 7–8.

51. *See id*. at 8.

52. *NASA Prizes Hearing*, *supra* note 25, at 29.

53. *See id*. ("The potential for a billion dollar space tourism market has helped teams justify their investments and fuel their enthusiasm."); *see also* NAE REPORT, *supra* note 13, at 7–8.

54. NAE REPORT, *supra* note 13, at 9. Inducement prize contests instituted for these purposes could focus innovative efforts and public attention on (1) what could be done with nascent technologies, thereby offering a "proof of concept" value that would extend beyond the achievement of specified goals, or (2) what *else* could be done with existing technologies, thereby reinvigorating interest in new applications of or improvements to "old" innovations in established fields. *Id*. The NAE workshop cites the goals of two similar aerospace prize contests—nonstop global circumnavigation by airplane and by balloon—as examples of achievements that did not depend on new technologies but nevertheless "provided dramatic demonstrations of advanced technologies and extensive publicity for aerospace as an exciting field to enter or support." *Id*.

55. *Id*. The Super Efficient Refrigerator Prize ("SERP"), organized in 1992 by a consortium of electric utilities to promote the development of energy-efficient refrigerators, offered a $30 million prize based on the number of units sold; by giving participants an incentive to market their advanced products, SERP sought to effect early commercialization of the underlying technology. *Id*.; *see also* Davis & Davis, *supra* note 22, at 14, 16.

56. NAE REPORT, *supra* note 13, at 9 (identifying complex challenges such as air pollution and violent crime as potential prize topics); *see also* William A. Masters, *Research Prizes: A New Kind of Incentive for Innovation in African Agriculture*, 7 INT'L J. BIOTECHNOLOGY 195, 204–06 (2005); James Pinkerton, *Let's Hold a Contest for Truly Honest Elections*, TCS DAILY, Jan. 15, 2001, http://www.tcsdaily.com/article.aspx?id=011501H.

57. NAE REPORT, *supra* note 13, at 10. The alliance between Paul Allen, Burt Rutan and Scaled Composites, and Richard Branson's Virgin Group in pursuit of the Ansari X Prize confirms the capacity of contests to provide for the formation of ad hoc partnerships in pursuit of a specific goal. *Id*.; Press Release, Scaled Composites, LLC, Paul G. Allen Confirmed as Long-Rumored Sponsor of SpaceShipOne (Dec. 17, 2003), http://www.scaled.com/projects/tierone/121803.htm.

3. Structure and Design of Inducement Prize Contests

Design and structure are central to an inducement prize contest's success.[58] Relying on case studies of selected prizes and relevant research,[59] the NAE workshop suggested several guidelines for structuring successful inducement prize contests.

First, contest rules should be, or at least should be perceived to be, "transparent, simple, fair, and unbiased."[60] According to Diamandis,

> Writing the prize rules is the most critical step to achieving [the greatest possible innovation]. Well written rules will deliver breakthroughs, diversity and innovation. Poorly written rules will result in no entries, or worse yet, trivial solutions.
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> . . . .
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> . . . The rule making process will determine the success or failure of a competition. Writing these rules is an art form requiring specifying just enough, but not so much as to limit the creativity of the contestants.[61]

As Douglas Holtz-Eakin, director of the Congressional Budget Office, elaborates, "Unclear or unenforceable rules are an invitation to conflict, and the [sponsor] will bear a cost of adjudication when disputes arise."[62] Fair, unbiased, and unobtrusive enforcement of contest rules is also essential; contestants must believe there is "an even playing field without bias for a preferred technology or company" and be left alone "to the maximum extent possible."[63] To preserve the integrity of the competition and its rules, contest sponsors also must refrain from rewarding partial performance or less-than-complete success.[64]

Second, prize values should correspond to the contest's required effort and technological goals.[65] Contest designers should define awards that "offer a good prospect of success but take account of the subsequent benefits of spreading technological innovation to the larger economy."[66] Put differently, contest designers should be wary of both underinvestment, or offering too little to induce innovation, and overinvestment, or offering more than necessary to induce innovation.[67]

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58. *See, e.g.*, *NASA Prizes Hearing*, *supra* note 25, at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

59. NAE REPORT, *supra* note 13, at 11, 18 n.6; *see also* Davis & Davis, *supra* note 22, at 26–28.

60. *See* NAE REPORT, *supra* note 13, at 11.

61. *NASA Prizes Hearing*, *supra* note 25, at 29–30.

62. *Id*. at 44.

63. *Id*. at 29.

64. *See id*. at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

65. NAE REPORT, *supra* note 13, at 11.

66. *NASA Prizes Hearing*, *supra* note 25, at 45 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

67. *See id*. at 40–41 (written statement of Molly K. Macauley, Senior Fellow, Resources for the Future); NAE REPORT, *supra* note 13, at 11; Davis & Davis, *supra* note 22, at 18.

Prize size should be commensurate with the closeness of the contest objectives to perceived market opportunities and potential contestants' existing capabilities; the closer the relationship, the lower the prize amount should be, as the contestants' costs of competition will be lower.[68]

Third, intellectual property treatment should be aligned with the prize contest's objectives and incentives.[69] Determining the proper approach to dealing with intellectual property rights will depend upon the particular circumstances of the prize contest.[70] Competitions restricting the intellectual property rights of successful winners (e.g., through surrender to the contest sponsor or the public domain) will appeal to fewer contestants, thereby drawing less effort, but will allow for more rapid technology diffusion.[71] In deciding whether to compete, potential contestants will contemplate their ability to exploit via patents any expected commercial value of the research or innovation called for by the prize contest.[72] Accordingly, inducement prize contest designers should adjust intellectual property rights awards and prize amounts to achieve the best fit with contest goals and objectives.

A final consideration of contest prize designers involves determining who can compete and how.[73] As with intellectual property rights, eligibility criteria should be tailored to the goals and objectives of the prize contest. For example, the X Prize Foundation instituted its namesake prize to promote the commercial development of the space tourism industry through competition among *private* entrepreneurs; as such, participation was off-limits to government-funded contestants.[74] In addition, a prize contest designer should determine and implement the type of inducement prize contest structure most conducive to satisfying the sponsor's objectives in offering the prize. For example, the award can be structured as a tournament, specifying an objective and a time limit, or as a race, specifying a goal but not necessarily specifying a time limit.[75] Each type offers advantages and disadvantages that the prize contest designer must consider in choosing a structure that best suits the contest's goals and objectives.

68. NAE REPORT, *supra* note 13, at 11.

69. *Id*. at 12.

70. *Id*.

71. *See NASA Prizes Hearing*, *supra* note 25, at 45 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office). Holtz-Eakin directs his recommendation at designers of government-sponsored prize contests. *Id*.

72. *See id*. at 40 (written statement of Molly K. Macauley, Senior Fellow, Resources for the Future).

73. Although the NAE workshop did not offer an explicit guideline to this effect, such recommendation can be inferred from prior discussion of the purposes and objectives of inducement prize contests. *See infra* Part II.A.2.

74. *See* X Prize Found., What is the ANSARI X PRIZE?, *supra* note 11.

75. *NASA Prizes Hearing*, *supra* note 25, at 44 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office). This taxonomy parallels that of the NAE workshop; a tournament structure is equivalent to a best-entry contest, and a race structure is equivalent to a goal-oriented contest. *Compare id*., *with* sources cited *supra* notes 28–32 and accompanying text.

B. Sponsorship and Administration of Inducement Prizes

The award authorized by the Longitude Act[76] offers a representative example of a purely public inducement prize contest. The Act established a panel of judges comprising scientists, naval officers, and government officials to evaluate proposals and to exercise sole discretion over the prize money.[77] The Board of Longitude, as the panel came to be known, also possessed authority to grant incentive awards of up to £2000 "necessary for making the Experiments"[78] on promising proposals; by the time it disbanded in 1828,[79] the Board of Longitude had disbursed more than £100,000.[80] Thus created, sponsored, and administered by force of statute, the prize contest established by the Longitude Act reflected a purely public effort to direct the innovative efforts of many at a seemingly intractable problem.[81] The Defense Advanced Research Projects Agency ("DARPA") Program for Award of Competitive Prizes to Encourage Development of Advanced Technologies provides a modern-day analogue to the Longitude Act: the enabling statute[82] authorizes DARPA to offer million-dollar inducement prizes (up to $10 million per year through 2007).[83] Today, DARPA administers the Grand Challenge, an inducement prize contest "intended to accelerate research and development in autonomous ground vehicles that will help save American lives on the battlefield."[84]

At the other end of the spectrum are purely private inducement prize contests. In 1919, Raymond Orteig offered $25,000 "'to the first aviator who shall cross the Atlantic [alone] in a land or water aircraft . . . from Paris . . . to New York, or from New York to Paris . . . without stop.'"[85] The Orteig Prize was one of more than one hundred aviation prizes offered between 1905 and 1935, of which almost all were offered by private individuals and companies, not governments.[86] By stimulating nine separate Atlantic crossing attempts and inspiring competitors to

76. *See supra* notes 4–5 and accompanying text.

77. Longitude Act, *supra* note 4; SOBEL, *supra* note 1, at 54.

78. Longitude Act, *supra* note 4.

79. *See* Nautical Almanack Act, 1828, 9 Geo. 4, c. 66 (Eng.).

80. SOBEL, *supra* note 1, at 54–55.

81. Davis & Davis*, supra* note 22, at 4.

82. National Defense Authorization Act for Fiscal Year 2000, Pub. L. No. 106-65, § 244, 113 Stat. 512, 552 (codified as amended at 10 U.S.C. § 2374a (2004)).

83. *Id.*; Bob Stump National Defense Authorization Act for Fiscal Year 2003, Pub. L. No. 107-314, § 248(a), 116 Stat. 2458, 2502 (codified at 10 U.S.C. § 2374a(f) (2004)) (extending the authority of DARPA to award prizes until September 30, 2007); *see also* 10 U.S.C. § 2374a(a), (c), (f) (2004).

84. DARPA, Overview, http://www.darpa.mil/grandchallenge/overview.html (last modified Aug. 23, 2006); *see also* discussion *infra* Part III.A.1.

85. CHARLES A. LINDBERGH, THE SPIRIT OF ST. LOUIS 530 (1953). The Raymond Orteig Prize was the primary inspiration for the Ansari X Prize. *See* X Prize Found., What is the ANSARI X PRIZE?, *supra* note 11.

86. ANSARI X PRIZE, Fact Sheet, http://www.ansarixprize.org/about/fact_sheet.php (last visited Sept. 30, 2006); *NASA Prizes Hearing*, *supra* note 25, at 35 (written statement of Molly K. Macauley, Senior Fellow, Resources for the Future).

spend sixteen times the prize amount,[87] the Orteig prize demonstrated the power of the private purse to induce technological innovation. The Ansari X Prize provides a modern-day analogue.

Hybrid or joint sponsorship and administration models combine elements of purely public and purely private prize contests.[88] Such partnerships might be particularly appropriate where a public entity's research holds great immediate interest for the public but where it is politically expedient (or even preferable) for private entities to sponsor and design the prize contest.[89] Such prize contests arguably enjoy the benefits of both purer models: "[t]he use of private-sector judges brings credibility and reduces political influence . . . [while] government participation adds prestige and a sense of fairness."[90]

C. Comparative Advantages of Inducement Prizes as Instruments of Public Policy

Many of the advantages of inducement prizes relative to other instruments of public policy in science and technology derive from the purposes and basic attributes of such contests.[91] For example, inducement prize contests can attract a broad spectrum of participants and ideas because of their potential to lower barriers to entry by reducing the costs, bureaucratic and regulatory obstacles, and compliance burdens typically associated with other instruments of public policy in science and technology.[92] Prize contests also can reduce selection and monitoring costs for the contest administrator.[93]

Relative to other instruments of public policy, prize contests also allocate risk more efficiently.[94] Unlike research grants or procurement contracts, where the administrator assumes the risk of failure, inducement prizes are awarded only when the stated goal is achieved, thereby shifting much of the risk involved in pursuing a scientific or technological objective from the contest administrator to the contestants.[95] To be clear, prize contests do not alter the underlying factors that potential contestants, who might otherwise seek grants or procurement contracts, use to assess risk and awards; potential contestants still will weigh the potential risks and costs in choosing whether to compete and in determining what efforts to exert.[96] The prize

87. Fact Sheet, *supra* note 86.
88. *See* NAE REPORT, *supra* note 13, at 12.
89. *See id*. at 13.
90. *Id*. at 12.
91. *See supra* Part II.A.1–2.
92. NAE REPORT, *supra* note 13, at 6.
93. *Id*.
94. *Id*. at 7.
95. *Id*.
96. *See NASA Prizes Hearing*, *supra* note 25, at 43 (written statement of Douglas Holtz-Eakin, Director, Congressional Budget Office).

mechanism merely shifts the risk burden to those better positioned to make such a calculus, thereby linking incentives to performance and enabling administrators "to be more tolerant of prudent risk-taking."[97] This freedom to take risks (and freedom from fear of risk) is essential to the discovery impulse underlying prize contests; as Diamandis notes,

> Space is a frontier and frontiers are risky! As explorers and as Americans, we must have the right to take risks that we believe are worthwhile and significant . . . .
>
> It is also critical that we take risk in our technology development and that we allow for failure. Without risk and without room for failure we can not have the very breakthroughs we so desperately need.[98]

As noted previously, some have argued that failure in a prize contest may prove valuable.[99] The more efficient allocation of risk in a prize contest thus raises the potential for greater reward while mitigating the effects of failure for an administrator and contest participants.

Another comparative advantage of the prize mechanism is its ability to induce collective contestant investment of resources far in excess of the actual prize amount offered.[100] Illustrative examples of this leverage or multiplier effect include the more than $50 million spent by Ansari X Prize contestants in competition for $10 million (a five-to-one ratio)[101] and the $400,000 spent by Orteig Prize contestants in competition for $25,000 (a sixteen-to-one ratio).[102] Non-cash incentives, including publicity generated by the contest, recognition within a community of peers, or increased commercial demand for a winning technology, offer additional value to potential contestants and may help to explain their collective willingness to duplicate efforts.[103]

A final comparative advantage of inducement prize contests is the potential to educate and inspire the public.[104] As discussed above, this strength is explicitly linked to a major secondary objective of many prize

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97. NAE REPORT, *supra* note 13, at 7.

98. *NASA Prizes Hearing*, *supra* note 25, at 30–31.

99. *See supra* notes 25–27 and accompanying text.

100. *See* NAE REPORT, *supra* note 13, at 7. Some argue that this duplicative effect might be a disadvantage of inducement prize contests: "[T]here is a lot of economics research about possibly wasteful effort if you have got a lot of folks competing for a prize. From a broad, societal perspective, some economic theories have suggested that can be very wasteful. There is a duplication of effort in some of those cases." *NASA Prizes Hearing*, *supra* note 25, at 33 (oral statement of Molly K. Macauley, Senior Fellow, Resources for the Future); *see also id*. at 40 n.15 (citing research on the analogous problem of "patent races" and "whether simultaneous pursuit of a new technology leads to wasteful duplication").

101. *See NASA Prizes Hearing*, *supra* note 25, at 29 (written statement of Peter H. Diamandis, Chairman and CEO, X Prize Foundation). In his oral statement, Diamandis estimated the amount spent by competing teams at more than $100 million, or ten times the prize amount. *See id*. at 27.

102. *See supra* note 87 and accompanying text.

103. NAE REPORT, *supra* note 13, at 7. For a discussion of duplication of effort based on case studies of early aviation prizes and SERP, see Davis & Davis*, supra* note 22, at 18–19.

104. NAE REPORT, *supra* note 13, at 7.

contests: building interest in and popular support for the technology underlying the contest.[105]

III. ANALYSIS

The public policy treatments of underlying technologies advanced by various inducement prize contests differ by the type of technology and the implications of associated innovation. Factors considered in deciding whether and to what extent to use inducement prizes as instruments of public policy can be determined by examining these disparate treatments.

A. Promoting Innovation in Favored Technologies

Where the technology underlying an inducement prize contest is relatively free of negative descriptive, normative, or political implications, and where private-sector interest is either substantially independent of or entirely dependent on government, the government can become a singular or silent partner, effectively but cooperatively acting as a constitutional monopsonist or ceding particular technologies or industries to the private sector.

1. Single-Buyer Sponsorship of Innovation: Defense Technologies

The U.S. Constitution obliges the federal government to provide for the common defense of the United States.[106] This constitutional monopoly on military provision, combined with export controls on defense technologies,[107] effectively limits the market for buyers of domestically manufactured defense technologies to a single entity—the federal government. This monopsony situation often necessitates that the federal government serve as the sole sponsor of innovation in technologies with military applications. The federal government directly supports innovation and research through traditional research grants and procurement contracts.[108] Although large companies receive the bulk of Department of Defense awards for research, development, test, and evaluation work ("RDT&E") in defense technologies, small businesses and individuals also benefit from various procurement programs.[109]

105. *See supra* notes 46–53 and accompanying text.

106. Specifically, this duty falls to the Congress. U.S. CONST. art. I, § 8, cl. 1. For further explication of this provision, see THE FEDERALIST NOS. 23–26 (Alexander Hamilton).

107. *See* Foreign Military Sales Act, Pub. L. No. 90-629, 82 Stat. 1320 (1968) (codified as amended at 22 U.S.C. §§ 2751–2799aa-2 (2004)); International Traffic in Arms Regulations, 22 C.F.R. §§ 120.1–130.17 (2004).

108. NAE REPORT, *supra* note 13, at 5. Research grants fund predominantly "long-term, fundamental research in university and government research institutions," while procurement contracts fund mostly "applied research, technology development, and product or service production . . . by nongovernmental entities." *Id.*

109. The one-hundred companies receiving the largest total dollar volume of Department of

Nevertheless, identifying and contracting with innovative procurement partners in new or rapidly evolving technologies remains a challenge to government agencies.[110] DARPA, the central research and development organization for the Department of Defense, is acclaimed as "a trailblazer in the use of alternative procurement mechanisms" to attract and engage promising innovators in support of its mission.[111] DARPA sought and received statutory authority to offer substantial inducement prizes in 1999; Congress later extended DARPA's authority through 2007 and granted similar authority to the Secretaries of the military departments and the heads of defense agencies.[112]

The DARPA Grand Challenge, created in response to legislative mandate,[113] is the first inducement prize contest established according to this statutory authority. The contest advances DARPA's goal of "promot[ing] innovative technical approaches that will enable the autonomous operation of unmanned ground combat vehicles."[114] DARPA envisions such vehicles "navigat[ing] from point to point in an intelligent manner to avoid or accommodate obstacles including nearby vehicles and other impediments."[115] The DARPA Grand Challenge tests this vision by setting specific goals for speed and distance over realistic terrain.[116] Fifteen qualifiers competed in the first Grand Challenge to

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Defense prime contract awards in fiscal year 2004 received more than three-quarters of total RDT&E awards, with four companies (Lockheed Martin, Boeing, Northrop Grumman, and Raytheon) together receiving nearly fifty percent of total RDT&E awards. *See* STATISTICAL INFO. ANALYSIS DIV., DEP'T OF DEF., 100 COMPANIES RECEIVING THE LARGEST DOLLAR VOLUME OF PRIME CONTRACT AWARDS—FISCAL YEAR 2004, at tbl.3, http://siadapp.dior.whs.mil/procurement/historical_reports/statistics/p01/fy2004/top100.htm (last visited Oct. 4, 2006). In fiscal year 2003, however, small firms received 14.4% of RDT&E defense procurement, or more than $4 billion, including 92% of RDT&E procurement for "Civil Functions." STATISTICAL INFO. ANALYSIS DIV., DEP'T OF DEF., DEPARTMENT OF DEFENSE: PROCUREMENT FROM SMALL AND OTHER BUSINESS FIRMS, OCTOBER 2002–SEPTEMBER 2003 2 tbl.2, *available at* http://siadapp.dior.whs.mil/procurement/historical_reports/statistics /p16/P16_FY03.pdf (last visited Oct. 4, 2006). The Department of Defense also runs the largest fund in the federal government's Small Business Innovative Research Program, awarding approximately $1 billion annually to independent companies with fewer than 500 employees; the goal of the program is to encourage research into new technologies of potential benefit to military operations with the desire that such sponsored innovations will "go commercial as quickly as possible to assure a stream of reliable and cost-effective suppliers." Elizabeth Olson, *Uncle Sam Wants You (to Apply for a Grant)*, N.Y. TIMES, Nov. 4, 2004, at C6.

110. NAE REPORT, *supra* note 13, at 5.

111. *Id*. at 6.

112. *See* Bob Stump National Defense Authorization Act for Fiscal Year 2003, Pub. L. No. 107-314, § 248(c), 116 Stat. 2458, 2502 (codified at 10 U.S.C. § 2374b (2004)) (granting authority to Secretaries of the military departments and the heads of defense agencies to award cash prizes); NAE REPORT, *supra* note 13, at 6; *see also supra* notes 83–89 and accompanying text.

113. Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001, Pub. L. No. 106-398, § 220(a)(2), 114 Stat. 1654, 1654A-38 (2000) ("It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that . . . by 2015, one-third of the operational ground combat vehicles are unmanned.").

114. DARPA, DARPA GRAND CHALLENGE 2005: RULES § 1.1 (Oct. 8, 2004) [hereinafter DARPA, RULES], http://www.darpa.mil/grandchallenge05/Rules_8oct04.pdf.

115. *Id*.

116. *Id*.

navigate a rugged 200-mile desert course.[117] None succeeded, and the $1 million prize went unclaimed.[118] The next year, DARPA held a second Grand Challenge and awarded a $2 million prize to Stanford Racing Team, the fastest of five entrants to complete a similarly demanding course.[119]

More than 450 people—composing 106 teams and including high school and university students, vehicle manufacturers, software publishers, garage mechanics, computer programmers, sensing experts, off-road racers, entertainment industry insiders, and robotics enthusiasts—applied to compete in the first Grand Challenge.[120] These myriad contributors reflect the success of the Grand Challenge in achieving a primary purpose of inducement prize contests: to identify and engage nontraditional participants and unorthodox approaches.[121] As DARPA Director Anthony Tether declared, "Our goal was to attract a diverse mix of disciplines and personalities."[122] Broad participation in the Grand Challenge also serves a major secondary purpose of inducement prize contests: to develop interest in, and educate and inspire the public about, the underlying technology.[123] As DARPA notes, "The Grand Challenge draws widespread attention to the technology issues associated with autonomous vehicles."[124] DARPA's noble characterization of the pursuit of the underlying technology—a "quest to develop a new generation of autonomous robotic ground vehicles that some day soon will save the lives of men and women in our armed forces by performing hazardous tasks on the battlefield"[125]—also serves this educational and inspirational purpose.

The DARPA Grand Challenge demonstrates the utility of employing inducement prize contests as instruments of federal science and technology policy. Where government already occupies the field or otherwise shapes the market in underlying technologies, inducement

117. *See* DARPA, THE DARPA GRAND CHALLENGE: COMMEMORATIVE PROGRAM, MARCH 8–13, 2004 6 [hereinafter DARPA, COMMEMORATIVE PROGRAM], *available at* http://www.darpa.mil/grandchallenge04/program.pdf (last visited Sept 9, 2006).

118. The most successful entry traveled only 7.4 miles. *See* Press Release, DARPA, Final Data from DARPA Grand Challenge (Mar. 13, 2004), http://www.darpa.mil/grandchallenge04/media/final_data.pdf. As noted earlier, though, failure to win the prize need not be fatal to the underlying technology. *See supra* notes 25–27 and accompanying text; *see also infra* note 119 and accompanying text.

119. *See* Press Release, DARPA, A Huge Leap Forward for Robotics R&D (Oct. 9, 2005), http://www.darpa.mil/grandchallenge05/GC05winnerFINALwTerraM.pdf. Twenty-three finalists competed in the race. *Id*.

120. DARPA, COMMEMORATIVE PROGRAM, *supra* note 117, at 3. Even more teams applied to compete in the second Grand Challenge. Press Release, DARPA, 195 Teams Sign Up to Compete in the DARPA Grand Challenge (Feb. 15, 2005), http://www.darpa.mil/grandchallenge05/GC05FinalApps2-15-05PR.pdf.

121. *See supra* notes 34–45 and accompanying text.

122. DARPA, COMMEMORATIVE PROGRAM, *supra* note 117, at 8.

123. *See supra* notes 46–53 and accompanying text.

124. DARPA, RULES, *supra* note 114, § 1.1.

125. DARPA, COMMEMORATIVE PROGRAM, *supra* note 117, at 3.

prize contests offer additional flexibility in research sponsorship. Inducement prize contests also enable the sponsoring agency to attract a broad spectrum of participants and ideas, many of which otherwise might be discouraged by prohibitively high barriers to entry or bureaucratic bloat associated with government grants and procurement contracts. Finally, as the 2004 Grand Challenge participants' collective failure illustrates, prizes need not be awarded unless a winner emerges. Reserving payouts thus frees agencies from incurring costs to back losing ideas and automatically aligns them with winning innovations; such efficiency is to be welcomed where government is the only possible party to one side of a market transaction.

2. The Sky's No Limit: Commercial Human Spaceflight

The internationally recognized altitude at which space begins—where one "slip[s] the surly bonds of earth" to "trod [t]he high untrespassed sanctity of space"[126]—is 100 kilometers above sea level.[127] As with provisions for the national defense, the federal government had long reserved reaching the universe beyond that boundary as its exclusive province. Such assumed authority over human spaceflight, however, emerged from descriptive fact, not constitutional decree; early would-be private actors lacked the technological abilities and financial resources to pursue manned spaceflight on their own. Reminiscent of early aviation, there now exists both substantial private-sector interest in human spaceflight and the means to achieve it. This does not mean that government and its agents lack innovative purpose in human spaceflight outside of traditional government efforts. Past technological achievements and operational successes and failures of the National Aeronautics and Space Administration ("NASA") offer object lessons for modern space entrepreneurs, informing and influencing their paths to technology development.

The era of human spaceflight began nearly fifty years ago. In 1958, the Congress enacted legislation establishing NASA, charging the agency

126. John Gillespie Magee, Jr., *High Flight*, *in* FAVORITE POEMS 203 (Helen Ferris Tibbets ed., 1957). President Reagan famously appropriated Magee's sonnet in eulogizing the *Challenger* crew. Address to the Nation on the Explosion of the Space Shuttle *Challenger*, 1986 PUB. PAPERS BOOK I, 94, 95 (Jan. 28, 1986) ("The crew . . . honored us by the manner in which they lived their lives. We will never forget them, nor the last time we saw them, this morning, as they prepared for their journey and waved goodbye and 'slipped the surly bonds of earth' to 'touch the face of God.'").

127. Dan Kois, *Where Does Space Begin?*, SLATE, Sept. 30, 2004, http://fray.slate.com/id/2107381. The altitude, admittedly arbitrary, is the speculated point "below which significant lateral thrust would be required to keep a craft flying level." *Id*. The World Air Sports Federation, which maintains the definitive list of flying records, adopted the so-called Karman Line (named for aeronautics researcher Theodore Von Karman) in the mid-1950s; many other agencies and organizations worldwide have adopted it since. *Id*. Still, the boundary of space remains an ambiguous concept. *Id*. ("[T]he distinction between space and the atmosphere is too fuzzy for a physics-based definition ever to be established."); *see also* National Aeronautics and Space Act of 1958, § 103(1)(A), 42 U.S.C. § 2452(1)(A) (2000) (defining "aeronautical and space activities" to mean, in part, "research into, and the solution of, problems of flight *within and outside the earth's atmosphere*") (emphasis added).

with "plan[ning], direct[ing], and conduct[ing] aeronautical and space activities" and authorizing it "to acquire . . ., construct, improve, repair, operate, and maintain . . . aeronautical and space vehicles."[128] Such vehicles could be manned or unmanned.[129] The Cold War was a primary motive for launching humans into space: "[A]t present the most impelling reason for our effort has been the international political situation which demands that we demonstrate our technological capabilities if we are to maintain our position of leadership."[130] In early 1961, a transition team advised President-elect Kennedy on the inevitability of human spaceflight and the need for forceful policy:

> We are rapidly approaching the time when the state of technology will make it possible for man to go out into space. It is sure that, as soon as this possibility exists, man will be compelled to make use of it, by the same motives that have compelled him to travel to the poles and to climb the highest mountains of the earth. There are also dimly perceived military and scientific missions in space which may prove to be very important.
>
> Thus, manned exploration of space will certainly come to pass and we believe that the United States must play a vigorous role in this venture.[131]

Three months later, Soviet cosmonaut Yuri Gagarin became the first person both in space and in orbit; although U.S. astronaut Alan Shephard became the first American in space a mere twenty-three days after Gagarin, more than ten months elapsed before John Glenn became the first American in orbit.[132] Recognizing these early voyages as the opening salvos of a Cold War competition in human spaceflight, President Kennedy publicly committed the United States to the goal of a manned moon mission before the end of the decade.[133] Such a commitment also found purpose outside immediate political considerations: "But this is not merely a race. Space is open to us now; and our eagerness to share its meaning is not governed by the efforts of others. We go into space because whatever mankind must undertake, free men must fully share."[134] However noble the ideal it embraced, this commitment nevertheless presupposed pursuit of the goal by the federal

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128. 42 U.S.C. §§ 2472, 2473(a)(1), 2473(c)(3).

129. *Id*. § 2452(2).

130. PRESIDENT'S SCI. ADVISORY COMM., REPORT OF THE AD HOC PANEL ON MAN-IN-SPACE 1 (Dec. 16, 1960), *available at* http://www.hq.nasa.gov/office/pao/History/report60.html.

131. WEISNER COMM., REPORT TO THE PRESIDENT-ELECT OF THE AD HOC COMMITTEE ON SPACE 15 (Jan. 10, 1961), *available at* http://www.hq.nasa.gov/office/pao/History/report61.html.

132. *List of Human Spaceflights, 1961–1986*, WIKIPEDIA: THE FREE ENCYCLOPEDIA (Sept. 30, 2006), http://en.wikipedia.org/wiki/List_of_human_spaceflights%2C_1960s.

133. Special Message to Congress on Urgent National Needs, 1961 PUB. PAPERS 396, 404 (May 25, 1961).

134. *Id*.

government alone. Backed by public policy edicts,[135] the Apollo program and later NASA efforts thus entrenched the agency's apparent monopoly on human spaceflight in the United States during the technology's formative first twenty-five years.

Beginning in 1982, however, new policy statements[136] and legislation[137] began to open space to commercial interests. At first, this expansion of opportunity applied only to commercial launch activities, such as cargo transportation, and did not extend to human spaceflight.[138] As of 1994, the market prospects for commercial human spaceflight remained unattractive to potential investors.[139] Signs of growing demand in space tourism since then, however, have prompted new investors to fund entrepreneurial commercial human spaceflight ventures.[140]

A shift in public policy has accompanied such increased demand. Rather than developing the space tourism industry itself, the government considers its primary role to "be one of creating a stable regulatory environment."[141] To that end, the Congress enacted the Commercial Space Launch Amendments Act of 2004 ("CSLAA"), which declares that "the goal of safely opening space to the American people and their private commercial, scientific, and cultural enterprises should guide Federal space investments, policies, and regulations."[142] Acknowledging that a clear and balanced regulatory regime for commercial human space flight best serves the public interest in that technology, the CSLAA provides for a responsive, adaptive approach: "[T]he regulatory

135. *See, e.g.*, Jimmy Carter, Presidential Directive, National Space Policy (May 11, 1978), *available at* http://www.hq.nasa.gov/office/pao/History/nsc-37.html; Statement Announcing Decision to Proceed with Development of the Space Shuttle, 1972 PUB. PAPERS 20, 20–21 (Jan. 5, 1972), *available at* http://www.nixonfoundation.org/clientuploads/directory/archive/1972_pdf_files/1972_0003.pdf; SPACE TASK GROUP, THE POST-APOLLO SPACE PROGRAM: DIRECTIONS FOR THE FUTURE (Sept. 1969), *available at* http://www.hq.nasa.gov/office/pao/History/taskgrp.html.

136. *See* United States Space Policy: Fact Sheet Outlining the Policy, 18 WEEKLY COMP. PRES. DOC. 872 (July 4, 1982) [hereinafter 1982 Space Policy] (establishing as a basic goal the expansion of United States private-sector investment and involvement in space and space-related activities); Ronald Reagan, Presidential Directive on National Space Policy (Feb. 24, 1984), *available at* http://www.hq.nasa.gov/office/pao/History/policy88.html ("[T]he United States government shall not preclude or deter the continuing development of a separate, non-governmental Commercial Space Sector."); Exec. Order No. 12,465, 49 Fed. Reg. 7211 (Feb. 24, 1984) (designating the Department of Transportation as the lead agency for "encouraging and facilitating commercial [expendable launch vehicle] activities by the United States private sector").

137. Commercial Space Launch Act, Pub. L. No. 98-575, 98 Stat. 3055 (1984) (codified as amended at 49 U.S.C. §§ 70101–70121 (2004)).

138. *See* sources cited *supra* notes 136–37. *But see* Commercial Space Launch Amendments Act of 2004 § 2(a), Pub. L. No. 108-492, 118 Stat. 3974, 3974 (2004) (amending code provisions governing commercial space launch activities to include human spaceflight).

139. *Commercial Human Space Flight: J. Hearing Before the Subcomm. on Space and Aeronautics of the House Comm. on Sci. and the Subcomm. on Sci., Tech., and Space of the S. Comm. on Commerce, Sci., and Transp.*, 108th Cong. 3 (2003) [hereinafter *Joint Commercial Spaceflight Hearing*] (hearing charter).

140. *Id*. These new investors include such Internet luminaries as Jeff Bezos, founder of Amazon.com, and Elon Musk, who sold his Internet companies for $1.8 billion to found his launch vehicle manufacturing firm. *Id*. at 3 n.1.

141. *Id*. at 4.

142. Commercial Space Launch Amendments Act of 2004 § 2(a)(5).

standards governing human space flight must evolve as the industry matures so that regulations neither stifle technology development nor expose crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry."[143] As introduced, the CSLAA imposed only a moderate burden on the commercial human spaceflight industry and clarified industry participants' potential liability to customers and third parties.[144] The CSLAA concentrates regulatory authority in a single agency, allows the issuance of experimental permits with lower compliance burdens, and extends existing liability indemnification for commercial launches to commercial human spaceflight.[145] In a broad concession to the space entrepreneurs, the CSLAA also limits requirements for informing passengers of the risks of their participation and obtaining written informed consent.[146] Finally, the CSLAA requires participants and crew to execute mutual liability waivers with licensees and the federal government.[147]

This high risk tolerance reflects that of the sponsors, administrators, and participants of the Ansari X Prize, an inducement prize contest that unquestionably informed congressional action on the burgeoning commercial human spaceflight industry.[148] The Ansari X Prize promised $10 million to the first entrant to reach space twice in two weeks using the same vehicle.[149] The X Prize Foundation used its prize funds, received as donations from corporations, organizations, and wealthy individuals,[150] to pay premiums on a "hole-in-one" insurance policy that expired at the end of 2004.[151] The goal of the Ansari X Prize contest

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143. *Id*.

144. *See* H.R. REP. NO. 108-429, pt. 2, at 3–4 (2004).

145. *Id.* pt. 5, at 6.

146. *Id*.

147. *Id*. The Senate dithered, proposing amendments to strengthen safety regulations and reduce risk; the resulting perception of regulatory imbalance nearly scuttled the bill. *See* Alan Boyle, *Suborbital Legislation Put on Hold*, MSNBC, Oct. 8, 2004, http://www.msnbc.msn.com/id/6201543. The Federal Aviation Administration, charged with regulating commercial spaceflight, issued proposed regulations that largely reflect the CSLAA's restraint. *See* Human Space Flight Requirements for Crew and Space Flight Participants, 70 Fed. Reg. 77,262 (Dec. 29, 2005); Darlene Superville, *Gov't Issues Proposed Space Tourism Rules*, SPACE.COM, Dec. 30, 2005, http://www.space.com/news/ap_051230_tourism_rules.html.

148. *See, e.g.*, *Perspectives on the President's Vision for Space Exploration: Hearing Before the House Comm. on Sci.*, 108th Cong. 104–05 (2005); *Joint Commercial Spaceflight Hearing*, *supra* note 139, at 4; H.R. REP. NO. 108-429, pt. 9, at 17; *see also supra* text accompanying notes 94–99 (discussing risk tolerance).

149. *See* X Prize Found., What is the ANSARI X PRIZE?, *supra* note 11. No restrictions were placed on competitors other than that flight vehicles must be privately financed and economically reusable, that is, "no more than 10% of [its] first-flight non-propellant mass may be replaced between the two flights." X Prize Found., Rules and Guidelines, http://www.ansarixprize.org/teams/rules_and_guidelines.php (last visited Sept. 9, 2006) [hereinafter X Prize Found., Rules].

150. X Prize Found., Our Donors, http://www.xprizefoundation.com/about_us/donors.asp (last visited Sept. 9, 2006).

151. Alan Boyle, *SpaceShipOne Wins $10 Million X Prize*, MSNBC, Oct. 5, 2004 [hereinafter Boyle, *SpaceShipOne Wins*], http://www.msnbc.msn.com/id/6167761.

founders and administrators was "to promote the development and flight of spaceships able to provide low-cost commercial transport of humans into space."[152] Twenty-six teams signed up to compete for the prize and invested more than $100 million in their efforts.[153] Aerospace designer Burt Rutan built the winning entry, *SpaceShipOne*, with the financial backing of software billionaire Paul Allen,[154] demonstrating the potential for inducement prize contests to build social capital.[155] Although Rutan and Allen spent more than $20 million to win the $10 million prize, they expect additional payoffs from successor spacecraft built for Virgin Galactic, which has leased the technology for commercial use.[156] Beginning in 2007, Virgin Galactic will offer suborbital human spaceflights for $200,000 each, though competitors are already promising lower fares.[157] Such competition suggests that the industry the Ansari X Prize helped launch is off to a promising start.

The Ansari X Prize has inspired similar prize contests in human spaceflight and in other underlying technologies. Following where it left off, the X Prize Foundation is sponsoring the X Prize Cup.[158] Bigelow Aerospace, which is currently developing inflatable orbital habitation modules, is sponsoring America's Space Prize, a $50 million inducement prize contest designed to push privately funded human spaceflight into orbit.[159] Even NASA has entered the fray: the Centennial Challenge is the agency's program of prize contests "to stimulate innovation and

152. X Prize Found., Rules, *supra* note 149.

153. X Prize Found., About the X Prize Foundation, http://www.xprizefoundation.com/about_us/default.asp (last visited Sept. 9, 2006).

154. Boyle, *SpaceShipOne Wins*, *supra* note 151.

155. *See supra* note 57 and accompanying text. An even more robust illustration of this social capital effect is the establishment of the Personal Spaceflight Federation, an industry group of top Ansari X Prize contestants that will enable its members to "'speak with one voice to the regulators.'" Alan Boyle, *Space Racers Unite in Federation*, MSNBC, Feb. 8, 2005, http://msnbc.msn.com/id/6936543 (quoting Gregg Maryniak, executive director of the X Prize Foundation and chief federation spokesperson).

156. Boyle, *SpaceShipOne Wins*, *supra* note 151.

157. Rocketplane plans to charge $150,000 per ride with service starting in 2007, while XCOR Aerospace will offer flights for $98,000 each beginning in fall 2006. Tariq Malik, *Space Tourism Group Picks Florida Launch Site*, SPACE.COM, Mar. 9, 2005, http://www.space.com/missionlaunches/aera_spacetourism_050309.html.

158. X Prize Found., X Prize Cup: Frequently Asked Questions, http://www.xpcup.com/index.cfm?goto=about_us.aboutfaq (last visited Sept. 9, 2006). Participants will compete in a number of contests, including race to sub-orbital space, highest altitude achieved, most passengers to space in a single flight, and fastest turnaround time between successive flights. *Id.* The X Prize Foundation also has moved beyond space-related technologies by planning to offer a $5 million to $20 million prize in genomics. Antonio Regalado, *Prize for DNA Decoding Aims to Fuel Innovation*, WALL ST. J., Jan. 27, 2006, at B3. The prize reflects "an ambitious effort by the X Prize Foundation to become 'a global brand that establishes people as geniuses and innovators.'" *Id.* (quoting Peter Diamandis).

159. The prize winner must reach a minimum altitude of 400 kilometers, reach velocity sufficient to complete two orbits at that altitude, carry at least five people, demonstrate its ability to dock with Bigelow Aerospace's habitat modules, and complete two orbital missions within sixty days. Bigelow Aerospace Inc., America's Space Prize, http://www.bigelowaerospace.com/multiverse/space_prize.php (last visited Sept. 9, 2006); *see also* Michael Belfiore, *The Five-Billion-Star Hotel*, POPULAR SCI., Mar. 2005, at 50, 87; Tariq Malik, *America's Space Prize: Reaching Higher than Sub-Orbit*, SPACE.COM, Oct. 6, 2004, http://www.space.com/businesstechnology/technology/spaceprize_techwed_041006.html.

competition in solar system exploration and ongoing NASA mission areas."[160] More generally, inducement prize contests in other underlying technologies often cite the Ansari X Prize, due in part to the success of the prize contest in attracting interest to a nascent industry, and in part to instances of interlocking directorates of prize contest administrators, that is, service in some capacity in the administration of multiple inducement prize contests.[161]

The rapid evolution of commercial human spaceflight evinces Congress's rational response to related new technologies and its measured approach to the regulation thereof. Such restraint, corroborating the adage that less is more, demonstrates the possibility of achieving desired public policy aims without active intervention in "the final free market."[162] As in early aviation, when major passenger airlines arose as byproducts of the government contracting with private carriers to deliver airmail, so too can commercial human spaceflight develop from public policy treatment that recognizes and rewards efficiency in private innovation.[163] In a recent report, NASA recognized an opportunity to refocus its efforts on deep-space exploration and scientific research by permitting the private sector a greater role in near-Earth space.[164] Aligning public policy goals and private innovation objectives thus allows for complementary coexistence even where an inducement prize unsettles an established but de facto government monopoly.

B. Stifling or Marginalizing Innovation in Disputed or Disfavored Technologies

Where innovation in an underlying technology requires a rethinking of what is or ought to be possible, the government often exerts a restraining or controlling influence. Advocates of disputed or disfavored technologies thus promote advancement either with the circumscribed approval of government or independent of such seeming authority but without the associated focus or legitimacy. Such marginalization can

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160. NASA, Centennial Challenges, http://exploration.nasa.gov/centennialchallenge/cc_index.html (last visited Oct. 4, 2006). In 2004, the agency solicited external inputs on its future prize competitions from, among others, the X Prize Foundation. *NASA Prizes Hearing*, *supra* note 25, at 19 (oral testimony of Craig E. Steidle, Associate Administrator for Exploration Systems, NASA).

161. For example, Diamandis is a non-science advisor to the Methuselah Mouse Prize and chairs the Foresight Institute's Nanotechnology Prize Steering Committee. *See* Methuselah Found., Administration, http://www.mprize.org/index.php?pagename=adminlist (last visited Sept. 9, 2006) [hereinafter Methuselah Found., Administration]; Press Release, Foresight Nanotech Institute, Diamandis to Guide Foresight Institute Nanotechnology Prizes (Oct. 12, 2004), http://www.foresight.org/cms/press_center/97; *see also* discussion *infra* Parts III.B.1-2.

162. Max Boot, *Space, the Final Free Market*, L.A. TIMES, Oct. 7, 2004, at B13.

163. *Id*.

164. PRESIDENT'S COMM'N ON IMPLEMENTATION OF U.S. SPACE EXPLORATION POLICY, A JOURNEY TO INSPIRE, INNOVATE, AND DISCOVER 7 (2004), *available at* http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf. *But see* Ashley A. Hutcheson, Note, *Dollars and Sense: Why the International Space Station Is a Better Investment than Deep Space Exploration for NASA in a Post-*Columbia *World*, 2004 U. ILL. J.L. TECH & POL'Y 295, 313.

temper the long-term prospects of contest-induced advancements, forcing the potential fruits of innovation to wither on the vine or rot: "[A] prize, while it can be highly effective in inducing innovation, cannot necessarily sustain the commercial development of that innovation, if the external environment (here, in particular, the regulatory framework) is not conducive to that end."[165] The following two case studies illustrate the effect of unfavorable public policy.

1. Impossibly Small? Disputing the Art of the Possible: Molecular Nanotechnology

Presently, nanotechnology is primarily a materials technology used in a few consumer products such as semiconductors, sunscreen, and stain-resistant pants.[166] As introduced by K. Eric Drexler nearly twenty years ago, however, "nanotechnology" means something far more revolutionary: molecular manufacturing, or the manipulation of individual atoms and molecules with control and precision to build structures in desired configurations.[167] The concept underlying Drexler's vision originates with Nobel laureate Richard Feynman, who suggested "the possibility of maneuvering things atom by atom" and "mak[ing] a thing very small which does what we want."[168] Manipulation at this minute level begins with a molecular assembler—a device "resembling an industrial robot arm but built on a microscopic scale . . . and able to grasp and apply molecular-scale tools."[169] Such assemblers would provide the microscopic "hands" that scientists and engineers currently lack to control molecules directly and conveniently.[170] Molecular assemblers promise profound consequences, allowing humanity to build "almost anything we can design—including more assemblers."[171]

The prospect of uncontrolled self-replication has become a prominent doomsday meme of nanotechnology, exploited to influence

165. Davis & Davis*, supra* note 22, at 18.

166. *See, e.g.*, MICHAEL CRICHTON, PREY xii (HarperCollins 2002); Kenneth Chang, *Tiny is Beautiful: Translating "Nano" into Practical*, N.Y. TIMES, Feb. 22, 2005, at F1; *The Nanotech Schism: High-Tech Pants or Molecular Revolution?*, NEW ATLANTIS, Winter 2004, at 101, 101; David Pogue, *Explaining Nanotechnology*, N.Y. TIMES, Feb. 3, 2005, at F1.

167. *See* K. ERIC DREXLER, ENGINES OF CREATION 4–5 (1986) [hereinafter DREXLER, ENGINES OF CREATION]; Frederick A. Fiedler & Glenn H. Reynolds, *Legal Problems of Nanotechnology: An Overview*, 3 S. CAL. INTERDISC. L.J. 593, 595 (1994).

168. Richard P. Feynman, There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics, Address at the Annual Meeting of the American Physical Society (Dec. 29, 1959), *available at* http://www.zyvex.com/nanotech/feynman.html (last visited Sept. 9, 2006).

169. K. ERIC DREXLER ET AL., UNBOUNDING THE FUTURE: THE NANOTECHNOLOGY REVOLUTION 33 (1991), *available at* http://www.foresight.org/UTF/Unbound_LBW/chapt_1.html (last visited Sept. 9, 2006).

170. *Id*. at 33–34. Human hands are approximately ten million times too large for this purpose. *Id*. at 33.

171. DREXLER, ENGINES OF CREATION, *supra* note 167, at 14. RNA molecules are an example of naturally existing replicators. *Id.* at 22–25. Other natural examples of molecular machines abound and demonstrate the capability of building objects of substantial size. *See, e.g.*, *id.* at 58 ("[T]hey build whales, after all.").

popular attitudes and public policy. Drexler depicts this threat as the obliteration of natural life:

> [E]arly assembler-based replicators could beat the most advanced modern organisms. "Plants" with "leaves" no more efficient than today's solar cells could out-compete real plants, crowding the biosphere with an inedible foliage. Tough, omnivorous "bacteria" could out-compete real bacteria: they could spread like blowing pollen, replicate swiftly, and reduce the biosphere to dust in a matter of days. Dangerous replicators could easily be too tough, small, and rapidly spreading to stop—at least if we made no preparation.[172] Although Drexler couched his explication of the "gray goo problem" as an admonition for proper nanotechnology safeguards,[173] others have seized on this dire scenario to popularize perceived dangers, to call for suppression of research, and to discredit the underlying concept of molecular manufacturing. Novelist Michael Crichton, for example, told the fictional tale of a protagonist who, after destroying self-sustaining and self-replicating clouds of predatory nanomachines that escaped from a desert laboratory, worries that ignorance of the implications of nanotechnology development might prove to be humanity's ultimate undoing.[174] Bill Joy, co-founder of and former chief scientist at Sun Microsystems, argued that the only realistic way to defend against dangerous technologies (including nanotechnology) is "to limit development of the technologies that are too dangerous, by limiting our pursuit of certain kinds of knowledge."[175] Nobel laureate Richard Smalley supported nanotechnology generally but rejected the idea of molecular assemblers altogether, dismissing it as forever "a futurist's daydream."[176]

172. *Id*. at 172.

173. *See id*. at 190 ("Nanotechnology and artificial intelligence could bring the ultimate tools of destruction, but they are not inherently destructive. With care, we can use them to build the ultimate tools of peace.").

174. *See* CRICHTON, *supra* note 166, at 362–63.

175. Bill Joy, *Why the Future Doesn't Need Us*, WIRED, Apr. 2000, at 238, 254, *available at* http://www.wired.com/wired/archive/8.04/joy.html. Drexler likens unilateral suppression of research in nanotechnology to "unilateral disarmament in a situation where resistance cannot work," noting with particular urgency the danger posed by non-democratic regimes:

> An aggressive state could use these technologies to seize and rule (or exterminate) even a nation of Gandhis, or of armed and dedicated freedom fighters.
>
> . . . Without some novel way to reform the world's oppressive states, simple research-suppression movements cannot have total success. Without a *total* success, a *major* success would mean disaster for the democracies.

DREXLER, ENGINES OF CREATION, *supra* note 167, at 192. For a discussion of relinquishment and prohibition of nanotechnology research, see Glenn Harlan Reynolds, *Nanotechnology and Regulatory Policy: Three Futures*, 17 HARV. J.L. & TECH. 179, 188–92 (2003).

176. Richard E. Smalley, *Of Chemistry, Love and Nanobots*, SCI. AM., Sept. 2001, at 76, 77 ("Wishing that a waltz were a merengue—or that we could set down each atom in just the right place—doesn't make it so."). Smalley also believed "that speculation about the potential dangers of nanotechnology threaten[ed] public support for it." Rudy Baum, *Point-Counterpoint:*

Smalley's skepticism reflects a larger divide between "those who think [nanotechnology] will simply improve our lives and those who think it will completely transform them."[177] This increasingly bitter divide has spilled over into public policy with results disadvantageous to the Drexlerian vision. The 21st Century Nanotechnology Research and Development Act expects annual federal nanotechnology spending to reach more than $1 billion by 2008.[178] As passed by the House of Representatives, the legislation called for a study to evaluate the technical feasibility of molecular *manufacturing* and, if found to be feasible, to develop a timeframe for commercial viability and recommendations for a research agenda.[179] As amended by the Senate[180] and later enacted, however, the legislation called only for a study of the feasibility of molecular *self-assembly*.[181] This seemingly minor change effectively "gut[ted] the intended feasibility study of all usefulness . . . ."[182] Backers of the Drexlerian vision blamed the study's change of focus on the NanoBusiness Alliance, an industry organization representing companies pursuing pragmatic nanotechnology.[183] The Alliance president in turn derided the "bloggers, Drexlerians, pseudo-pundits, panderers and other denizens of their mom's [sic] basements" for "develop[ing] an elaborate fantasy about how molecular manufacturing research work was pulled from the bill by some devious

Nanotechnology, CHEMICAL & ENGINEERING NEWS, Dec. 1, 2003, at 37, 38. Drexler and Smalley publicly debated the prospect of molecular manufacturing at length. *See, e.g.*, *id.*

177. *The Nanotech Schism, supra* note 166, at 101; *see also The Societal Implications of Nanotechnology: Hearing Before the House Comm. on Sci.*, 108th Cong. 64–65 (2003) (written statement of Christine Peterson, President, Foresight Institute) (distinguishing near-term nanotechnology, "almost any technology significantly smaller than microtechnology," from advanced nanotechnology, "enabling broad control at the level of individual atoms . . . .").

178. 21st Century Nanotechnology Research and Development Act (2003), Pub. L. No. 108-153, § 6, 117 Stat. 1923, 1929 (codified at 15 U.S.C. § 7505 (2004)) [hereinafter Nanotechnology Act].

179. H.R. REP. NO. 108-89, at 5 (2003).

180. 149 CONG. REC. S15,086 (2003).

181. Nanotechnology Act § 5(b).

182. *The Nanotech Schism, supra* note 166, at 102 ("[M]olecular self-assembly is not merely feasible, it has actually already been achieved.").

183. *Id*. Critics of the NanoBusiness Alliance's alleged influence even resorted to Seussian satire:

The Schmirk hated the future! Hated nanotechnology!
Rejected the vision, no hint of apology!
. . . .
"Here is what must be done," said the Schmirk with a sneer,
And he called in his minions from far, wide, and near.
"We'll discredit the science, spread doubt and derision,
Politically swaying the funders' decision!"
And he quickly distributed papers and articles,
Detailing troubles with moving small particles.
. . . .
But the Schmirk didn't stop at that—"No," he averred,
"I'll stop any funding for even one Nerd!"
So he called in his minions again, did the Schmirk,
And said "Find me proof that THEIR nano WON'T WORK!"

Howard Lovy's NanoBot, http://nanobot.blogspot.com/ (Dec. 23, 2003, 12:39).

cabal."[184] Lost in the study's changes and ensuing invective was an opportunity to address the issue of molecular manufacturing's feasibility and cope with the consequences.[185] The legislation's commitment to triennial studies of the ethical, legal, environmental, and other appropriate societal concerns of nanotechnology[186] could further marginalize the Drexlerians.[187]

As expressed by legislative preference, public policy thus disputes the revolutionary vision of nanotechnology while embracing the evolutionary or pragmatic model, though there are signs of change.[188] As such, survival of the Drexlerian vision, at least in the short term, will depend largely on non-governmental institutions and efforts. The Foresight Institute, a non-profit organization focused on molecular nanotechnology, shares Drexler's preparatory imperative and has developed guidelines for responsible nanotechnology research and development.[189] The Foresight Institute also has established the $250,000 Feynman Grand Prize in Nanotechnology, to be awarded to the entrant who first designs and constructs two devices central to the revolutionary vision.[190] Recognizing the potential role of prize contests in technological advancement, the Foresight Institute sees the large award, expected to increase to $1 million through additional fundraising, as a way "to focus the efforts of many researchers working in nanotechnology-related fields."[191] The Foresight Institute also noted the potential for prize contests to stimulate nascent industries: "'[T]he rewards awaiting those who achieve significant nanotechnology breakthroughs will be far greater than the prize itself.'"[192] Annual Feynman Prizes (currently $10,000),

184. Mark Modzelewski, *Industry Can Help Groundbreaking Nanotech Bill Fulfill Its Promise*, SMALL TIMES, Jan. 26, 2004, http://www.smalltimes.com/document_display.cfm?document_id=7292.

185. *See, e.g.*, *The Nanotech Schism*, *supra* note 166, at 103 ("If Drexler's ideas can be proven definitively wrong, then we can relax in our comfortable nano-pants. But if Drexler is correct, there is much work to be done.").

186. 21st Century Nanotechnology Research and Development Act (2003), Pub. L. No. 108-153, § 5(a)(6), 117 Stat. 1923, 1929 (codified at 15 U.S.C. § 7505 (2004)).

187. *See The Nanotech Schism, supra* note 166, at 103 ("Soon, universities will have professional nanoethicists making a living by pointing out the dangers of nanotech."); *cf. infra* Part III.B.2 (discussing effects of prescriptive rebuttals to potential technological innovations).

188. *See, e.g.*, Posting of Adam Keiper to Howard Lovy's NanoBot, http://nanobot.blogspot.com/ (Feb. 10, 2005 09:09) (reporting on committee proceedings at National Research Council nanotechnology research workshop).

189. *See generally* NEIL JACOBSTEIN & GLENN HARLAN REYNOLDS, FORESIGHT INST., FORESIGHT GUIDELINES VERSION 4.0: SELF ASSESSMENT SCORECARDS FOR SAFER DEVELOPMENT OF NANOTECHNOLOGY (2004), http://www.foresight.org/guidelines/04GuidelinesBooketFinal.pdf (establishing guidelines to encourage informed policy decisions with respect to nanotechnology).

190. The devices are a 100-nanometer-scale robotic arm "demonstrating the controlled motions needed to manipulate and assemble individual atoms or molecules into larger structures, with atomic precision" and a 50-nanometer-scale digital computing device capable of performing the functions of a conventional 8-bit adder. Foresight Inst., Feynman Grand Prize, http://www.foresight.org/GrandPrize.1.html (last visited Sept. 9, 2006) [hereinafter Foresight Inst., Feynman Grand Prize].

191. *Id.*; *see also supra* notes 34–45 and accompanying text (discussing a primary purpose of prize contests).

192. Foresight Inst., Feynman Grand Prize, *supra* note 190 (quoting K. Eric Drexler).

which recognize significant advances in theoretical and experimental molecular nanotechnology, further encourage research.[193] These combined efforts demonstrate the ability of inducement prizes to promote—through the promise of proof-of-concept rewards—a disputed and as-yet-unproven technology despite unfavorable public policy treatment.[194]

2. *Advocating Anti-Anti-Aging: Discouraging Engineered Negligible Senescence*[195]

Public policy need not take the form of legislation or regulation to influence technologies underlying inducement prize contests. Particularly where the implications of a new technology are seen as prescriptive rather than descriptive—where the question becomes *should*, rather than *could*, such technology be achieved—informal public policy treatment opposed to the technology can create an external environment unfavorable to private innovation just as easily as can more formal public policy means. Although mitigating elements may emerge, the discouraging effect of adverse public policy treatment threatens to stifle innovation in disfavored technologies such as longevity research. Inducement prize contests in such technologies can help advance debate on, and prevent foreclosure of innovation due to, the perceived negative implications. Current arguments and efforts directed toward longevity research illustrate this tension.

Aging is an enduring object of human contemplation, often but not always considered in conjunction with death or immortality.[196] Indeed,

193. Foresight Inst., 2004 Foresight Institute Feynman Prize, http://www.foresight.org/FI/2004Feynman.html (last visited Sept. 9, 2006). These awards exemplify best-entry contests. *See supra* notes 28–32 and accompanying text.

194. In May 2005, the Foresight Institute changed its name to the Foresight Nanotech Institute and its mission from "'educating policy makers, professionals and the general public about the potential of nanotechnology'" to "'ensuring the beneficial implementation of nanotechnology.'" Press Release, Foresight Nanotech Inst., Foresight Nanotech Institute Adopts New Mission (May 23, 2005), http://www.foresight.org/cms/press_center/113 (quoting Foresight Nanotech Institute President Scott Mize). To that end, the Foresight Nanotech Institute adopted the Foresight Nanotechnology Challenges, six problems to which nanotechnology offers valuable solutions. *See id.* Despite this new focus, the Foresight Nanotech Institute continues to offer the above-discussed prizes. *See id.*

195. "Senescence" means aging, though not as an increase in number of years lived but rather as the "gradual and progressive loss of various functions over time, beginning in early adulthood, leading to decreasing health, vigor, and well-being, increasing vulnerability to disease, and increased likelihood of death." PRESIDENT'S COUNCIL ON BIOETHICS, BEYOND THERAPY: BIOTECHNOLOGY AND THE PURSUIT OF HAPPINESS 164 (2003) [hereinafter BEYOND THERAPY], *available at* http://www.bioethics.gov/reports/beyondtherapy/beyond_therapy_final_webcorrected.pdf. "Senescence" also may be defined as "the progressive increase in an organism's likelihood to die soon" or as expressing "a positive correlation between age and risk of death." Aubrey de Grey, SENS: Basis for the Name "Engineered Negligible Senescence," http://www.sens.org/ENSdef.htm (last visited Sept. 9, 2006). To biogerontologists, "engineered negligible senescence" means "the biotechnological conversion of a population that shows senescence . . . into one that does not." *Id.*

196. *See, e.g.*, BEING HUMAN: CORE READINGS IN THE HUMANITIES 369–436 (Leon Kass ed., 2004) [hereinafter BEING HUMAN] (excerpting various literary works addressing aging, immortality, and death).

"[s]ince Gilgamesh, civilization has sought to . . . achieve a perpetually youthful physiological state . . . by intervention to combat the aging process."[197] Reflections on aging became especially significant in the twentieth century as life expectancy increased dramatically.[198] This fixation on aging is also big business: estimated U.S. sales of anti-aging products and services topped $42.7 billion in 2002 are forecasted to approach $56 billion by 2007.[199] Medical efforts to prolong life and prevent death are also considerable.[200] Aspiring to longevity is both quantitative and qualitative, a "pursuit not only of longer lives, but also of lives that remain vigorous longer."[201] As technology has accelerated understanding of aging, the potential for interventions that retard or reverse senescence—that "not only . . . add years to life, but also . . . life to years"[202]—has both inspired interest and caused concern.

One of the leading advocates of life-extending biotechnological interventions is Aubrey de Grey of the University of Cambridge.[203] While many gerontologists believe that average life expectancy at birth in a developed country in 2100 will be 80 to 100 years (slightly higher than today), de Grey's estimate—5000 years—is much higher.[204] To

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197. Aubrey D.N.J. de Grey et al., *Time to Talk SENS: Critiquing the Immutability of Human Aging*, 959 ANN. N.Y. ACAD. SCI. 452, 453 (2002) [hereinafter de Grey, *Time to Talk SENS*]. Such interventions are not always scientific or even sensible:

> The history of radical solutions to the problem of human aging is colorful yet rather lacking in distinction. Until the dawn of modern medicine, the standard prescription was that old men should inhale the sweet breath of virgin girls to restore "innate moisture." At the end of the 19th century, the physician Charles E. Brown-Séquard recommended an injection of the macerated sex glands of monkeys or dogs to keep the sands of time at bay. In the go-go 1990s, a Virginia medical school professor, William Regelson, sold a ton of books touting the "melatonin miracle" as an aging cure-all and hormonal good-for-what-ails-you.

Joseph Hooper, *The Prophet of Immortality*, POPULAR SCI., Jan. 2005, at 72, 72.

198. From 1900 to 1999, average life expectancy at birth in the United States increased from forty-eight to seventy-eight years, largely due to efforts to combat early-life causes of death. BEYOND THERAPY, *supra* note 195, at 165.

199. Press Release, FIND/SVP, New Anti-Aging Market Creates Opportunities for Marketers (Apr. 8, 2003) (on file with the University of Illinois Journal of Law, Technology, and Policy); *see also* Aubrey D.N.J. de Grey, *Biogerontologists' Duty to Discuss Timetables Publicly*, 1019 ANN. N.Y. ACAD. SCI. 542, 542–43 (2004) [hereinafter de Grey, *Duty to Discuss Timetables*].

200. For example, patients in their last year of life incur about twenty-eight percent of all annual Medicare costs, a trend that has persisted over several decades. Daniel Altman, *How to Save Medicare? Die Sooner*, N.Y. TIMES, Feb. 27, 2005, § 3, at 1; *see also* James D. Lubitz & Gerald F. Riley, *Trends in Medicare Payments in the Last Year of Life*, 328 NEW ENG. J. MED. 1092, 1092–96 (1993) (analyzing distribution of last-year-of-life Medicare costs from 1976 to 1988); *cf.* de Grey, *Duty to Discuss Timetables*, *supra* note 199, at 543 ("Similarly, the enormous amount spent on medical care to combat—again only to a modest degree—age-related diseases is apparently considered money well spent.").

201. BEYOND THERAPY, *supra* note 195, at 165.

202. *Id*.

203. Sherwin Nuland, *Do You Want to Live Forever?*, TECH. REV., Feb. 2005, at 36, 41;
Aubrey de Grey, Aubrey de Grey: Biographical Sketch, http://www.sens.org/AdGbio.htm (last visited Sept. 9, 2006).

204. Theo Richel, *Will Human Life Expectancy Quadruple in the Next Hundred Years? Sixty Gerontologists Say Public Debate on Life Extension Is Necessary*, 6 J. ANTI-AGING MED. 309, 310 tbl.1 (2003) (presenting survey results of sixty gerontologists). The risk of fatal accidents is essentially all

achieve this multi-millennial lifespan, de Grey proposes a program called Strategies for Engineered Negligible Senescence ("SENS").[205] The program conceives of aging as "'a reasonably small set of accumulating and eventually pathogenic molecular and cellular changes in our bodies, each of which is potentially amenable to repair.'"[206] This small set of changes comprises several underlying processes, each of which SENS proposes to reverse through specific interventions.[207] With regard to progress on such interventions, de Grey insists that biogerontologists have a collective duty to defy their entrenched timidity and commit publicly to realistic timetables for innovations in longevity.[208] Driving de Grey's sense of urgency is "the simple fact that over 100,000 people die every day of causes that kill virtually no one under 30"[209] and that "inaction in not pursuing the possible opportunity of extending life for thousands of years . . . hasten[s] death."[210]

Despite an acknowledged lack of evidence that aging can be reversed, de Grey believes that the indefinite postponement of aging may be within sight and as near as twenty-five years away.[211] Allying political and public will with supposed scientific feasibility, however, requires a proof of concept to break "an institutional 'fatalism logjam.'"[212] Enter the Methuselah Mouse Prize ("M Prize"), an inducement prize contest to develop the longest-living mouse.[213] The M

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that limits de Grey's estimate. *See* Hooper, *supra* note 197, at 72; David Stipp, *The End of Aging*, FORTUNE, June 14, 2004, at 136, 140.

205. Nuland, *supra* note 203, at 41.

206. *See id*. at 38 (quoting Aubrey de Grey).

207. *See* de Grey et al., *Time to Talk SENS, supra* note 197, at 456 tbl.1. These "seven horsemen of death" include: loss and atrophy of cells; accumulation of unwanted cells; chromosomal mutations; mitochondrial mutations; accumulation of "junk" within the cell; accumulation of "junk" outside the cell; and protein cross-links outside the cell. Nuland, *supra* note 203, at 41. The proposed application of engineering principles to curing aging illustrates the noteworthy extent to which the SENS methodology deviates from standard practice in biology and reflects its founder's background. *See id*. at 38 (describing the main conceptual contribution of de Grey, a computer scientist self-taught in biology, as "the goal-driven orientation of an engineer rather than the curiosity-driven orientation of the basic scientists who have made and will continue to make the laboratory discoveries that he intends to employ"); *see also* Strategies for Engineered Negligible Senescence Home Page, http://www.sens.org/index.html (last visited Sept. 9, 2006).

208. *See* de Grey, *Duty to Discuss Timetables*, *supra* note 199, at 543–44; Stipp, *supra* note 203, at 138.

209. De Grey, *Duty to Discuss Timetables*, *supra* note 199, at 544.

210. Nuland, *supra* note 203, at 43.

211. *See* de Grey et al., *Time to Talk SENS, supra* note 197, at 459–60; Nuland, *supra* note 203, at 37.

212. Stipp, *supra* note 203, at 140. Such fatalism by the public fuels a vicious cycle, "lead[ing] inevitably to lack of public funding for anti-aging work, and thence to lack of advocacy of anti-aging work by experts, which in turn serves to maintain public pessimism." Methuselah Found., MPrize: Frequently Asked Questions, http://www.mprize.org/index.php?pagename=FAQ (last visited Sept. 9, 2006).

213. Methuselah Found., What Is the Methuselah Mouse Prize?, http://www.mprize.org/index.php?pagename=whatisthemmp (last visited Spet. 9, 2006). Aubrey de Grey is Chairman of the Methuselah Foundation and the main architect of the MPrize structure. Methuselah Found., Administration, *supra* note 161. The prize is named for the antediluvian Biblical figure who lived 969 years. *Genesis* 5:27. Yoda, a dwarf mouse raised by original M Prize participant

Prize comprises two prize competitions: the Longevity Prize, for the oldest-ever mouse, and the Rejuvenation Prize, for the best-ever successful late-onset intervention.[214] A common fund of more than $4 million[215] provides for a succession of prizes to innovators whose mice break the record in either competition.[216] Prize administrators chose to reward effective interventions in mice to demonstrate a proof of concept in anti-aging work and thereby refute popular attitudes towards the inevitability of aging.[217] Other explicit purposes of the M Prize reflect those of inducement prize contests generally:

> The public cannot be expected to take progress in understanding aging as evidence that we are getting close to intervening effectively: like any non-specialist, what they understand is the final result.
>
> However, there are numerous interventions that might well increase the lifespan of mice but are not being actively pursued. This is because explicitly anti-aging research is not easy to fund . . . . Many groups could quite cheaply extend studies whose main purpose is not gerontological in ways that would explore

Richard Miller, lived four years, a long lifespan in modern human terms (136 years). *See* Nicole Dyer, *From the World's Oldest Mouse*, POPULAR SCI., July 1, 2004, at 94, 94; Press Release, Methuselah Found., First Four Teams of World Renowned Scientists Answer Starting Gun for Competition to Win the Methuselah Mouse Prize (Sept. 25, 2003), http://www.pressbox.co.uk/Detailed/9446.html. GHR-KO 11C lived nearly five years, or 180–200 years in human terms, and earned Andrezj Bartke the first M Prize. Methuselah Found., Record Holders, http://www.mprize.org/index.php?pagename=recordholders (last visited Sept. 9, 2006); Press Release, Methuselah Found., Anti-Aging Research Foundation Throws Down Funding Gauntlet (Mar. 14, 2004), http://www.mprize.org/index.php?pagename=newsdetaildisplay&ID=017.

214. Methuselah Found., Prize Structure, http://www.mprize.org/index.php?pagename=structure (last visited Sept. 9, 2006). This bifurcation serves the Methuselah Foundation's main purpose of finding interventions that are effective when initiated at a late age. *Id*. For standardization purposes, entrants are restricted to *Mus musculus*, the species of mouse most commonly used in laboratory work. *Id*.

215. Press Release, Methuselah Found., The $4 Million Mom: Methuselah Mouse Prize Fund Passes $4 Million Milestone, http://www.mprize.org/index.php?pagename=newsdetaildisplay&ID=113 (Dec. 11, 2006); Methuselah Found., Prize Details, http://www.mprize.org/index.php?pagename=funddetaildisplay (last visited Dec. 11, 2006).

216. Awards for the Longevity Prize are in proportion both to the size of the fund when the record is broken and to the margin by which the previous record is broken. *See* Prize Structure, *supra* note 214 (defining Longevity Prize amount as *$Z * (Y/(X+Y))*, where *$Z* is the prize fund at noon GMT on the record-breaking mouse's day of death, *X* is the previous record in days, and *Y* is the number of days by which the record-breaking mouse's life exceeded that of the previous record-holding mouse). The Rejuvenation Prize is awarded for a published study with treated and control groups of at least twenty mice each where (1) intervention was begun "at an age at least half of the eventual mean age at death of the longest-lived 10% of the control group" (to satisfy the late-age intervention purpose); and (2) a "statistically significant reversal in the trajectory" of five distinct markers that change significantly with age in the controls results. *Id*. Later prizewinners must beat the mean age at death of the longest-lived 10% of the previous prizewinning study's treated group. *Id*.

217. Methuselah Found., What is the Methuselah Mouse Prize?, *supra* note 213. Mice also offer a useful analogue to humans due to similarity in genome organization between the species. Elizabeth Svoboda, *Pluck Everlasting*, SCI. & SPIRIT, Mar.–Apr. 2005, at 54, 56, *available at* http://www.science-spirit.org/article_detail.php?article_id=480. Interestingly, the Methuselah Foundation, with the *Technology Review*, now offers a smaller prize to *disprove* SENS. *See* The SENS Challenge, http://www.trblogs.com/blog/pontin/posts.aspx?id=14968&p=1 (July 28, 2005).

> these interventions. Hence, our strategy is to provide scientists with motivation for such work.
>
> In order to maximise [sic] this motivation (for a given level of resources), and in order to avoid prejudging what types of intervention are likely to work, it is reasonable to set up a prize. This will promote maximum diversity of work aimed at lifespan extension, and will also capture the public imagination.[218]

Retarding and reversing aging in mice thus will enable humans to achieve "escape velocity"—the "happy state in which ongoing medical advances will be able to add years to life faster than they're subtracted by the passage of time"[219]—by the intermediate steps of encouraging broad participation in, and unorthodox approaches to, longevity research and stirring public interest in the potential for technology to overcome aging.

But *should* technology conquer aging? The President's Council on Bioethics ("the Council") recently tackled this question.[220] Established in 2001, the Council's purposes include "advis[ing] the President on bioethical issues that may emerge as a consequence of advances in biomedical science and technology" and "explor[ing] specific ethical and policy questions related to these developments."[221] The Council sounded a cautious note on potential innovations in longevity: "The prospect of effective and significant retardation of aging—a goal we are all at first strongly inclined to welcome—is rife with barely foreseeable consequences," many of them normative.[222] Considering the impulse for life extension to be a "declaration of opposition to death," the Council warned against reconceiving aging "as a disease to be cured."[223] The

218. Methuselah Found., Frequently Asked Questions, *supra* note 212.

219. Stipp, *supra* note 204, at 140.

220. BEYOND THERAPY, *supra* note 195, at 159–204.

221. Exec. Order No. 13,237, 66 Fed. Reg. 59,851, 59,851 (Nov. 28, 2001). *See also* Exec. Order No. 13,316, 68 Fed. Reg. 55,255, 55,255 (Sept. 17, 2003) (continuing the Council through September 30, 2005). The National Bioethics Advisory Commission, created in 1995, was similarly tasked. *See* Exec. Order No. 12,975, 60 Fed. Reg. 52,063, 52,063–65 (Oct. 3, 1995) (establishing the National Bioethics Advisory Commission), *revoked by* Exec. Order No. 13,316, 68 Fed. Reg. at 52,255.

222. *See* BEYOND THERAPY, *supra* note 195, at 197. The Council also noted a descriptive objection of particular relevance to the objectives of the M Prize by suggesting that inter-species differences limited the usefulness of animal models in improving our understanding human aging. *Id.* at 180 ("[W]e are not simply more complicated versions of worms, flies, or mice.").

223. *Id.* at 186. Although the Council distinguished between life-extension and immortality, it lumped the motivations for the former into the desire for the latter:

> Life-extension does not mean immortality, to be sure—if for no other reason than that the attainment of immortality is scientifically implausible. But the impulse to extend our lives in general, rather than to combat particular diseases or ailments that shorten our lives, is a declaration of opposition to death as such. In addressing aging as a disease to be cured, we are, in principle, and at least tacitly, expressing a desire never to grow old and die, or, in a word, a desire to live forever. . . . Taken to its extreme, the underlying impulse driving age-retardation research is, at least implicitly, limitless, the equivalent of a desire for immortality.

Id. De Grey unequivocally rejects such correlation with immortality. *See* de Grey et al., *Time to Talk SENS, supra* note 197, at 453 ("This phrase ['strategies for engineered negligible senescence'] makes explicit the inevitable exposure to extrinsic, age-independent causes of death. . . ."); Aubrey de Grey, SENS: Timeframe for Progress in Life Extension, http://www.sens.org/time.htm (last visited Sept. 9, 2006) ("Immortality means inability to die . . . . [T]here is always a non-zero probability of dying some

Council declared such transhumanism would obsolesce conventional notions of death and aging and thereby deprive humanity of its transcendent aspirations.[224] The Council also asserted that overcoming aging might upset the carefully tuned balance of overlapping lifecycles:

> Generation and nurture, dependency and reciprocated generosity, are in some harmony of proportion, and there is a pace of journey, a coordinated coherence of meter and rhyme within the repeating cycles of birth, ascendancy, and decline—a balance and beauty of love and renewal giving answer to death that, however poignant, bespeaks the possibility of meaning and goodness in the human experience. All this might be overthrown or forgotten in the rush to fashion a technological project only along the gradient of our open-ended desires and ambitions.[225]

Less philosophical but no less worrisome is the Council's concern for cultural stasis in a world dominated by the ancient.[226] Although the Council and SENS proponents cover many of the same concerns in their considerations of the ethical issues associated with aging research,[227] neither directly comments on the other.

The Council and SENS supporters thus are engaged in a struggle over public opinion on longevity research. This tension reflects, in part, the descriptive logjam depicted by de Grey.[228] Prescriptive implications, especially as advanced by "the conscience of the country" on bioethical issues,[229] may further depress public interest in anti-aging innovations. The M Prize counteracts that effect to some extent by attracting interest to relevant research. Timing may also change attitudes, as public self-interest, particularly among aging baby boomers—"a plenitude of eager seekers after the death-defiant panaceas [de Grey] promises"[230]—may drive people to consider the possibility of defeating aging in their lifetimes. Nevertheless, an inducement prize contest, by virtue of recognizing the achievement of a specific technological objective, better

time—and indeed a non-zero probability of dying in any given year. . . . [W]e will never make ourselves immortal.").

224. BEYOND THERAPY, *supra* note 195, at 200 ("[Aging and death] invite us to notice that the evolution of life on earth has produced souls with longings for the eternal and, if recognized, a chance to participate in matters of enduring significance that ultimately could transcend time itself.").

225. *Id*. at 199.

226. *Id*. at 195–96. Others express this concern more gruesomely: "'If we're still listening to Britney Spears in 5,000 years, we really will be buggered.'" Hooper, *supra* note 197, at 97 (quoting bioremediation expert John Archer).

227. For the ethical perspectives of SENS proponents, see, for example, John K. Davis, *Collective Suttee: Is It Unjust to Develop Life Extension if It Will Not Be Possible to Provide It to Everyone?*, 1019 ANN. N.Y. ACAD. SCI. 535, 536 (2004); John Harris, *Immortal Ethics*, 1019 ANN. N.Y. ACAD. SCI. 527, 529 (2004); Gregory B. Stock, *The Pitfalls of Planning for Demographic Change*, 1019 ANN. N.Y. ACAD. SCI. 546, 548–49 (2004).

228. *See* Aubrey de Grey, *Nature of the Aging Process: Open Discussion*, 959 ANN. N.Y. ACAD. SCI. 463, 464–65 & 65 fig.1 (2002); *see also supra* note 212 and accompanying text.

229. Remarks Prior to a Meeting with the President's Council on Bioethics, 38 WEEKLY COMP. PRES. DOC. 85 (Jan. 17, 2002).

230. Nuland, *supra* note 203, at 40.

addresses descriptive issues than prescriptive concerns. Just because a winning innovation satisfies the technical criteria for victory (answering whether the technology *could* be achieved) does not mean that such innovation is necessarily "good" or "right" (answering whether it *should* be achieved). Informal public policy opposed to new technologies, then, can influence opinion on whether such technologies should be pursued and can create substantial obstacles to innovation. To overcome such obstacles, supporters of such technologies must change hearts as well as minds.

IV. RECOMMENDATION

In 1999, the NAE workshop recommended "limited experiments in the use of federally sponsored induce prize contests to stimulate private-sector research, innovation, and technology deployment in service of agency and societal goals."[231] Tepid as this endorsement may be,[232] it provides a useful starting point for a consideration of whether, when, and how the government should sponsor inducement prize contests or interfere where inducement prizes already exist.

A. Conditions for Intervention via Prize Contest Sponsorship

Where public policy goals and inducement prize contest objectives are aligned, prize contests flourish and complement public policy efforts.[233] The alignment of goals and objectives validates government intervention where it is constitutionally mandated but precludes interference with an outperforming private sector. Where public policy goals and inducement prize contest objectives are unaligned, however, underlying technologies suffer from adverse public policy treatment founded on descriptive or prescriptive objections.[234] Prize contests thus assume antagonistic postures to concurrent public policy while attempting to influence public policy through proofs of concept or appeals to principle. An assessment of these interactions between public policy and inducement prize contests yields the following conditions for government intervention.

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231. NAE REPORT, *supra* note 13, at 15.

232. The workshop committee called only for further feasibility studies and noted adamantly that the purpose of such limited experiments "would be to test the effectiveness of prizes and contests as complements to—not replacements for—traditional R&D grants and procurement contracts." *Id*. Recent endorsements are more enthusiastic. *See, e.g.*, Rich Karlgaard, *Why We Need Goofy Contests*, FORBES, Nov. 14, 2005, at 43, 43 ("Contests are not only fun. They can also be key to our survival. . . . Commit America to big, gaudy, public contests in space travel and energy. These will fire up an entire country.").

233. *See supra* Parts III.A.1–2 (analyzing defense and commercial human spaceflight technologies).

234. *See supra* Parts III.B.1–2 (analyzing nanotechnology and longevity research).

1. There Exists a Distinct Objective

This first condition requires a cognizable desired outcome. Such objective need not be a final technological achievement in itself, in the sense of resolving a large, open-ended problem or inquiry, but rather can serve as a guidepost by which the sponsoring entity can direct its efforts. For example, the distinct objective identified by DARPA—achievement of autonomous ground combat vehicles—originated in legislation.[235] The winning technology from the Grand Challenge, however, will not completely satisfy DARPA's identified objective. Rather, the technological achievement will set the agency moving along a path more likely to lead toward the ultimate fulfillment of that objective. A similar pursuit of "right paths" guides NASA's Centennial Challenges program of inducement prize contests.[236]

The requisite distinct objective to be achieved need not be a technological goal at all. As the molecular nanotechnology and engineered negligible senescence case studies show, distinct objectives that compel interference with existing prize contests can be mere refutations of the technological possibilities those contests advocate. However, distinct objectives identified as negative goals—for example, to demote an underlying technology relative to a competing vision (molecular nanotechnology) or to inhibit advancement in a disfavored technology (engineered negligible senescence)—obstruct achievement and foreclose potential innovation. Accordingly, such objectives fail to provide a strong position from which to justify intervention through public sponsorship of an inducement prize contest.

2. Other Policy Instruments Cannot Achieve or Have Not Achieved That Objective to the Sponsoring Entity's Satisfaction

Identifying a distinct objective is a necessary but insufficient condition for intervention. Public entities contemplating intervention should consider distinct objectives in the context of other public policy means by which those objectives might be achieved. Inducement prize contests, for example, will not prove as useful as grants to tackle objectives best suited to investigation via long-term research.[237] Similarly, objectives to find the lowest-cost providers of standardized items are most amenable to the procurement contract bidding process, not inducement prize contests.[238] Yet, where identified distinct objectives present intractable, open-ended, or otherwise stupefying problems that

235. *See supra* note 113 and accompanying text.

236. *See* NASA, Introduction to Centennial Challenges 2 (2004), http://exploration.nasa.gov/documents/centennialchallenges/Intro_to_CC.pdf ("NASA will need to leverage the ideas and expertise resident in the Nation's universities and industry . . . [by] establishing prizes for specific accomplishments that advance solar system exploration.").

237. *See* NAE REPORT, *supra* note 13, at 5.

238. *See id*.

might benefit from the application of unorthodox ideas, inducement prize contests constitute fitting interventions.[239]

Public entities weighing intervention also should remember that inaction in itself can be an instrument of public policy. As the commercial human spaceflight case study shows, a successful inducement prize contest left to develop with minimal interference can create new opportunities for the public entity without acting against public policy. Of course, inaction is not always appropriate; without DARPA's intervention, development of autonomous ground combat vehicles would attract little interest.[240] Nevertheless, public entities should consider the consequences of inaction in their total consideration of public policy instrument options.

3. The Proposed Contest Must Outperform Existing or Potential Private-Sector Efforts

Having identified (and positively formulated) a distinct objective and having determined that an inducement prize contest would best accomplish that objective relative to other possible instruments of public policy in science and technology, a public entity weighing intervention should then consider whether existing or potential private-sector efforts could do a better job. Sometimes, as in the DARPA defense technologies case, there are no private-sector efforts, nor could there be. In such circumstances, intervening through public sponsorship of an inducement prize contest would offer superior performance. In other circumstances, where an existing prize contest like the Ansari X Prize succeeds at attracting many different participants and ideas, inspiring and educating the public, and growing the prize purse, it would make little sense for a public entity pursuing aligned public policy to intervene and thereby dilute the public's attention or direct any remaining scarce resources away from an already-established contest.[241]

Even where public policy goals are not aligned with the objectives of an existing privately sponsored prize contest, the public entity weighing intervention should consider the probable performance of private sector or quasi-public sector efforts. In the molecular nanotechnology case, for example, two competing visions for an underlying technology waged a public battle without government interference to decide the direction that technological pursuit should take. Having out-shouted the Drexlerians at a fortunate moment, the pragmatists gained and lobbied for political influence in the guise of advantageous public policy

239. *See supra* notes 34–45 and accompanying text.

240. Such lack of interest would be due, in large part, to the federal government's monopsony position in the market for defense technologies. *See supra* notes 106–07 and accompanying text.

241. *See* NAE REPORT, *supra* note 13, at 13 (discussing areas for caution in the implementation of prize contests).

treatment.[242] By entering the fray how and when it did, the government chose sides in an unsettled debate and curtailed public determination of the true technological possibilities of molecular nanotechnology.[243] Such interference bred resentment and discouraged advocates of nanotechnology's more revolutionary vision.[244] To forestall such abuses, public entities should consider whether informal and indefinite institutions can perform the same determinative function as intervention.[245] If so, and if such institution would outperform the contemplated intervention, the public entity should refrain from action.

4. The Proposed Contest Must Employ Disinterested Panels and Apply Disinterested Criteria

Enforcement of contest rules and determinations of winners must be objective, fair, and balanced.[246] It follows, then, that those enforcing the contest rules and determining the winners should act in an objective, fair, and balanced manner. The series of unfortunate events befalling John Harrison, the eventual winner of the Longitude Prize, illustrates this necessity in the context of publicly sponsored prize contests.

Harrison was a watchmaker, and his approach to solving the longitude problem involved constructing "a clock that would carry the true time from the home port, like an eternal flame, to any remote corner of the world," no mean feat for his era.[247] Possessed of such a clock, a sailor could accurately measure his longitude by converting the hour difference between the time on ship and the time at the home port.[248] Although self-taught, Harrison nevertheless succeeded in making clocks that kept nearly perfect time.[249] Those successes drew the ire of the scientific elite, including Nevil Maskelyne, the astronomer royal, who favored an alternative approach to determine longitude known as the lunar distance method.[250] The commissioners of the Longitude Board, including Maskelyne, changed the rules of the contest at a whim, "so as to favor the chances of astronomers over the likes of Harrison and his fellow 'mechanics.'"[251] Harrison struggled for forty years to claim the full monetary reward.[252]

242. *See* DREXLER, ENGINES OF CREATION, *supra* note 167, at 205 (discussing how "quiet scientists and engineers are drowned in the clamor" of modern public debate).
243. *See supra* notes 178–87 and accompanying text (chronicling changes to the 21st Century Nanotechnology Research and Development Act).
244. *See, e.g.*, sources cited *supra* note 183.
245. Such institutions could serve an informative function as well. *See infra* Part IV.B.
246. *See supra* notes 60–64 and accompanying text.
247. SOBEL, *supra* note 1, at 8. Even Isaac Newton believed the task to be impossible. *Id.*
248. *Id.* at 4–5.
249. *See id.* at 9.
250. *Id.* at 8–9, 23–24, 112.
251. *Id.* at 9.
252. *Id.* at 9–10.

Harrison's treatment by a panel that was anything but disinterested in the outcome of the contest underscores the importance of neutral rule enforcement and winner determination. To honor the purposes of inducement prize contests, it is essential that such contests be rooted in transparent, objective criteria. This is particularly true for publicly sponsored prize contests because tax dollars likely will constitute the prize purses. Any indication of favoritism or undue preference for one participant or idea over another will be viewed, quite rightly, with suspicion. More broadly, publicly sponsored prize contests may be more susceptible to criticisms typically directed at other instruments of science and technology policy, namely, that such instruments "fall[] prey to political pressure, complexities of congressional oversight, and the self-protection of agencies."[253] The potential for institutional parochialism to compound individual prejudice is a concern that any public entity considering sponsoring a prize contest should address.

The above conditions provide a rough framework for determining whether intervention via public sponsorship of an inducement prize contest is justified. Assuming a public entity satisfies those criteria and elects to intervene by offering an inducement prize, it should adopt a number of practices to ensure optimal performance. Several such practices are discussed in an earlier section detailing the proper structure of successful inducement prize contests.[254]

B. Approaches to Addressing Disputed or Disfavored Technologies

Given the conditions outlined above, public sponsorship of prize contests makes little sense where public policy and the underlying technologies are unaligned. Moreover, governmental interference with disputed or disfavored technologies risks marginalizing the efforts of private prize contests to advance those technologies. Such interference, however, whether rooted in descriptive or prescriptive concerns, could be made less intrusive through the promotion of and greater reliance on open institutions for resolving technological controversies.

As technologies become increasingly complex and powerful, the obfuscation of technical facts for ulterior purposes becomes correspondingly more dangerous.[255] As Drexler contends, "We need ways to handle technical complexity in a democratic framework, using experts as instruments to clarify our vision without giving them control of our lives."[256] Obversely, the increasing influence of policy concerns on scientific research lays bare the need for protecting the independence of

253. NAE REPORT, *supra* note 13, at 13.
254. *See supra* Part II.A.3.
255. DREXLER, ENGINES OF CREATION, *supra* note 167, at 204.
256. *Id*. at 204–05.

science and resisting Malthusian pessimism in technology's promise.[257] Arthur Kantrowicz, considered to have originated the concept of a science court,[258] an institution to serve such purposes, warns, "If we do not separate the power to state the facts from the power to decide what is to be done, then arbiters of value will be tempted to defend their policies with factual statements biased to make those policies seem consistent with the values of their audience."[259]

Using open institutions to resolve technological controversies and inform policymakers offers an alternative to this "'prostitution of the decision making process.'"[260] Such institutions can mitigate the appearance and effects of impropriety or undue preference in disputed technologies by neutrally adjudicating technical facts. For disfavored technologies, a determination of technological viability can clarify the scope of a technology's consequences, thereby providing proponents and policymakers with a shared (and public) understanding of what is possible. Two examples of such open institutions are considered below.

1. Fact Forums: Judging Scientific and Technological Truth

Fact forums are due process[261] institutions designed to decide technical controversies, much the same way that judges and juries decide factual controversies.[262] Such boards of technical inquiry could exist "to sift facts for policymakers," thereby filling a gap left by the evolution of scientific institutions.[263] Fact forums separate policy decisions from technical judgments, reserving policy decisions to "[i]ndividuals, companies, and elected officials" and limiting technical experts to descriptions of technical facts.[264] Clarifying technical facts through distillation by a fact forum puts proponents and policymakers on common footing, diminishing the likelihood of factual discord being mistaken for bad political motives.[265]

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257. *See* Arthur Kantrowicz, *The Separation of Facts and Values*, 6 RISK 105, 105–06 (1995) (characterizing Rev. Thomas Malthus's prediction that food supply would limit England's population growth as "a classic case of mixing facts and values to force an allegedly scientific conclusion").

258. *See* DREXLER, ENGINES OF CREATION, *supra* note 167, at 211; Thomas G. Field, Jr., *The Science Court is Dead; Long Live the Science Court!*, 4 RISK 95, 95 & n.1 (1993). For a discussion of science courts, see *infra* Part IV.B.1.

259. Kantrowicz, *The Separation of Facts and Values*, *supra* note 257, at 108.

260. Arthur Kantrowicz, *Elitism vs. Checks and Balances in Communication Scientific Information to the Public*, 4 RISK 101, 102 (1993) (quoting PROCEEDINGS OF THE COLLOQUIUM ON THE SCIENCE COURT 25 (1977)). Anthropologist Margaret Mead offered this characterization. *Id.*

261. *See* DREXLER, ENGINES OF CREATION, *supra* note 167, at 207 ("Due process is a basic idea, not restricted to courts of law.").

262. *See id*. at 207, 211. Drexler terms such institutions "fact forums," reserving "science courts" for government-backed fact forums. *Id*. at 211. This Part draws heavily on Drexler's analysis.

263. *See id*. at 209.

264. *Id*. at 212.

265. *Id*. at 206.

Fact forums are neither new nor radical, and they would require only minimal structural changes to implement.[266] Many competing groups, including government,[267] could sponsor such institutions. Popular and respected forums would gain influence, while those that abuse the fact-clarifying procedure would suffer bad reputations and be ignored.[268] Reliability through redundancy will ensure that no one sponsoring group will be able to obscure technical facts on an important issue.[269] Because "[d]ue process is a matter of degree," fact forums could continually build upon their procedures; existing institutions, for example, could make minor changes and consult a variety of opinions before appointing expert committees.[270]

Implementing public policy with regard to the disputed and disfavored technologies discussed above would be well served by a fact forum. In the molecular nanotechnology case, a fact forum could have settled the descriptive discord between proponents of the competing visions (at least temporarily).[271] With common technical footing, advocates for all sides could have negotiated an approach to addressing the potential implications of the molecular assembler technology commensurate with the likelihood of its determined feasibility. Application of fact forums to disfavored technologies such as engineered negligible senescence could be justified on grounds of efficiency: determining whether a particular innovation is possible also can offer guidance as to the worth of addressing that innovation's prescriptive implications.

2. Idea Futures: Using Markets to Aggregate Information and Predict the Future

By bringing scientific expertise to bear on an adjudication of technological truth, fact forums and science courts would introduce a welcome separation of facts from values in the policymaking process. Yet such expertise necessarily would be limited to empanelled experts. Others who might possess additional relevant knowledge could be left

266. Presidential candidates Ford, Carter, and Reagan all endorsed science courts during their respective campaigns. *See id.* at 211.

267. Drexler is understandably wary of government fact forums: "Yet it is reasonable to fear government sponsorship of science courts: centralized power tends to beget lumbering monsters. A central 'Science Court Agency' might work well, do little visible harm, and yet impose a great hidden cost: its very existence (and the lack of competition) might block evolutionary improvements." *Id.* at 214–15.

268. *Id.* at 213.

269. *Id.*

270. *Id.* at 213–14.

271. *Id.* at 213 ("When new evidence arrives, a question can be reopened; ideas need no protection from double jeopardy.").

out in the cold, thereby exposing such institutions to fair charges of elitism.[272]

Open information markets[273] trading in idea futures offer an additional mechanism for guiding public policy with respect to technological controversies. Such institutions constitute "a radical, market-based alternative for reaching scientific consensus."[274] Conceptually, however, idea futures are not revolutionary; in fact, they are similar to futures contracts currently traded on commodities markets except that the underlying "asset" is a specific, predictive scientific or technological claim.[275] Idea futures thus tie their payoffs to the resolutions of scientific controversies, while interim prices reflect the then-current consensus as to such controversies.[276] If the market in idea futures is efficient, such consensus develops as investors incorporate information into their assessments of the underlying claim's viability. The prospect of real-money payouts and trading profits provides the necessary incentive to bring such information to bear on the market, heightening the accuracy of the reflected consensus through the aggregation of otherwise disparate and decentralized information.[277]

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272. Although offered outside the fact forum context, Professor Robin Hanson aptly expresses these concerns: "Our policy-makers and media rely too much on the 'expert' advice of a self-interested insider's club of pundits and big-shot academics." Robin Hanson, Idea Futures—The Concept, http://hanson.gmu.edu/ideafutures.html (last visited Sept. 9, 2006). Nevertheless, fact forums and science courts remain a preferable alternative to policymaking mechanisms that fail to distinguish facts from values.

273. "Information markets," "prediction markets," and "speculative markets" are used here interchangeably to refer to exchange-based mechanisms for aggregating information on the outcomes of future events. *See infra* notes 274–77 and accompanying text.

274. Robin Hanson, *Idea Futures: How Making Wagers on the Future Can Make It Happen Faster*, WIRED, Sept. 1995, at 125, 125 [hereinafter Hanson, *Idea Futures*].

275. Markets trading in idea futures would be "like corn futures markets, except you'd bet on the future settlement of a scientific controversy instead of the future price of corn." *Id.*; *see also* Tom W. Bell, *Gambling for the Good, Trading for the Future: The Legality of Markets in Science Claims*, 5 CHAP. L. REV. 159, 161–62 (2002) (describing a hypothetical traded claim predicting correlation between heat waves and earthquakes).

276. Hanson offers the following example:

> [P]eople might bet on whether cold fusion will be used to produce power by the year 2020. Right now the odds would be fairly low—say 20-to-1 against. But as the results of new research became known, and if more people became convinced that cold fusion worked, the odds would rise. And if cold fusion became a reality by 2020, those early supporters would make a bundle.

Hanson, *Idea Futures*, *supra* note 274, at 125; *see also* Bell, *supra* note 275, at 162 (describing price movements of hypothetical traded claim). This price discovery function illustrates the market's role as an aggregator of information. Joyce Berg et al., Accuracy and Forecast Standard Error of Prediction Markets 2 (July 2003) (unpublished manuscript), *available at* http://www.biz.uiowa.edu/iem/archive/forecasting.pdf.

277. Predictive markets typically outperform other information-aggregating mechanisms. *E.g.*, Bell, *supra* note 275, at 164; Robin D. Hanson, *Decision Markets*, IEEE INTELLIGENT SYS., May/June 1999, at 16, 18 [hereinafter Hanson, *Decision Markets*]. *But see* Emile Servan-Schreiber et al., *Prediction Markets: Does Money Matter?*, 14 ELECTRONIC MARKETS 243, 250 (2004) (finding no significant difference in predictive accuracy of play-money and real-money prediction markets). The Foresight Exchange is a long-running play-money prediction market trading in idea futures. Foresight Exchange, http://www.ideosphere.com/fx/index.html (last visited Sept. 9, 2006); *see also* Bell, *supra* note 275, at 163.

Several potential benefits arise from using open information markets to inform public policy toward disputed or disfavored technologies. Perhaps most obvious, the price discovery function of an efficient information market provides a highly accurate and up-to-date assessment of the underlying claim's technological viability, or what Hanson terms "a scientific barometer to guide mass media and public policy."[278] Such a system would "quantify the current consensus about complicated issues quickly, cheaply, and accurately,"[279] thus enabling the policymaking process to capture the same benefits as those derived from fact forums—efficiency and common technical footing[280]—while incorporating a broader range of relevant information. Further, serious participation in open information markets compels proponents and policymakers alike to answer the call to "put your money where your mouth is," i.e., the markets demand a real commitment to a professed position. As Hanson notes, "Naysayers could no longer suppress [proponents] with silence or ridicule."[281] Such an outcome would enhance the dialogue between proponents and policymakers and help to avoid the sort of acrimony involved in the molecular nanotechnology case study.[282] Finally, an information market in idea futures mirrors the benefits of inducement prize contests by encouraging broad participation and having the potential to spur public interest.

Calls to incorporate information markets into the policymaking process are not new, though they have enjoyed increased attention recently.[283] Such markets, however, are not without their limits. At present, information markets face an uncertain legal status: "Accepted functions of markets now include entertainment, capitalization, and hedging, but not *information aggregation*."[284] The seeming similarity of information markets to both gambling and commodities future trading suggests that similarly restrictive regulation might apply, though this need not be the case.[285]

278. Hanson, *Idea Futures*, *supra* note 274, at 125.
279. Bell, *supra* note 275, at 162.
280. *See supra* Part IV.B.1.
281. Hanson, *Idea Futures*, *supra* note 274, at 125.
282. *See supra* notes 177–87 and accompanying text.
283. *See, e.g.*, Robert W. Hahn & Paul C. Tetlock, *Using Information Markets to Improve Public Decision Making*, 29 HARV. J.L. & PUB. POL'Y 213, 216–18 (2005) (listing recent literature and describing the authors' contribution). *See generally* Bell, *supra* note 275; Hanson, *Idea Futures*, *supra* note 274.
284. Hanson, *Decision Markets*, *supra* note 277, at 18.
285. *See* Bell, *supra* note 275, at 164–76 (analyzing options for the legal treatment of information markets). As Bell notes, the Iowa Electronic Markets, "a real-money on-line futures market where real-world events, most notably the outcomes of political elections, determine contract payoffs[,] . . . operates by the grace of a special 'no action' letter issued by the Commodities Futures Trading Commission." *Id.* at 164; *see also* Iowa Electronic Markets Frequently Asked Questions, http://www.biz.uiowa.edu/iem/faq.html (last visited Sept. 9, 2006) (providing hyperlinks to the no-action letters).

V. CONCLUSION

Inducement prize contests provide powerful incentives for innovation. The promise of monetary awards for specific achievements draws the participation of those who might not otherwise contribute their particular skills or knowledge. Beyond the participants themselves, inducement prize contests can inspire and educate the public by communicating compelling visions of future scientific possibilities.

Although most inducement prize contests are privately sponsored, history and a need for creative thinking among government suppliers provide a basis for sponsorship of such contests by governmental institutions. Where public policy goals and prize contest objectives are aligned, underlying technologies thrive. Where public policy goals and prize contest objectives are unaligned, however, a tension arises that can undermine underlying technologies.

Regardless of the underlying technologies, public entities should exercise caution when deciding whether to sponsor prize contests or engage in actions that conflict with existing privately sponsored prize contests. A properly conceived prize contest will identify a distinct objective to be achieved. Such an objective should be of a type most suitable to being addressed by a prize contest. The public entity should intervene to offer the prize contest only if private sector efforts are not doing or could not do a better job, and fairness and objectivity must characterize any such intervention. Governmental interference in disputed or disfavored technologies that are the subjects of private prize contests presents additional problems. Support of and reliance on open institutions to resolve technological controversies can mitigate the impropriety of interference by clarifying the possible and separating that determination from prescriptive policymaking. Fact forums and prediction markets offer two examples of such institutions.

The power of prizes to attract contestants and inspire observers offers great promise for technological innovation. Such contests harness the engines of competition and imagination to advance ideas through incentives. Achievement effected through prizes answers the twin challenges of defining where technology is and envisioning where it can go—a journey from longitude to altitude.