THE HAMILTON PROJECT

Advancing Opportunity, Prosperity and Growth

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Thomas Kalil

Prizes for Technological Innovation

THE BROOKINGS INSTITUTION

The Hamilton Project seeks to advance America's promise of opportunity, prosperity, and growth. The Project's economic strategy reflects a judgment that long-term prosperity is best achieved by making economic growth broad-based, by enhancing individual economic security, and by embracing a role for effective government in making needed public investments. Our strategy—strikingly different from the theories driving current economic policy—calls for fiscal discipline and for increased public investment in key growth-enhancing areas. The Project will put forward innovative policy ideas from leading economic thinkers throughout the United States—ideas based on experience and evidence, not ideology and doctrine—to introduce new, sometimes controversial, policy options into the national debate with the goal of improving our country's economic policy.

The Project is named after Alexander Hamilton, the nation's first treasury secretary, who laid the foundation for the modern American economy. Consistent with the guiding principles of the Project, Hamilton stood for sound fiscal policy, believed that broad-based opportunity for advancement would drive American economic growth, and recognized that "prudent aids and encouragements on the part of government" are necessary to enhance and guide market forces.

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This discussion paper is a proposal from the author. As emphasized in The Hamilton Project's original strategy paper, the Project is designed in part to provide a forum for leading thinkers across the nation to put forward innovative and potentially important economic policy ideas that share the Project's broad goals of promoting economic growth, broad-based participation in growth, and economic security. Authors are invited to express their own ideas in discussion papers, whether or not the Project's staff or advisory council agree with the specific proposals. This discussion paper is offered in that spirit.

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Abstract

Science, technology, and innovation are essential to America's continued economic growth, and can help achieve a wide range of national and global policy objectives. One currently underutilized tool for stimulating technological innovation is inducement prizes, which encourage efforts by contestants to accomplish a particular goal. A related policy instrument is an Advanced Market Commitment, under which governments commit to buy a given quantity of a product or service that meets prespecified performance goals. This paper proposes expanding the US government's use of prizes and AMCs in five areas: space exploration, African agriculture, vaccines for diseases of the poor, energy and climate change, and learning technologies. Under certain circumstances, inducement prizes may act as a useful complement to grants and contracts as a way to encourage technological innovation. The government can establish a goal without determining who is in the best position to reach the goal or what the most promising technical approach is. The government only pays the prize money if someone is successful, and may be able to leverage additional funding from foundations, philanthropists, and contestants who value the reputational benefits of winning the competition. Prizes can also generate public excitement and enthusiasm for science and technology, and encourage more young people to pursue careers in science, engineering, or technology-based entrepreneurship. Inducement prizes and AMCs cannot substitute for robust research funding, protection of intellectual property, and development of a world-class workforce, but they can be a powerful complement to those efforts. Although the optimal level of investment in prizes is not clear, it is surely much larger than the government's current very modest investment. We still have much to learn about the strengths and limitations of prizes, but the time to start additional experiments is now.

Contents

1. The Role of Prizes in Promoting Research and Development

Science, technology, and innovation are central to America's continued economic growth. As policy analysts and economists have long recognized, private sector firms and the government play essential and complementary roles in innovation, including the development of new technology. Broadly speaking, the government creates an institutional setting and sponsors a knowledge base that makes innovation possible, whereas private sector firms take the lead on deciding what innovative new products and services should actually be produced.

Government efforts to promote research and development (R&D) rest on three pillars: funding, intellectual property rights, and education. First, the federal government uses grants, contracts, and appropriations to fund research efforts by private institutions, academic institutions, national laboratories, and other federally funded facilities; and uses tax incentives to encourage private firms to carry out R&D. Second, the federal government legislates and enforces intellectual property rights, such as those embodied in patents and trade secrets, so that private sector innovators have less reason to fear that other firms will copy their discoveries in the short term. Third, federal and state governments support higher education, which helps create the workforce that is needed for research-intensive science and engineering firms.

Nordhaus (2004) estimates that innovators themselves captured only 2.2 percent of the total value of their innovations during the period 1948–2001. The balance of the social benefit goes to other producers and to consumers of products that use the new invention. Even with publicly funded scientific discovery, patents, tax incentives, and other public support for science and technology, the innovators' benefits from innovation are only a small fraction of the broader social benefits. Clearly, the private sector invests less in R&D than is justified by the benefits for society as a whole.

This paper proposes greater use of inducement prizes, an old but currently underutilized public policy tool that stimulates technological innovation. Inducement prizes encourage efforts by contestants to accomplish a particular goal (NAE 1999). They are different from recognition prizes, such as the Nobel Prize, that reward researchers for past achievement. Inducement prizes are similar in spirit to advance market commitments (AMCs): Under AMCs, governments commit to buy a given quantity of a product or service that meets prespecified performance goals. Inducement prizes and AMCs are policy tools that help to blend the best of public purpose and the creativity, energy, and passion of private sector entrepreneurial teams.

Inducement prizes are not new. In 1714, in response to several shipwrecks that had resulted from inaccurate longitude measurements, the British Parliament established a prize for the precise determination of a ship's longitude (Sobel 1996). In 1795, a prize was offered for a method of food preservation that would be usable by Napoleon's military forces (Scotchmer 2004). In the early twentieth century, many advances in aviation such as faster speed, greater distance, and new technologies were driven by prizes sponsored by aeronautical societies, newspapers, mail companies, and interested individuals (Schroeder 2004).

After frequent use between the eighteenth and early twentieth centuries, prize competitions largely fell out of use as a means to stimulate technological innovation. They have enjoyed a renaissance in recent years, however, attributable in part to the success of the Ansari X PRIZE. In 1996, Peter Diamandis established the X PRIZE to "promote the development and flight of spaceships able to provide low-cost commercial transport of humans into space." The X PRIZE Foundation offered a ten million dollar prize to the team that, without government support, developed a craft that could

successfully send the pilot and two passengers (or equivalent weight) to a suborbital altitude of at least one hundred kilometers, and then repeat the flight within two weeks. Aerospace designer Burt Rutan and his team at Scaled Composites, backed by Microsoft cofounder Paul Allen, won the prize on October 4, 2004, with the SpaceShipOne (Miller 2005). The X PRIZE Foundation is now sponsoring the X PRIZE Cup, which will eventually award prizes for spaceships that are faster, cheaper, safer, and can travel higher. In addition, the X PRIZE Foundation recently announced a ten million dollar prize for inexpensive and rapid sequencing of the human genome, and is exploring new prizes in areas such as high-mileage autos, education, space, the environment, nanotechnology, medicine, and social entrepreneurship.[1]

The proposal for a more widespread use of inducement prizes is in no way intended as a substitute for a more comprehensive and robust public science and technology policy. For example, the mainstream agenda recently set forth by the National Academies deserves and is beginning to receive serious consideration by policymakers (National Academies 2005).[2] Inducement prizes can be a useful complement to, and under some circumstances may have advantages over, traditional funding mechanisms:

1. Prizes are especially suitable when the goal can be defined in concrete terms but the means of achieving that goal are too speculative to be reasonable for a traditional research program or procurement. For example, the Methuselah Foundation is sponsoring the Mprize for the research team that develops the longest living mouse. The long-term goal of the foundation is the "defeat of age-related disease and the extension of the healthy human lifespan." Researchers from MIT, Harvard, and UCLA have already announced their intention to compete for the prize, which currently stands at $3.9 million (Mprize 2006), although many researchers in gerontology are skeptical about the potential of radical life extension.

2. Government research grants typically require that the funding agency both determines who will receive funds to achieve a certain goal and chooses among different approaches for achieving that goal. In contrast, public inducement prizes allow the government to establish a goal without being prescriptive as to how that goal should be met or who is in the best position to meet it. The value of leaving open the best way to meet the goal is vividly illustrated by the outcome of the Orteig Prize, a twenty-five thousand dollar prize sponsored in 1919 by hotel owner Raymond Orteig for the first nonstop flight between New York and Paris (Schroeder 2004). The conventional wisdom of the day was that such a transatlantic flight would require a heavy, multiengine plane with a large crew. Charles Lindbergh successfully completed the first transatlantic flight in 1927 solo in a single-engine plane.

3. Prizes can also address some of the problems that are associated with government support for applied R&D. As Kremer and Glennerster (2004, p. 49) note, "researchers funded on the basis of an outsider's assessment of potential rather than actual product delivery have incentives to exaggerate the prospects that their approach will succeed, and once they are funded, may even have incentives to divert resources away from the search for the desired product."

1. See for example Nicholas Wade, "$10 Million Prize Set Up for Speedy DNA Decoding," *New York Times*, October 5, 2006.

2. Policies discussed in this report include increasing federal support for basic research by 10 percent a year for the next seven years; increasing the tax incentive for private sector research and development and making it permanent; recruiting ten thousand of America's brightest students to become math and science teachers every year; increasing the number of undergraduate and graduate fellowships for science and engineering; investing five hundred million dollars a year to upgrade the research infrastructure at American universities and national labs; creating a new agency to support energy research; reforming the U.S. patent system; and allowing each federal program manager to allocate 8 percent of his budget to high-risk, high-return research projects.

Inducement prizes avoid this problem by paying only if someone meets the predefined objective. By comparison, if the government provides a grant or a contract, it pays even if the recipient is unsuccessful, on the condition that the scope of work was completed. For example, NASA gave Lockheed Martin more than nine hundred million dollars to build the X-33, a technology-demonstrator for NASA's next-generation reusable space-launched vehicles (David 2001). When the program was cancelled because of problems associated with the X-33's composite fuel tanks, no one expected Lockheed to give the money back.

4. Under some circumstances, prizes can stimulate philanthropic and private sector investment that is greater than the cash value of the prize. For example, the ten million dollar Ansari X PRIZE was financed by a one million dollar insurance policy, and the X PRIZE Foundation reports that the prize stimulated at least one hundred million dollars in private sector investment (Diamandis 2006). This leverage can come from a number of different sources. Companies may be willing to cosponsor a competition or invest heavily to win it because of the publicity and the potential enhancement of their brand or reputation. Private, corporate dollars that are currently being devoted to sponsorship of America's Cup or other sports events might shift to support prizes or teams. Wealthy individuals are willing to spend tens of millions of dollars to sponsor competitions or bankroll individual teams simply because they wish to be associated with the potentially historical nature of the prize. Most areas of science and technology are unlikely to attract media, corporate, or philanthropic interest, however.

5. Prizes can attract teams with fresh ideas who would never do business with the federal government because of procurement regulations (e.g., accounting and reporting requirements) that they may find burdensome. This effect is important because, as Baumol (2004, p. 5) notes, "the independent innovator and the independent entrepreneur have tended to account for most of the true, fundamentally novel innovations. In the list of the important innovative breakthroughs of the twentieth century, a substantial number, if not the majority, turn out to be derived from these sources rather than from the laboratories of giant business enterprises." As examples of small-firm innovations, Baumol cites the airplane, air conditioning, the electronic spreadsheet, FM radio, the high-resolution CAT scanner, and the microprocessor.

Prizes have significant limitations. In most circumstances, they should not be the policy instrument of choice for science and technology. Since only winning teams receive prizes, and only after they have won, all entrants must have or raise the funds necessary to compete. Most researchers and small- and medium-sized companies find it difficult to self-finance or raise external funding. For example, offering a prize for a breakthrough in high-energy physics would not work if it required physicists to raise billions of dollars to build a new particle accelerator. Furthermore, it may be impossible to clearly specify in advance what the victory conditions are, since the outcomes of fundamental research are, by definition, unknowable or difficult to quantify in advance. Many of the most interesting discoveries in science are serendipitous. Even when the goals of a prize are generally understood, it may be difficult to develop appropriately specific proxies for those goals, such as an improvement in the price-to-performance ratio of a given technology, or widespread market acceptance. Finally, prizes are more likely than traditional funding mechanisms to lead to duplication of effort, although this effect can be mitigated through careful program design (Newell and Wilson 2005).

2. Harnessing the Power of Prizes

Inducement prizes are better suited to some situations than others. NASA has suggested six criteria for determining whether prizes are likely to work well in a particular situation: (1) the simpler, the better; (2) prizes relevant to the agency mission; (3) right level of difficulty; (4) follow-on opportunities; (5) interest for cosponsors and competitors; and (6) public excitement. Of course, not all prizes will meet all of these criteria, and it may occasionally make sense to experiment with a prize that explicitly violates one or more of them. Nevertheless, a list such as this one, combined with the benefits of prizes described in §1, offers a useful vocabulary for describing when prizes are likely to work well.

To appreciate how an expanded policy of inducement prizes and AMCs might work, consider how they have been and could be applied in five areas: (1) space exploration, (2) African agriculture, (3) vaccines for diseases of the poor, (4) energy and climate change, and (5) learning technologies. These proposed prize competitions are summarized in Table 1. In some cases, work has been done to estimate how large the prize or AMC would need to be to attract private sector participation. In other cases, I have made some rough judgments of a reasonable starting point for federal investment in prizes.

2.1. Space Exploration

Among all federal agencies, NASA has shown the greatest interest in using prizes to achieve its goals. With the passage of its 2005 authorization legislation, NASA can sponsor a prize of any dollar amount. It can also accept matching funds from the private sector. In 2004, NASA launched the Centennial Challenges program with prizes in several different categories. These prizes range from Flagship challenges that are large enough to encourage major private sector space missions, to Quest challenges designed to get more young people interested in science, technology, engineering, and mathematics.

NASA is also teaming with private organizations to sponsor nine competitions for technologies such as flexible astronaut gloves, space elevators, a simulated lunar lander, personal air vehicles, and others. Finally, NASA is exploring another six competitions with prizes totaling fourteen million dollars. The goals include a lunar all-terrain vehicle, low-cost space suits, a lunar night power source, and a micro reentry vehicle capable of returning viable samples from orbital research platforms. For example, to win the Micro Reentry Vehicle Challenge prize of two million dollars, the reentry vehicle must return six of twelve eggs safely to Earth from a starting point of two hundred kilometers above the surface of the Earth (NASA 2006).

NASA has been very imaginative in its use of prizes. I propose that it now also move forward with some more ambitious competitions that are under discussion, such as an Earth-Moon solar sailcraft race and a lunar lander-rover. Under this plan, NASA would devote at least one hundred million dollars of its $16.8 billion annual budget to prizes. Assuming that the initial experience is positive and that there are other appropriate ideas for competitions, NASA would eventually allocate 2–3 percent of its annual budget to prizes. Below are two examples of the more ambitious competitions that NASA should pursue:

(1) Earth-Moon solar sailcraft race: A fifteen million dollar prize pool would be offered to the first two teams whose solar sailcraft circle the moon and return to a specified Earth orbit. Solar sailcraft would be useful as monitoring stations that would provide advanced warning of solar storms, and for future outer planet or even interstellar missions.

(2) Lunar lander-rover: A twenty million dollar prize would be established for the first team to land a robotic rover on the lunar surface that is able to travel ten kilometers and send a video signal back to

TABLE 1

Proposed Prize Competitions for Technological Innovation

Area of innovation	Examples of specific goals	Proposed financial commitment
Space exploration	Earth-Moon solar sailcraft Lunar lander-rover	Short term: $100 million a year Longer term: 2%–3% of NASA's budget
African agriculture	Disease-resistant bananas, cassavas, and millet; heat-tolerant wheat; maize with increased protein content; drought-resistant sorghum; and sheep and goats resistant to intestinal parasites (Kremer and Zwane 2004)	$50–$100 million
Vaccines for diseases of the poor	AMCs for HIV/AIDS, pneumococcus, tuberculosis, malaria, rotavirus, and human papillomavirus	U.S. share of AMC for all six vaccines: $3.7–$4.1 billion
Energy and climate change	Zero-energy buildings, reductions in urban greenhouse gas (GHG) emissions, fuel-efficient cars	Short-term: $100–$200 million a year
Learning technologies	Software for early reading; math and science software for middle schools; software for introductory college courses in math and science	$100 million a year

Source: Author's proposals.

Earth. It has been more than thirty years since the United States conducted exploration on the surface of the moon, and such a competition could provide NASA with innovative, low-cost technology options for renewed exploration. An analysis conducted for NASA (X PRIZE Foundation 2003) notes that, in 2000, a start-up firm called BlastOff was created to place a robotic explorer on the Moon, but, having been created after the dot-com implosion of the late 1990s, it was not able to raise sufficient funds. A prize would make it easier for entrepreneurial firms to raise the money for this mission by making sponsorships and media sales more attractive to private funders.

The two most compelling advantages of prizes, for NASA, are the potential to increase public interest in science and technology, and the possibility of attracting a broader range of researchers and entrepreneurs to work on innovation related to NASA's work. For example, Team Snowstar, a team of undergraduates from the University of British Columbia who performed the bulk of their work in a dorm room, was voted "most likely to succeed" on the basis of their performance in the 2005 space elevator competition. Given that students have been responsible for Netscape, Yahoo!, Google, Napster, and many other successful technology companies, it is vital to engage students and other nontraditional performers. In the short run, of course, NASA is unlikely to rely on prizes for innovations that are on their critical path for important missions, and will need more experience with prizes before making them a mainstream tool.

2.2. African Agriculture

Increased productivity in Sub-Saharan Africa's agricultural sector is critical to fostering economic growth and reducing hunger and poverty in that region. Agriculture is the primary livelihood of

roughly 65 percent of people in Africa. It represents 30–40 percent of the region's GDP, and accounts for nearly 60 percent of its income from exports (World Bank 2006).

Unfortunately, crop yields in Africa have been stagnant, Africa has made no progress in reducing malnutrition, and stunting currently affects approximately 41 percent of preschool-age children in Africa (World Bank 2006).

Africa has not benefited from the Green Revolution—the combination of new seed varieties, irrigation, and fertilization techniques that led to sustained increases in agricultural productivity in Asia. With funding from the Rockefeller Foundation and the Ford Foundation, researchers developed plants that were more responsive to fertilizer, could mature more quickly and grow at any time of the year, and could support heavier heads of grain. Farmers in Asia rapidly adopted these high-yield varieties. From 1970 to 1995, cereal and calorie availability for each person in Asia increased by nearly 30 percent (International Food Policy Research Institute 2002). Although the Green Revolution has its critics, there is little doubt that it averted major increases in hunger and poverty in Asia.

However, African soil, climate conditions, and major crops are considerably different from Asia's. Africa is not typically suited for growing rice, which was one of the great successes of the Asian Green Revolution. Instead, African agriculture focuses more on crops such as cassava, bananas, sorghum, and millet. Of course, soil and climate conditions are far from the only problems with African agriculture. Irrigation systems are often underdeveloped, fertilizer and transportation costs are high, and public policies in many African countries have favored urban food consumers over rural food producers.

Although prizes will not solve all of the challenges facing African agriculture, they could prove useful in stimulating R&D of improved crop varieties that are especially suited for the region. Kremer and Zwane (2005, p. 3) report that "virtually no private agricultural R&D investment is targeted toward smaller or economically stagnant developing countries." Companies have no incentive to pursue agricultural R&D on African crops: The people in these countries are impoverished, so they cannot reward corporate efforts with money. Moreover, if farmers can use seeds from a first crop to plant a second crop, the ability of agribusiness firms to gain a reward on their R&D investment may be limited.

I propose that the United States join other developed countries in establishing prizes that would encourage increased R&D for plant and animal agriculture in Africa. By linking these prizes to their actual use, the prizes would encourage developers to promote the deployment of their technology. As agricultural economist William Masters (2005, p. 4) notes, "Since prizes can easily be divided, they offer innovators a strong incentive to collaborate with others in achieving and documenting the impact of their work." This is a clear advantage of prizes over an innovation strategy that relies solely on traditional funding mechanisms.

At a minimum, the United States should contribute fifty million to one hundred million dollars a year to such R&D efforts. If these initial competitions are successful, the United States should ramp up its level of investment.

Donors could establish prizes for specific crops, regions, nutritional objectives, or other agricultural improvements with large public benefits. Specific targets that have been suggested are included in Table 1. Over time, the prize secretariat for administering these prizes could become "a vibrant marketplace for innovations that donors want to pay for, that researchers can develop, and that African farmers desperately need" (p. 6). Early prizes for the deployment of agricultural innovations that have already been developed could give researchers the money needed to invest in future efforts.

Masters (2005) argues that prizes should be a fraction (initially 20 percent) of the invention's benefits to the public, as measured by controlled experi-

ments and farm surveys of actual adoption. Other analysts, however, believe that assessing the societal benefits would require too many subjective judgments, which might trigger controversy and legal disputes and diminish the attractiveness of the agricultural prizes (Kremer and Zwane 2004).

2.3. AMCs for Vaccines

Currently, only 10 percent of global health R&D is devoted to diseases that affect 90 percent of the world's population (Global Forum for Health Research 2004). Although AIDS and malaria together cause the deaths of millions of people each year, no effective vaccines exist for these diseases, or for certain other diseases that disproportionately affect the poor. In other cases, vaccines exist, but they have not been optimized for the strains of the disease that are prevalent in developing countries. Companies in high-income countries have little financial incentive to invest in the development and production of new vaccines for developing countries because the total market size for all vaccines in developing countries is only five hundred million dollars per year (Levine et al. 2005).

The Center for Global Development's AMC Working Group (Levine et al. 2005) has issued a detailed proposal to make markets for vaccines for the diseases of the poor. They have estimated that the average lifetime revenue from a new drug is three billion dollars, and determined that paying three billion dollars for a malaria vaccine, for example, would be a cost-effective public health intervention, since it would save lives at fifteen dollars a life-year. Under their proposal, donor governments would make a legally binding commitment to buy a certain number of treatments at a guaranteed price. For example, donor governments might commit to purchase two hundred million doses of an effective malaria vaccine at fifteen dollars a dose, with sponsors providing fourteen dollars and eligible low-income countries providing a one dollar copay per dose. Other elements of the commitment would include the technical specification of the vaccine, such as efficacy, duration of protection, usability, safety, and regulatory approval, and the establishment of an independent adjudication committee to enforce the commitment.

Some analysts believe that sponsors of AMCs may overpay by 20 to 30 percent to overcome drug company skepticism that the prize money may never be paid, and because sponsors have imperfect information about the future costs of drug development (Maurer 2005). Even so, as noted above, a commitment of three billion dollars for a malaria vaccine would be an extraordinarily cost-effective form of development assistance. The market size would be comparable to the average revenues for new drugs in developed countries, and therefore would be sufficient to "mobilize the ingenuity, energy, intellectual assets and managerial capacity of the pharmaceutical sector—from biotechs to multinational firms" (Levine et al. 2005, p. 17). Although donor governments might guarantee a market of three billion dollars for a vaccine, the order would not necessarily go to only one supplier. Companies that developed demonstrably better second-generation products would also be eligible for the price guarantee, although the total size of the market guarantee would not increase.

Another advantage of AMCs is the ability to influence the plant size decisions of companies and to negotiate lower prices for vaccines after companies have recouped their initial investment by selling vaccines at the supported price.

One major challenge is whether the public health systems of developing countries could effectively deliver enough of the vaccine. Some vaccines (particularly those with multiple doses) are a challenge for any public health system to deliver effectively; the difficulties are particularly great in developing countries.

The Center for Global Development's proposal is beginning to attract attention at a high level. In September 2005, Senators John Kerry and Richard Lugar introduced the Vaccines for a New Millen-

TABLE 2
Proposed AMCs for Major Diseases

Disease	Annual deaths (millions)	AMC commitment (billion dollars)	Years of life saved* (millions)
HIV/AIDS	3	2.3–2.5	17.6
Pneumococcus	1.6	0.8–1.1	No estimate available
Tuberculosis	1.6	2.3–2.5	3
Malaria	1.1–2.7	2.4–2.6	13.8
Rotavirus	0.4–0.5	0.7–0.8	No estimate available
Human papillomavirus	0.3	0.7–0.8	No estimate available
Total	**8–9.7**	**9.2–10.3**	—

Sources: Tremonti 2005, Berndt et al. 2005.
* The number of lives saved multiplied by the average remaining lifespan of persons saved, adjusted for disability. It is an annual figure, starting once the number of immunizations given has stabilized.

nium Act of 2005. In December 2005, the finance ministers of the G8 countries issued a communiqué in which they pledged to develop a pilot AMC in 2006. The accompanying report identified six potential candidates for AMCs: vaccines for HIV/AIDS, pneumococcus, tuberculosis, malaria, rotavirus, and human papillomavirus (G8 Finance Ministers 2005). In recent months, Canada, Italy, and the United Kingdom have all committed to help finance an AMC for a pneumococcal vaccine.

Although some of the details of an AMC remain to be negotiated, the broad outlines of its potential benefits and costs are clear. About eight to ten million people die each year from these six diseases. I propose that the United States join with other wealthy countries and sponsor AMCs for all six vaccines. Assuming that the United States were to contribute 40 percent of program costs (its share of the GDP of OECD nations), it would pay about four billion dollars.

2.4. Energy and Climate Change

Fossil fuels account for roughly 85 percent of the world's energy consumption (Hoffert et al. 2002). Burning fossil fuels increases atmospheric carbon dioxide, threatening global warming and climate change known as the greenhouse effect. In addition, burning fossil fuels creates a number of lower-level air pollutants such as mercury and sulfur dioxide.

Prizes and AMCs can play a role in energy and climate change policy, although they are clearly not a substitute for the more sweeping actions such as a cap and trade system to control carbon dioxide and other greenhouse gas (GHG) emissions. Congress has begun recently to support energy prizes. In May 2006, the House passed legislation (U.S. Congress 2006) authorizing seventy million dollars over ten years for so-called H-Prizes to accelerate the emergence of a hydrogen economy. Prizes would be awarded for technological advancements in hydrogen production, storage, distribution, and use; prototype vehicles; and transformational technologies.

The *Energy Policy Act of 2005* (U.S. Congress 2005a) gives the secretary of energy the authority to award cash prizes of ten million dollars for "breakthrough achievements in research, development, demonstration, and commercial application" that are related to the Department of Energy's (DOE) mission, and five-million-dollar Freedom Prizes (§1012, p. 46) that reduce our dependence on Middle East oil. I propose that

the DOE not only implement this program, but also lay the groundwork for even more ambitious prizes by working with successful entrepreneurs and foundations that may be willing to match the federal government's investment. Out of its annual $5.1 billion budget for nondefense R&D, DOE should invest at least one hundred million to two hundred million dollars in energy-related prizes. Following are discussions of some prizes I recommend.

A first possible prize is for technologies leading to zero-energy buildings. In September 2006, Daniel Kammen (2006) of the University of California at Berkeley testified before Congress, calling for prizes for the construction of buildings that cleanly generate some or all of their own energy needs. Currently, the energy required by residential, commercial, and industrial buildings account for 43 percent of U.S. carbon dioxide emissions. Usually, building projects are awarded to the team that proposes the lowest-cost building, not to the team that minimizes the costs of building and operating the building over the next several decades by installing more efficient heating, ventilation, and air conditioning systems. The challenge, here, is to find ways of using on-site renewable energy technologies for heat and power. A wide range of technology opportunities exist, including smart roofing materials that absorb solar energy in cool weather and reflect it in hot weather; windows with coatings that reduce the heating and air conditioning load by up to 40 percent; and integrated systems that more efficiently combine space heating, air conditioning, and water heating.

A second possible prize would encourage cities to reduce global warming. For example, the 2006 Energy Freedom Challenge will award a prize to the city government that meets more than half of its electricity needs using renewable energy sources. This challenge potentially will extend the competition to citywide electricity use. It should be significantly expanded beyond that, with at least twenty million dollars a year in prizes for both annual progress and for meeting goals in clean energy and total reduction in GHG emissions. A more visible prize might encourage grassroots partnerships among city governments, industry, foundations, and environmentalists.

A third area for prizes related to energy is fuel-efficient cars. The X PRIZE Foundation has pledged to launch an Automotive X PRIZE (2006) designed to "radically reduce oil consumption and harmful emissions," and "result in a new generation of super-efficient and desirable mainstream vehicles that people want to buy." Their rationale for "Why a prize?" (Mercer 2006, p. 1) is worth quoting at length because it speaks to the potential symbolic and emotional impact of a successful competition:

> There is no stronger catalyst, no clearer depiction of the possible … than a competition leading to a winner. … Americans want to see the best man, woman, book, film, team, or would-be pop star *win*. Winning a fair and open competition confers on the victors and their ideas a legitimacy that no amount of argument, endorsement, data, or regulation can achieve. … American drivers will not be cajoled or lectured into buying more efficient vehicles—but they will drive a winner!

The X PRIZE Foundation has also stated that their prize will contain a "units sold" metric. Although the details of the prize have not been announced, they have identified one hundred miles a gallon as a meaningful goal. At a minimum, the DOE should cosponsor that prize.

Other energy-related prizes have been proposed for power storage, storage for off-peak wind-generated energy, advances in solar cells, net zero energy consumption appliances, and utilities that act as markets for selling clean power generated at homes and businesses.

Policymakers may find it challenging to define appropriate victory conditions for energy-related prizes that are intended to increase deployment of

clean energy or energy-efficient technologies. A prize given for improvements in the efficiency of solar cells, for example, might result in a solar cell that is efficient but that includes rare and expensive materials in its construction, or that is difficult to manufacture and install. Policymakers may also find it difficult to define victory conditions that include a proxy for improvements in price-to-performance ratio. For instance, one could establish a prize for increasing the efficiency of plastic (inexpensive) solar cells, but this would prescribe which technology is likely to lead to a breakthrough.

2.5. Learning Technologies

From 1980 to 2000, the resources devoted to U.S. public schools from kindergarten through twelfth grade (K-12) increased significantly. Annual real spending for each student increased from $5,124 to $7,591 dollars in those years. The percentage of teachers with a master's degree or more increased from 49.6 to 56.2 percent, while the student-teacher ratio declined from 18.7 to 16.0. Meanwhile, the average performance of 17-year-old students showed only modest improvements (Hanushek 2003). While there are many proposals for improving student performance, it is worth exploring the role that learning technologies could play.

Some economists have questioned whether the use of computers in the classroom has improved or can improve student performance (Rouse et al. 2004). It took decades of investments in information technology before businesses began to enjoy sustained increases in productivity; a similar period of experimentation may be needed in the educational sector. Prizes for educational technology solutions that have a demonstrable impact on student performance may be a useful way of making progress. In 1995, fewer than 0.1 percent of the three hundred billion dollars spent on K-12 education were devoted to R&D, as compared to the 23 percent R&D-to-sales ratio in the pharmaceutical industry (President's Committee of Advisers on Science and Technology 1997). Moreover, the market for educational software is not attractive. School spending on software is low (only ten dollars per student), the market is fragmented, and the review and adoption process is slow (Kalil 2002). The home market for educational software is actually contracting.

To encourage private sector investment in technologies for education and lifelong learning, I propose that the Department of Education and other funding agencies devote at least one hundred million dollars a year to prizes. Several potential targets follow.

IN DETAIL

A Prize for Reading Software

In the area of reading technology, the Department of Education could announce a cash prize to a company, nonprofit organization, or university-based research team that creates software or some other form of educational technology that demonstrably improves early reading skills. The social benefits of improving early reading are enormous. Currently, 38 percent of fourth graders cannot read and comprehend a paragraph found in a simple children's book. More than 75 percent of the children who eventually drop out of school report difficulties in reading, and at least half of adolescents and young adults who have criminal records have reading difficulties (Lyon 2001). The economic benefits of improved reading skills would be substantial. Recent estimates suggest that increasing overall student achievement test scores by one standard deviation would increase the present value of lifetime earnings for an 18-year-old student by between $110,000 and $256,000 (Kane and Staiger 2002).

As computing power increases, one intriguing approach to improving early reading is to develop software that approaches the effectiveness of a one-on-one tutor—by combining advances in speech technology, intelligent tutoring systems, cognitive science, and human-computer interaction. For example, software developed by researchers at Carnegie Mellon University allows a computer to "listen" to students read stories on a screen, and to intervene when the reader makes mistakes, gets stuck, or asks for help (Mostow and Aist 2001).

The potential of modern computers and advanced software to improve early reading is real, but has not yet been conclusively demonstrated. As the National Reading Panel 2000, p. 17) concludes:

> Until recently, computers were not considered capable of delivering reading instruction effectively. They could not comprehend oral reading and judge its accuracy. They also were unable to accept free-form responses to comprehension questions, so their use had to rely primarily on multiple-choice formats. Today, the situation is much improved. New computers have speech recognition capabilities as well as many multimedia presentation functions. … The Panel is encouraged by the reported successes in the use of computer technology for reading instruction, but relatively few specific instructional applications can be gleaned from the research.

Obviously, technology is no substitute for motivated, competent teachers and caring parents who read to their children. It would be wildly unrealistic to expect that technology alone can address deep-rooted inequities, such as the fact that there are 199 age-appropriate books in the average home in Beverly Hills, 2.7 in Compton, and only 0.04 in Watts (Smith et al. 1997).* Still, it is worth exploring whether technology can play a useful role.

Victory Conditions and Size of Prize. The reading technology competition should require a randomized control trial performed by independent, credible researchers in a school setting. These stud-

* These two cities and the district of Watts, all within Los Angeles County, have average household incomes of about $71,000, $32,000, and $18,000, respectively.

ies measure an intervention's effect by randomly assigning individuals to either an intervention group (which receives the treatment) or to a control group (which does not). Currently, there are very few evaluations of educational interventions, including technology, that use random assignment.

The competition could award several million dollars every two years to the team that demonstrates the largest improvement in student performance relative to the current state of the art, as measured by effect size. This criterion would reward cumulative innovation and improvement. A grand prize could be awarded to a technology that meets a goal that is ambitious but realistic, such as software that enables a student who is one grade level behind average student performance to catch up to his peers during the course of a school year.

This prize should be large enough to attract the most talented teams in the software industry. A relevant benchmark is the development cost for a new video game for the Microsoft Xbox 360, which is reported to average twenty million dollars (Irwin 2006).

The Department of Education should convene experts to determine the most appropriate ways to measure student performance in early reading (for example, in phonemic awareness, phonics, fluency, vocabulary, and text comprehension). A variant on this prize could focus on low-cost educational toys that are designed to improve some aspects of school readiness, such as spoken vocabulary, familiarity with numbers, classification abilities, and familiarity with the alphabet.

Stage of Innovation. The prize should be awarded to a technology that is robust and mature enough to be used without technical support beyond the minimum (Internet-connected computers or video games). This will ensure that the winning solution can be adopted widely, does not require specialized personnel, and is more likely to be cost effective.

Advantages of a Prize. Given the strong philanthropic and corporate interest in K-12 education, a prize for reading software could stimulate additional investment. This private sector investment could match a federal contribution to the prize or back particular teams. It might also encourage any software developer that was confident of its product to have it rigorously evaluated, whether or not the evaluation was paid for with federal grants.

Potential Challenges. Even rigorous studies of educational interventions yield different results: It may not be possible to measure the effectiveness of learning technologies with enough accuracy to fairly reward incremental improvements. Any grand prize that is tied to a specific absolute goal, such as a particular effect size, will be somewhat arbitrary.

Use of Resulting Technologies. Before promoting wide deployment of whatever technology is developed as a result of the prize, agencies should analyze its cost effectiveness compared to other approaches.

In the area of math and science software, the Department of Education could sponsor a prize for games or educational software that significantly improves student performance in key areas of concern, such as middle school math or science. The prize should be large enough to encourage leading game or software developers to team up with cognitive scientists, instructional designers, and subject-matter experts to produce games that are fun, engaging, and pedagogically effective.

Technology, used effectively, can improve student performance in science and math in several different ways (Kalil 2002, Kelly 2005). First, it can make learning more compelling and engaging, making students likely to spend more time learning. The best game developers have clearly learned something important about how to grab and maintain the attention of children and young adults. The average player of one popular game, "Everquest," spends 4.7 hours a day immersed in the game's virtual world.

Second, computer simulations and virtual environments can allow K-12 students to learn by doing in the same way that a student learning to be a pilot might use a flight simulator, or a medical student might practice surgery on a virtual patient. Simulations and interactive visualizations make it easier for students to master concepts involving, for example, time and motion.

Third, advanced artificial intelligence systems can continuously assess the student's strengths and weaknesses and the level of her understanding of the subject matter; generate appropriate instructional material tailored to the student's progress; develop a computer model of what an expert knows in a particular subject area; use a variety of pedagogical approaches, including explanations, coaching, and critiquing; and monitor, evaluate, and improve its own teaching performance as a function of experience. In one experiment, students who used an intelligent tutoring system developed at Carnegie Mellon University performed 15 to 25 percent better on standardized tests in algebra, and 50 to 100 percent better on assessments of complex mathematical problem solving than a control group (Koedinger et al. 1997).

There are certainly reasons to be concerned about U.S. performance in math and science. In an international comparison of the ability of 15-year-old students to solve real-world math problems, the United States ranked twenty-fourth out of twenty-nine industrialized nations. The students performed marginally better in science, falling between seventeenth and twenty-third place (OECD 2003).

These prizes need not be limited to K-12 education. The National Science Foundation should establish a prize competition for computer games for tertiary-level physics, chemistry, and calculus that would reduce the 50 percent attrition rate among undergraduate students who aspire to a degree in the natural sciences or engineering. These games could help to replace or deemphasize the large lecture-format courses that so often alienate students (Mayo 2005).

3. Institutionalizing Prizes as Policy

To date, individuals, foundations, and philanthropists have taken the lead in sponsoring prizes. Two federal agencies, NASA and the Defense Advanced Research Projects Agency (DARPA), have started to experiment with relatively small prizes. However, the federal government's current use of prizes and AMCs is still too modest, given their enormous potential. The discussion in §2.6 suggested a beginning set of prizes that would be a useful starting point. As the government expands the use of prizes and reaches a deeper understanding of their efficient design, the next step is to institutionalize prizes, so that they are a regular feature of science and technology policy.

3.1. Generating Ideas for Prizes

The next step is to generate a stream of additional specific ideas for prizes. I propose that the president or appropriate congressional committees direct federal agencies to identify areas where inducement prizes or AMCs would be the effective way to meet agency goals and simultaneously advance the public interest. Every agency should designate at least one smart, entrepreneurial program manager to identify opportunities for the increased use of prizes. The designated program manager should be given a modest budget to support workshops, online consultations, and planning grants. Agencies should consult widely to generate ideas for prize topics. This should be done in a transparent way so that if an agency decides not to pursue an idea with some promise, a private sponsor could pursue it.

For the most promising proposals, agencies should charter interdisciplinary working groups of outside experts to serve as prize designers. These groups would address the design issues discussed above in §2.4 and §2.6 (victory conditions) and in §4 (eligibility and size of the prize or AMC). Alternatively, agencies could partner with organizations such as the X PRIZE Foundation that are developing expertise in prize design and management.

The Office of Science and Technology Policy or the National Economic Council should establish an interagency forum that would allow program managers interested in prizes to collaborate and share lessons learned as they accumulate.

3.2. Legislative Authority

Once agencies have some additional compelling ideas for prizes and AMCs, Congress should authorize them to proceed. Some agencies have recently been granted the authority to sponsor prizes. The *NASA Authorization Act of 2005* gives NASA the ability to "competitively award cash prizes to stimulate innovation in basic and applied research, technology development, and prototype demonstration" (U.S. Congress 2005b, §314, p. 11). Congress has passed legislation to allow the National Science Foundation, DOE, DARPA, and the military services to conduct prize competitions.

Congress could continue to pass prize legislation on an agency-by-agency basis, or amend procurement laws to make it clear that all agencies have the authority to support prizes and AMCs. A wholesale legislative change would obviously be more efficient, but the agency-by-agency approach would give different congressional committees an opportunity to learn about and approve the use of prizes.

Ideally, prize legislation would encourage and enable agencies to partner with nonprofit and private sector entities, which could take the lead on public relations, eligibility requirements, the recruiting of additional commercial and philanthropic sponsors, implementation, judge selection, and other logistical issues. Although DARPA took the lead in implementing its challenge for unmanned ground vehicles, there is no reason to believe that agencies will have a comparative advantage in running competitions. Nongovernmental entities are also likely to be able to mobilize additional resources

and to bring fresh thinking to structuring and publicizing competitions. X PRIZE Foundation CEO Peter Diamandis envisions creating competitions with accompanying reality TV shows that capture "the minds and hearts of 50 million Americans" (Diamandis 2004, p. 154). This is not likely to be the first idea that occurs to a civil servant.

The U.S. government should have authority to negotiate with other governments to secure the funding for prizes and AMCs for purposes such as innovations that benefit agriculture in the developing world or vaccines for developing countries.

The prize legislation should give the agency the discretion to experiment with many different approaches to prizes and AMCs, and avoid being overly prescriptive on issues such as intellectual property rights, rules, and prize amounts. It needs to make government commitments to provide prizes legally binding, and not subject to the whims of an annual appropriations process. The legislation might also require that the government's prize program be periodically evaluated by a credible third party such as the National Academy of Sciences to identify lessons learned, promising practices, and missed opportunities.

4. Designing Effective Prizes and AMCs

In §4, I will identify a set of eight issues that prize designers should consider: victory conditions, the stage of the innovation process, distributed innovation, the size of the prize, eligibility requirements, intellectual property rights, budgeting for the prize, and widespread interest in the prize.

4.1. Victory Conditions

A prize sponsor may have a broad long-term goal, but in creating the prize the sponsor should establish a specific objective and a clear definition of the victory conditions (Newell and Wilson 2005). Enunciating the most productive set of conditions is an art, not a science, and prize sponsors have sometimes had problems articulating the criteria.

For example, in 1959, physicist Richard Feynman gave the first lecture on nanotechnology (Feynman 1959). At its conclusion, he offered to pay one thousand dollars to anyone who could build an operating electric motor that would be no larger than one-sixty-fourth of a cubic inch. The next year, an engineer figured out how to do it using conventional tools. He met the conditions of the prize, but failed to advance the science of nanotechnology, as Feynman had hoped (Miller 2005).

Other sponsors of prizes have made the victory conditions too difficult. The Rockefeller Foundation established a one million dollar prize for a low-cost way to test for gonorrhea or chlamydia (Masters 2005). The criteria were that the test would be 99 percent accurate, cost less than twenty-five cents per usage, use noninvasive samples, and provide immediate and reliable results that could be interpreted by health workers with a primary education and no more than two hours of training. The Rockefeller Prize was never claimed.

Policymakers must seek a balance in which the victory conditions for a prize are neither too easy nor too difficult to achieve. Victory conditions must be specified with appropriate precision. Victory conditions that are too ambiguous about how a winner will be determined can reduce the number of entrants willing to participate in a contest or lead to litigation about the final outcome. For example, a prize allocated to "the best new technology for reducing GHGs" might be too broad. Even if two contestants achieved the same reduction in GHGs, "one might require more up-front capital expenditures, whereas the other might have higher operating costs. Deciding which entrant was superior would become a contentious and subjective process" (Newell and Wilson 2005, p. 27). On the other hand, being too specific can limit the creativity of the contestants, and may inadvertently foreclose some technological options.

Prize designers must also decide whether to pick the winner using a contest or a first-past-the-post method. The latter awards the prize to the first contestant to meet a prespecified technological goal. This approach is the simplest, but it may reward speed over quality. The former allows judges to weigh a number of different factors, at a cost of greater subjectivity.

Finally, policymakers must decide whether to provide multiple prizes. Allowing for multiple winners can increase the probability of any single participant achieving some success, and thereby can increase the willingness of individuals and firms to participate. For example, the X PRIZE Foundation has concluded that a competition for a human orbital vehicle should be structured to support multiple prizes (David 2005).

4.2. Stage of the Innovation Process

Innovation happens through a series of stages: from the initial idea and concept, to invention, to translation to a commercial product or process, and finally to widespread use of the product or process. Although innovation does not occur in a straight-

forward, linear fashion, it is useful to think about the role that inducement prizes can play in these stages.

Ideas and Concepts. Sometimes ideas and concepts, ambitious goals called grand challenges, or visions can have a powerful influence on the evolution of a field or technology. In 1968, for example, MIT professor J. C. R. Licklider argued that computers would become an important communications device, and that they would enable the formation of online interactive communities based on common interest rather than geography (Licklider and Taylor 1968). This vision played a key role in shaping the computer science research agenda, stimulating research that led to today's Internet. White paper competitions that encourage people to describe their ideas for promising research directions or goals would be inexpensive. Moreover, a condition of the competition could be that all ideas in the white papers would be made publicly available.

Invention. At this stage, the sponsor may be able to attract many contestants—including individuals, researchers, and firms—for relatively small prizes, even though only a small fraction of inventions are ever commercialized. Also, the sponsor may be interested in improving the price-to-performance ratio of a given technology. As noted above, it will be hard to verify what the ultimate costs and performance will be at the invention or research prototype stage.

Translation of Invention to Commercial Product or Process. This requires making the difficult transition from the ideas behind a potential product or process to the creation of the product itself, which can require high-volume, repeatable, cost-effective manufacturing.

Widespread Use of Product or Process. Some inducement prizes, including most AMCs, are designed to encourage widespread adoption and use of an innovation. However, prizes based on widespread adoption or AMCs are likely to be expensive if they are to change the incentives that innovators face.

4.3. Distributed Innovation

Some innovation processes, such as the creation of open source software, take advantage of the decentralized contributions of many individuals. Agencies might establish prizes that leverage the small efforts of the many as opposed to the large efforts of the few (Kalil 1996).

One example of this distributed innovation process is the efforts by the synthetic biology research community to create an open repository of parts and devices that can be used to engineer biological systems (Endy 2005). These engineered biological systems might be used to produce drugs and specialty chemicals, break down heavy metals, create clean energy from sunlight and atmospheric carbon dioxide, and seek out and destroy cancerous tumors. Agencies with an interest in advancing synthetic biology, such as the DOE, could establish prizes for parts and devices with specific functionality, or for parts and devices that were used the most by other research or industrial groups.

Another example is Innocentive, an online marketplace that matches scientists and inventors to companies with tough challenges (Howe 2006). More than ninety thousand solvers from forty scientific disciplines and 175 countries participate in Innocentive's network. This intellectual diversity is a source of strength, with one researcher finding that the odds of a solver's success increased in fields in which the solver had no formal experience. As of late 2006, Innocentive is focusing on problems in chemistry and biology. Agencies should experiment with the use of these markets to determine whether they are a cost-effective tool for meeting mission goals. For example, the Environmental Protection Agency might use Innocentive to identify green chemistry technology solutions, such as the reduction of hazardous substances in the design, manufacture, and use of chemical products.

4.4. Size of the Prize

The size of the prize should be related to the development cost of the innovation, the potential social gain, and the probability of success. A technological

target that will be expensive and difficult to achieve, or with high social value, will require a large prize. Setting the cash value of the prize is difficult, but establishing a prize that is approximately correct is important. If it is too small, few will compete. If it is too large, too many teams may compete, leading to overinvestment and duplication of effort. Prize sponsors can also automatically increase the value of the prize over time.

Prize sponsors confronted with these issues have proposed several different methodologies. The X PRIZE Foundation established a ten-million-dollar prize, which signaled that this was a prize worth taking seriously. Since Microsoft cofounder Paul Allen spent twenty million dollars backing the winning team, he clearly had motivations that transcended economic considerations. If contestants are willing to enter the contest for the reputational benefits, or philanthropists are willing to bankroll contestants, then the size of the prize may only need to be large enough to command attention.

Another approach for establishing the cash value of the prize is to determine how large the prize would need to be to attract private investment by profit-maximizing firms, and then calculate whether paying this amount is a cost-effective intervention. Alternatively, sponsors could estimate the social benefits of the innovation, and set the prize at some fraction of that amount.

4.5. Eligibility Requirements

Prize designers must determine who will be eligible to compete in the prize. Will foreign companies or researchers be allowed to compete for a prize funded by U.S. taxpayers? Will national labs or government personnel be allowed to compete? Will competitions have qualifying events to winnow down the number of eligible contestants (Gibbs 2006)?

4.6. Intellectual Property Rights

The prize designer must grapple with whether the winner of the prize will be allowed to keep the intellectual property rights of the innovation, which may include trade secrets, copyrights, and patent rights. A variety of approaches have been proposed. The DARPA Grand Challenge left all intellectual property with the entrants. NASA, when announcing prize competitions, has stated that the assignment and licensing of intellectual property rights will vary depending on the goals of the competition. When the goal of the competition is to encourage the development of a private sector capability that NASA or other users can purchase in the future, most or all of the intellectual property will remain with the contestants. When the competition is designed to develop an innovation for a government system, NASA will require the competitors to grant NASA a license to use the innovation, but competitors will retain all rights for non-NASA applications. Under the Center for Global Development's proposal for an AMC for vaccines, the intellectual property would remain with the company that developed the vaccine. In return for taking advantage of a guaranteed price for a specified number of doses, the producer would be obligated to sell future treatments at a fixed, low price at a reasonable mark-up over estimated production costs.

Prizes could also be used as a substitute for intellectual property rights. Innovative firms benefit from owning intellectual property rights because they are able to charge a higher price than they would if the innovation were available to all. While these higher prices offer a reward for innovation, they also discourage the technology from being as widely used. Some economists have argued that, at least in certain cases, a prize that required the inventor to put his invention in the public domain and thus let competitive firms use the technology would provide a similar reward to the original innovator, while not leading to higher prices that would discourage the widespread use of the innovation (Scotchmer 2004).

4.7. Budgeting for the Prize

Contestants need to be convinced that prize organizers will honor their commitments to award a

promised prize or to make a guaranteed purchase. Governments also need to be able to budget for an inducement prize that may result in money being spent ten to fifteen years after the competition is established.

A prize can be funded in one of three ways: full, front-loaded financing; periodic contributions; or a contingent liability to be paid when the prize is won. For example, the legislation that allows NASA to offer prizes requires that NASA have all of the funding in hand (from either the private sector or congressionally appropriated funds) before announcing the prize.

4.8. Widespread Interest in the Prize

A prize that is well publicized—generating interest from potential competitors, cosponsors, and the public—will probably bear more fruit. In a broader sense, the publicity around prizes can encourage people to pursue careers in science, engineering, and high-tech entrepreneurship. Media attention will make it more attractive for competitors to win the prize, and for cosponsors to be associated with it. Peter Diamandis (2004) argues that the X PRIZE competition was successful because it "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!'" (p. 57).

5. Questions and Concerns

Although prizes should play a larger role in science and technology policy, they also have limitations and raise some legitimate concerns.

1. Do prizes place too much emphasis on a "technological fix"?

Some people object to prizes on the grounds that they tacitly or explicitly assume that technological innovation is sufficient to solve major economic and societal problems. This is obviously not the case. For example, creating vaccines will not be effective without a public health system that is capable of delivering them. The technology for electronic medical records that would reduce administrative costs and medical errors has existed for decades, but deployment has been modest because of political, economic, and institutional barriers. Most of the proponents of prizes argue for them in the context of a broader strategy.

2. Prizes provide no cash flow to finance R&D up front.

Some contestants may be able to fund their upfront R&D costs through corporate or philanthropic sponsors, internal funds, or access to private capital markets. However, depending on the nature of the prize, some contestants will not have financing available to cover the costs of their participation. One response to this concern is that prizes are not intended as a substitute for other research funding. Another response is that many existing prizes have attracted a considerable diversity of teams.[3]

3. Will prizes reduce funding for other research?

Some university representatives are worried that the increased use of prizes will result in less funding for traditional research grants. It would be preferable if overall government spending on science and technology were increased, but most of the prizes identified here are not costly relative to other federal spending programs. Many useful and productive prize competitions could have prizes of one million to twenty million dollars. In addition, many of those who currently receive government funding for research would be the same people who could participate most actively in prize competitions.

4. Prizes will not work for long-term, fundamental research.

This criticism is largely valid. It is often impossible to specify the goal of fundamental research. Many important technological innovations are the outgrowth of curiosity-driven research. For instance, no sponsor would have established a prize to understand why certain species of jellyfish produce bioluminescence (light), but today the green fluorescent protein is one of the most important techniques for studying genes and proteins in living cells. Furthermore, research funding also helps support graduate education and the infrastructure that is needed for science, such as shared facilities. Prizes are not a substitute for stable, long-term support for fundamental research.

However, even in fundamental research, competitions can play a useful role by helping a research community evaluate progress in the field (O'Neill 2005). One example of this is the Critical Assessment of Techniques for Protein Structure Prediction. Every two years, research teams make blind predictions about the structures of proteins from a given set of amino acids. Last year, more than two hundred teams from twenty-four countries provided more than thirty thousand predictions. Before this competition, too many published models relied on known results. As prominent biologist David

3. For instance, NASA is delighted by the diversity of teams that are competing for their Centennial Challenges. These teams are composed of small companies, university professors and students, and hobbyist enthusiasts (Prospero 2006)

Baker puts it, without competitions—also known as community experiments—the issue is "whether you actually have captured some essential truth about how things work or whether you've just managed to twiddle all the numbers so that you reproduce a certain set of results" (quoted in O'Neill 2005).

5. What if attempts to win a prize raise safety or liability issues?

Participation in a competition could result in property damage, injuries, or even fatalities. The H-Prize legislation passed by the House requires registered participants to obtain liability insurance, and to indemnify the federal government against third-party claims related to the competition.

Some members of Congress are concerned that prizes for space exploration might encourage risky behavior. Others believe that these risks are necessary and worth taking. As Peter Diamandis (2004, p. 57) 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."

6. Will prizes be subject to interest group politics or congressional micromanagement?

Decisions about which projects science agencies should fund are made largely by the research community through peer review. Some researchers are concerned that members of Congress could establish prizes for their pet causes. Interest groups or individual firms could also capture the process of prize design and write the rules to inflate the value of the prize, favor their technological approach, or establish a prize for a technology they would probably develop in the absence of any inducement.

Although the risks of intertwining politics and science are real, they should be evaluated in the context of the alternative policy in which government gives grants for R&D. Pork-barrel politics can also influence grant funding for R&D. Moreover, potential grantees or contractors have an incentive to exaggerate their chances of reaching a particular technological goal, and it is difficult for federal program managers to monitor the performance of their contractors once the grant or contract has been awarded.

Prizes, on the other hand, must be publicly announced. They will presumably be monitored by a host of possible contestants, who are sure to cry foul if politics has intruded. Prizes do not specify how the technological innovation will be achieved; this will tend to limit micromanagement.

6. An Old Idea Whose Time Has Come Again

Although the idea of prize competitions has been around for three hundred years, it is time for us to focus on them more attentively. Inducement prizes and AMCs cannot substitute for robust research funding, protection of intellectual property, and development of a world-class workforce, but they can be a powerful complement to those efforts.

Under certain circumstances, inducement prizes may act as a useful complement to grants and contracts as a way to encourage technological innovation. The government can establish a goal without determining who is in the best position to reach the goal or what the most promising technical approach is. The government only pays the prize money if someone is successful, and may be able to leverage additional funding from foundations, philanthropists, and contestants who value the reputational benefits of winning the competition. Prizes can also generate public excitement and enthusiasm for science and technology, and encourage more young people to pursue careers in science, engineering, or technology-based entrepreneurship.

This paper has suggested some useful starting points for inducement prizes and AMCs in a number of areas, including space exploration, vaccines, African agriculture, reducing GHG emissions, and education. The president and Congress could direct agencies to identify other areas where prize competitions are likely to be cost effective. Congress could give additional agencies the authority they need to sponsor prizes, and be prepared to consider expanding the magnitude of prizes as our understanding of this policy tool develops.

A broad range of historical examples and other empirical evidence suggests that well-designed prizes work. Although the optimal level of investment in prizes is not clear, it is surely much larger than the government's current investment, which is currently limited to DARPA's recently completed two-million-dollar Grand Challenge for autonomous ground vehicles, and NASA's Centennial Challenge program. We still have much to learn about the strengths and limitations of prizes, but the time to start additional experiments is now.

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