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Accelerating Innovation with Prize Rewards

History and Typology of Technology Prizes and a New Contest Design for Innovation in African Agriculture

William A. Masters

Benoit Delbecq

International Service for National Agricultural Research

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AUTHORS

William A. Masters, Purdue University
Department of Agricultural Economics
wmasters@purdue.edu

Benoit Delbecq, Purdue University
Department of Agricultural Economics

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ABSTRACT

This paper describes how governments and philanthropic donors could drive innovation through a new kind of technology contest. We begin by reviewing the history of technology prizes, which operate alongside private intellectual property rights and public R&D to accelerate and guide productivity growth towards otherwise-neglected social goals. Proportional “prize rewards” would modify the traditional winner-take-all approach, by dividing available funds among multiple winners in proportion to measured achievement. This approach would provide a royalty-like payment for incremental success. The paper provides concludes with a specific example for how such prizes could be implemented to reward and help scale up successful innovations in African agriculture, through payments to innovators in proportion to the value created by their technologies after adoption.

Keywords: productivity growth, technology adoption, R&D, intellectual property

1. INTRODUCTION

Innovation is the wellspring of economic growth, but it is extremely difficult to obtain. By definition, it involves the creation of something that does not yet exist. Promoting innovation for African farmers has proven especially challenging, due to a wide variety of technological and institutional obstacles. This paper examines a new kind of intervention designed to help innovators overcome these hurdles and accelerate the spread of new production, storage and transport or processing methods targeted to the requirements of African farmers. The urgent need for appropriate new farm technologies in Africa has been emphasized by the World Bank (2008) in the *World Development Report 2008*, the African governments' own NEPAD (2005) in the *Comprehensive African Agriculture Development Programme* (CAADP), and in many previous analyses (e.g. Masters 2005).

Numerous papers address the question of how best to accelerate and guide innovation, as surveyed for example by Scotchmer (2004). Most of these analyses focus on how patents and other intellectual property rights (IPRs) motivate private investment in new technologies.[1] A related area of research concerns the design of grants, contracts, public-private partnerships and other payment mechanisms used by governments and philanthropic donors to complement private investment. In this paper, we focus on the role of ex-post prizes, a class of incentive used by both private investors and public funders. We offer a brief history of prizes for new technology, analyze the conditions under which each kind of funding mechanism can best meet funders' needs, and propose a specific new kind of proportional prize program that we call "prize rewards."

Ex-post prizes are used when a funder announces the intention to reward a particular type of breakthrough, and later makes payment to whoever succeeds in meeting the prize criteria. Prizes typically operate alongside IPRs and other mechanisms, seeking to complement them and improve their effectiveness. Some prize contests elicit innovations that are themselves patentable, or help promote patenting. A remarkable example is provided by Brunt, Lerner and Nicholas (2008), who use a detailed dataset of historical prize offerings from the Royal Agricultural Society of England (RASE) to show that fields targeted for prizes attracted more patented innovations than fields for which prizes were not offered. The positive effect of prizes on patenting was observed even when the target for prizes was determined by simple rotation, and could not have been chosen in response to pre-existing innovative activity. The estimated size of the prize effect on patenting was quite large: doubling the amount of prize money available in RASE contests for a given field was associated with up to 33 percent more patents granted in that field in subsequent years. Of course, not all of the technologies elicited by prizes turn out to be patentable. Some may be marketed without patents, and some may be spread through non-market mechanisms. Prizes work equally well for patentable as non-patentable technologies, and so complement rather than replace other funding mechanisms.[2]

In this paper, we begin by reviewing how prizes have helped jump-start innovation for many kinds of technology in Europe and North America over the past 300 years. We then provide a typology of funding mechanisms and the technology categories for which they are best suited, and identify the strengths and limitations of various kinds of prizes. Finally, we show how some of these limitations could

[1] An overview of how IPR policy can be formulated to promote international development is provided by the Commission on Intellectual Property Rights (2002). An example of a specific reform proposal to favor developing countries is found in the Foreign Filing License concept of Lanjouw (2002).

[2] In a few cases, governments have tried to use prizes as a replacement for other funding approaches. As shown in this paper, however, the one-off nature of prizes makes them poorly suited to this task; we argue that prizes are best used to attract and inform the allocation of other funds, not to replace them. Notable attempts to use prizes instead of IPRs, grants and contracts include the invention reward system of the Soviet Union (Hughes, 1945; Kremer, 1998), and the "patent compensation" paid by the United States for nuclear technologies under the Atomic Energy Act of 1946 (Hay, 1958; Galane, 1952). There are some current proposals to use prizes instead of other funding mechanisms for pharmaceuticals in the United States (e.g. Senate Bill 2210 introduced by Senator Bernie Sanders in October 2007), but our analysis suggests that a more promising approach would be the prize programs sketched by the National Academy of Science's Committee on the Design of an NSF Innovation Prize (2007) and by Kalil (2006). Some of those prizes might benefit from using the proportional-payment feature described in this paper.

be overcome with proportional payments, in which funds are distributed to many winners in strict proportion to their degree of success. A proportional-prize approach is particularly suited to help meet the needs of African farmers. For that purpose we propose a specific way to implement prize rewards, to recognize and reward value creation from new technologies after their adoption by African farmers. A similar approach could be used in other settings, offering incremental payments at the margin to reward increased effort towards whatever measurable goal is specified by the funder.

2. WHAT PRIZES HAVE BEEN USED? A BRIEF HISTORY OF TECHNOLOGY CONTESTS

Prizes are among the oldest instruments used to define success, elicit effort and identify promising candidates capable of achieving difficult tasks. Since antiquity, governments, philanthropists and private investors have used award contests, such as military competitions in ancient Greece, chariot races in ancient Rome, and so forth. Contemporary technology has been influenced by prizes since the 18th century. Figures 1 and 2 provide a visual history, summarizing a search of the historical literature as described in Masters (2006) and extended in Pelletier (2007), drawing also on Knowledge Ecology International (KEI, 2008). The figures document all major contests for specific new technologies made in Europe or North America for which we could identify a particular funder, purpose, prize amount and eventual winner (if any). The awards in our list include only the largest prizes for pre-specified breakthroughs, not routine awards or those given for general professional and artistic achievement.

Detailed information on each prize is appended to this paper in Table A1, in chronological order. The list of prizes is astonishing in the diversity of topics and funders involved. Figures 1 and 2 reveal patterns in the data, showing that there are bursts of contests at a particular time, with wide variations in prize values. In the figures, each prize is shown as a line, whose start date and length along the horizontal axis shows when the prize was offered, and whose vertical position shows its approximate value after conversion into 2006 US dollars. For obvious reasons, the vertical axis is not drawn to scale. The values range from very small (often much less than $50,000) to very large (over $2 million in the pre-1930 period, and over $1 billion today). Prizes are numbered for cross-referencing to Table A1. The figures reveal that there are often clusters of contests in similar fields offered by similar funders, but once success in that field is achieved, the prizes are typically replaced by other funding mechanisms. Only a few prize offers remain in place for very long.

Figure 1 presents technology prizes from 1700 to 1930. The 18th and 19th centuries were marked by a few very successful prizes in Europe, first in pursuit of ways to measure longitude at sea (denoted 1 and 2; described at length in Sobel, 1995 and Davidian, 2005), and then a series of French prizes in industry and medicine (e.g. 5, 6 and 7). A remarkable case was the initially small sum that was increased to a very large prize offered for a remedy to the devastating Phylloxera outbreak of the late 19th century (denoted 23; described in Campbell, 2005). The early 20th century saw an even greater burst of prizes for breakthroughs in transportation and civil aviation, often financed by newspapers and other third parties not directly involved in the transportation or aviation sectors (Schroeder, 2004). This period ended with the most famous of the aviation prizes: an award for solo transatlantic flight from New York to Paris that was and financed by Raymond Orteig, a Franco-American hotel owner in New York, and won by Charles Lindbergh in 1927 (denoted 39 in Figure 1).

A notable aspect of these awards is their link to other sources of funding. Prize-seekers consistently invested as much as (or even more than) the prize itself in pursuit of the award. Competitors often pursued prizes using techniques and resources they had developed for other purposes, and added substantial new investments targeted specifically at the prize criteria. For example, Raymond Orteig offered a prize of $25,000 (almost $300,000 in 2006 adjusted dollars), and Charles Lindbergh spent about as much as he won. The eight other teams competing for the prize spent even more. Collectively, the contestants spent about 16 times the sum offered by Orteig. Some contestants might have invested more than they could possibly win out of vanity or foolishness, but the historical record suggests that the contestants' investments often paid off. Each prize contest offered not just a cash award, but also an objective and trustworthy test for demonstrating the performance of a contestant's approach, thereby opening up a much larger market for their product. Prize sponsors were often not themselves engaged in the same market as that of the prize objective, but may have stood to gain from the contest itself and from the growth of that market. For example, Orteig could have benefited from additional guests coming to his hotels in response to publicity from the prize, and also from the eventual growth of transatlantic travel.

Figure 1. A visual history of technology inducement prizes, 1700-1930

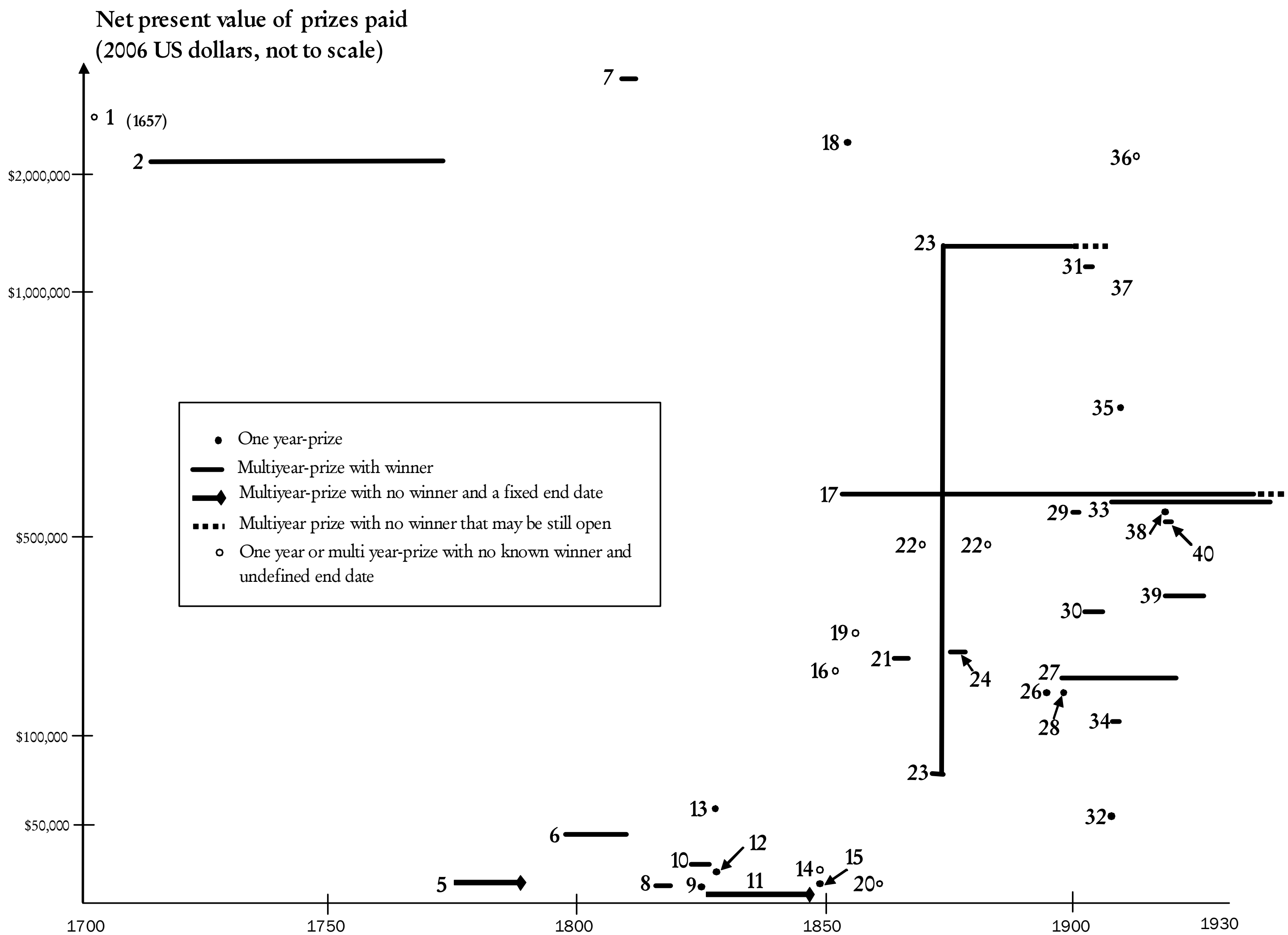
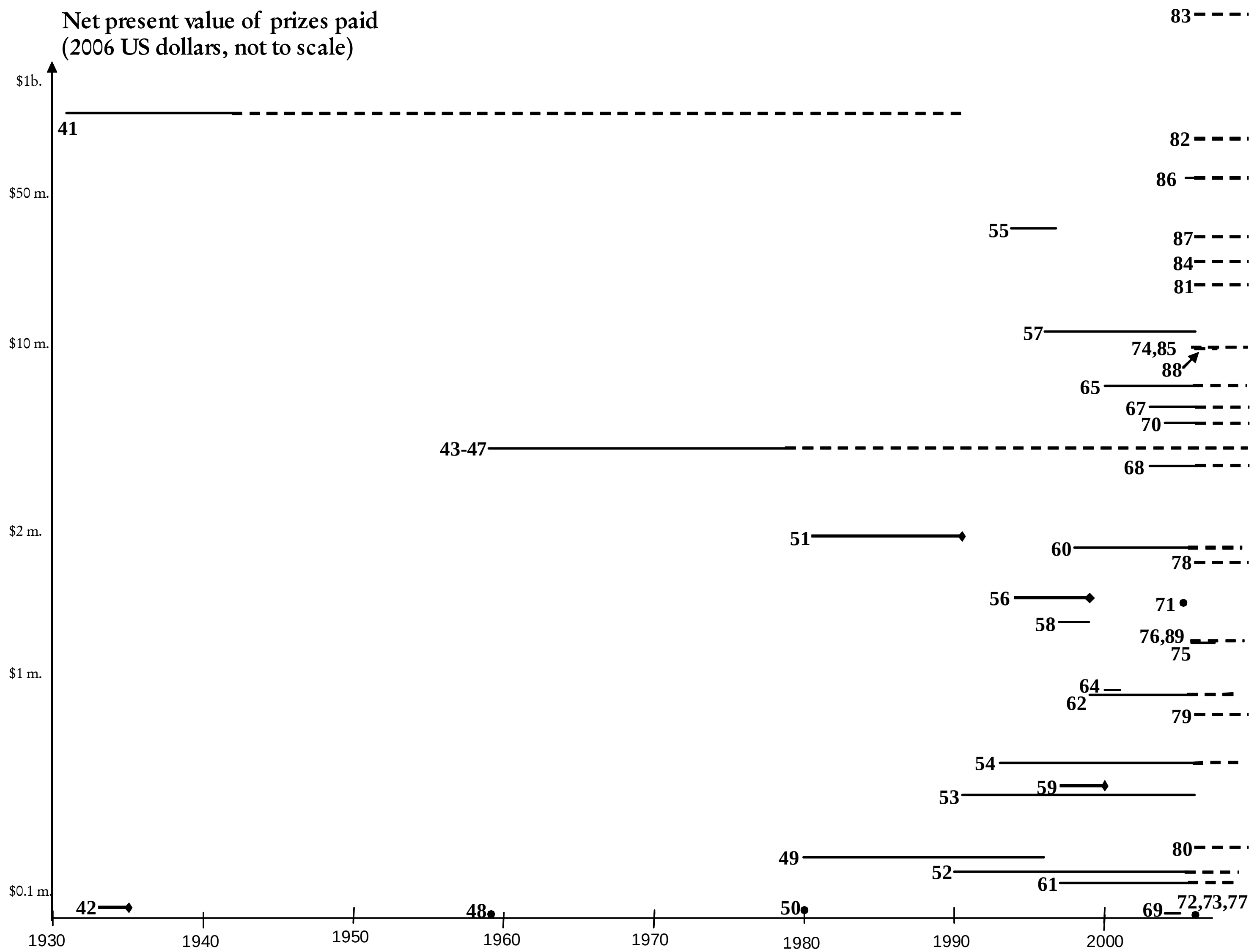


Figure 2 shows the major technology prizes offered from 1930 to 2007, with dashed lines indicating awards that remained unclaimed in 2007. After Lindbergh won the Orteig prize in 1927, far fewer prizes were offered, typically for non-commercial applications in fields such as human-powered flight, math and computing. In Europe and North America, commercial technology development proceeded without many further prizes, under the guidance of the patent system and rapid growth of public research and development (R&D) institutions that are funded through government grants and contracts. In the case of aviation, demand for the services of aviation prize contestants, such as Lindbergh, came through government contracts for military and postal services, as well as the needs of civilian aviation, which operated with some patent protection.

In the 1980s, prizes were rediscovered as a major instrument for stimulating commercial innovation. This trend is reviewed in Bloch et al. (1999), among others. Figure 2 shows the dramatic nature of the rebound in technology innovation prizes, including a very dense cluster of prizes aimed at opening up large commercial markets in various fields. Almost all of these are lump-sum prizes, but two pioneering efforts involve incremental payments linked to quantities sold. An early example of this type of a variable prize payment was the US Super-Efficient Refrigerator Program (SERP), denoted prize number 55 in Figure 2. The SERP contest was initiated in 1990 by a consortium of refrigerator manufacturers in collaboration with the US Environmental Protection Agency (Davis and Davis, 2004; Windham, 2000). Variable payments also characterize the largest single contest, denoted number 83 in Figure 2, which promises up to $1.5 billion in an Advance Market Commitment (AMC) to purchase vaccines against childhood pneumococcal diseases (GAVI Alliance, 2007; Berndt et al., 2006). In both cases, a winner’s payment would depend on the number of units deployed, thereby offering an important kind of reward for incremental success over and above the yes/no achievement of particular technical criteria.

Figure 2. A visual history of technology inducement prizes, 1930-2007



3. WHEN ARE PRIZES NEEDED? A NEW TYPOLOGY OF INNOVATIONS AND FUNDING INSTRUMENTS

Considering the prizes described above and listed in Table A1, the historical experience raises the question of what situations best suit prizes versus other funding mechanisms. Kalil (2006) proposes a list of comparative advantages and drawbacks of inducement prizes. Here, we summarize the extensive economics literature on this question, applying a new typology of innovations and matching each with the payment mechanisms used to fund them.

Figure 3 presents four categories of innovations and their typical funding mechanisms. The technologies that benefit most from prizes fall in the bottom-right corner of this classification. The two columns correspond to the source of funding; the first column contains innovations that are typically funded by for-profit private investors, while the second contains innovations that are typically funded by governments or philanthropic donors. The label at the top of each column indicates the type of funder, while the label at the bottom suggests the kinds of technology these funders are likely to be able to support. All desirable innovations, in either column, create value for their beneficiaries above the cost of R&D. However, in order for the innovation to be funded on a for-profit basis, and hence fall in the left column, it must be a type of technology for which a sufficient share of value can be captured (through market sales or licensing) for the funder of the R&D to recoup their investment. Value capture is typically easier for innovations that are embodied in goods and services that can be sold or rented, unit by unit, while excluding potential beneficiaries who might not be able or willing to pay for its benefits. Even for excludable technologies, however, much of the value created by innovation cannot be captured by the innovators, even with strong intellectual property protection. For example, Nordhaus (2004) estimates that innovators in the US economy captured less than 5 percent of the total value created by new technologies during the period 1948-2001.

The most important determinant of excludability, and hence the potential for value capture, is the innovator's physical ability to prevent non-payers from benefiting. Easy exclusion of non-payers, sometimes called "natural excludability," is a characteristic of many technologies embodied in physical products (e.g. machinery, chemicals and medicines); these technologies would typically be found in the left-hand column of Figure 3.

A second source of excludability involves legal IPRs. The legal right to sue an imitator may facilitate value capture and excludability, but enforcement may be sufficiently costly that benefits remain non-excludable despite strong IPR legislation. For example, in the US we observe much more private investment in maize breeding than wheat breeding. The two plant types face the same IPR regimes, but hybridization of maize gives it natural excludability, whereas improved wheat remains open-pollinated. Therefore, a maize breeder can readily sell hybrid seed while keeping the genetic material proprietary, thereby earning a profit on their intellectual property. A wheat breeder, in contrast, has much less ability to capture value in this way; the genetic material of an improved seed becomes easily accessible once the seed is sold, and it is prohibitively expensive to pursue infringers.

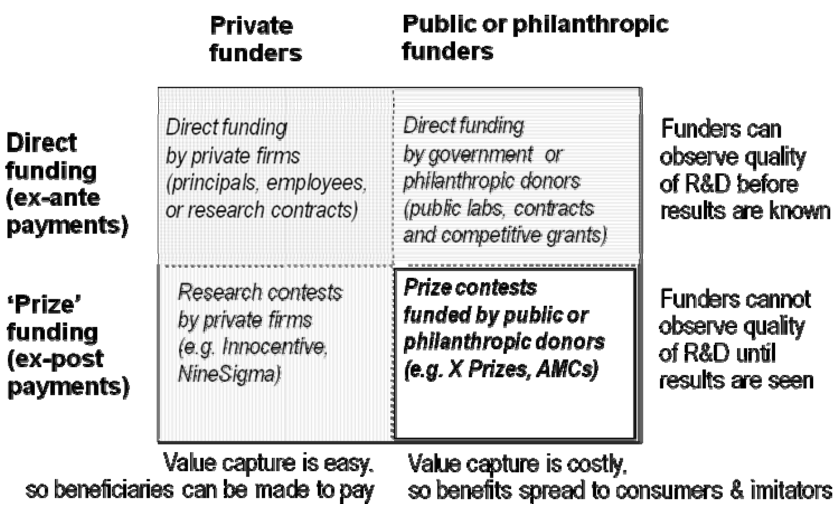
A third and more subtle determinant of excludability involves market structure, which determines who benefits from productivity gains. In competitive markets with inelastic demand, for example, much of the economic value from productivity gains will be transferred to consumers through lower prices. This kind of value creation cannot readily be captured by innovators, but it can be recouped by governments through consumer taxation. The pursuit of such cost and price reduction is a major factor explaining why agricultural innovation tends to be government-funded, whereas products that are sold in less competitive markets or that face more elastic demand tend to attract more private R&D (Figure 3, left-hand column).

If the benefits of a technology are not excludable, for whatever reason, that technology will be unable to sustain for-profit funding. Innovation for these technologies will occur haphazardly (if at all) unless it is subject to deliberate funding by governments and philanthropies. Such public funding may address a whole field that would otherwise be neglected, such as high-energy physics, or it may focus on the public aspects of a technology that is mostly developed in the private sector, such as automobile safety features or medical treatments for extremely poor people.

The rows in Figure 3 represent the type of funding instrument, in terms of the funder's choice between ex-ante and ex-post payments. Following Wright (1983), the cost-effectiveness of this choice depends largely on whether funders can observe the quality of the R&D process before the results are known. If R&D performance is observable with clear milestones and quality assurance, the funder can effectively target the investment towards a successful innovation, thereby justifying ex-ante payments to the innovator. Otherwise, the funder may wait until the results are known before deciding which innovator(s) to pay, using ex-post payments or prizes of various kinds. Kremer and Glennester (2004) call these "pull" mechanisms, in contrast to the ex-ante "push" mechanisms whereby a funder pays before the results are known.

The rows and columns of Figure 3 create a typology of four kinds of innovation, each corresponding to a different kind of funding. This paper is concerned primarily with the second row of funding instruments. The bottom-left is a category for profit-seeking, proprietary technology prizes. The examples shown in Figure 3 are InnoCentive and NineSigma, two competing web-based marketplaces where companies post challenges along with the price they'll pay to whichever innovator provides the best solution. InnoCentive was formed in 2001 under the leadership of drug maker Eli Lilly (InnoCentive, 2008; Wessel, 2007; Lakhani, 2006), while NineSigma is a similar marketplace founded in 2000, with challenges posted by Proctor & Gamble and others. The bottom-right, in contrast, is the category of greatest interest to governments and philanthropists. This includes the Advance Market Commitments (AMCs) and most of the prizes shown in Figures 1 and 2, such as the famous X Prizes for civilian space travel.

Figure 3. When are prizes needed?



The X Prizes are a series of philanthropically-funded contests initiated in 1995 by Peter Diamandis. The first of these was the Ansari X Prize, which offered $10 million to the first privately-funded firm whose aircraft could carry a pilot plus the weight of two passengers 100 km into space twice within two weeks. This prize was won in 2004 by an aviation-design firm led by Burt Rutan, with investment from Paul Allen of Microsoft. The funders spent more than twice the value of the prize to win it (Schwartz, 2004), and the combined spending of all contestants was perhaps ten times the prize value. These investment-to-prize ratios are roughly similar to those elicited by the Orteig prize in the 1920s, on a somewhat larger scale in terms of constant dollars. The team that won the Ansari X Prize, however, quickly earned much more than the prize itself by licensing the successful technology to Richard

Branson's Virgin Galactica for commercial use, and then earned a many-fold return by selling the entire company to Northop Grumman, primarily for use in serving government defense and space contracts.

The highly visible success of the Ansari X Prize demonstrates that a well-designed contest can help kick-start the development of entirely new kinds of technology capable of serving both commercial markets and the public sector. But what defines a "well-designed" prize? Under what circumstances are prize contests most successful?

One fundamental feature of any high-impact prize program is that it posits an achievable but difficult goal, as emphasized by Kalil (2006). Timing is key, since the objective is a moving target. Technological progress changes achievable possibilities, and socioeconomic conditions influence the desirability of those possibilities. The Orteig prize for transatlantic flight, for example, initially attracted no contestants; it went unclaimed until it was later renewed and pursued using an improved generation of aircraft. The same was seen for prizes aimed at space travel, as an earlier contest for Cheap Access to Space (CATS) ended in 2000 with the prize unclaimed (Aldridge, 2004).

A second fundamental feature of successful prize contests is that they offer a clear measure of success, in a field where achievement is desirable but measurement had been lacking. This point is emphasized by Newell and Wilson (2005). At the start of civilian aviation, for example, barnstorming airplanes would make local demonstrations under diverse conditions, but performance comparisons were difficult. The aviation prize contests created well-defined, unambiguously measurable criteria of success. These were most successful when they were closely related to actual commercial needs. Orteig's contest for the first transatlantic crossing offered a relatively small prize, as shown in Figure 1, but was extremely influential because it provided a clear measure of success in a highly desirable achievement.

A third feature is that prize contests must make a credible commitment to pay the winner, and must employ impartial judges. The need for credible commitment is a key focus of Kremer and Glennerster (2004). Without commitment and impartiality, the prize will attract less investment from contestants, and success in the contest will be a less useful signal of achievement. One way to overcome the credibility constraint is to set prize criteria just slightly ahead of current technology, so that relatively small sums can be disbursed quickly. Proposals for an Advanced Market Commitment (AMC) that involves long time lags and large sums have had great difficulty establishing credibility, as emphasized by Maurer (2005).

However, although these three features can help make prizes successful, even successful prizes do not stand alone. The very definition of success is that prizes leverage other funds by providing a measurable benchmark for identifying achievements that are valuable to others. Prize winners may pursue commercial sales of their technology for excludable applications (such as the space tourism offered by Virgin Galactica using the X Prize-winning techniques), or pursue government contracts for non-excludable applications (such the largely defense-related aviation offered by Northup Grumman).

The above-described advantages apply to prizes that are implemented under appropriate conditions; in reality, most traditional prize contests have serious limitations. These limitations help explain why, once a prize has been won, further R&D for that kind of technology is typically funded through grants and contracts instead of additional ex-post prizes. As shown historically from the data in Figures 1 and 2 and listed in Table A1, technology prizes have typically been offered alone or in bursts of prizes in related areas, as part of a search for breakthroughs in particular fields. Once a field is well enough established, it grows through other funding mechanisms. This observation begs the question of why technology prizes are not used even more often than they are. In other words, based on observable outcomes, why doesn't every corporate R&D program promote "open innovation" competitions such as those offered through InnoCentive and NineSigma? The results shown in Figure 3 suggest that when research quality is observable ex-ante, funding will occur ex-ante: the funders will have no reason to wait until a result is observed before they make a grant or contract with a particular innovator whose success is visible only ex-post. But why is this? The historical fact that funders repeatedly choose ex-ante grants and contracts implies that there must be disadvantages to contests with ex-post payments.

One well-known disadvantage of contests with ex-post payments is inherent to any competition for a fixed prize. This problem is described in the innovation literature as a "patent race" (Loury 1979, with application to agriculture in Oehmke 1999 and others). The problem arises because contestants may use similar methods, thereby duplicating each other's efforts. The patent race problem implies that funders should generally use the easiest available method to find out who or what is likely to succeed, and then issue direct grants and contracts to those groups or techniques having the highest likelihood of success.

Another set of disadvantages is associated with the specific design of prize contests. By specifying a particular threshold for achievement, prize contests give no incentive for incremental improvements other than crossing that threshold, and prize results give no information about performance that could have been achieved using more or less ambitious goals. More subtly, by specifying a narrow target for achievement, prizes fail to provide information about contestants who could or have reached different but related targets.

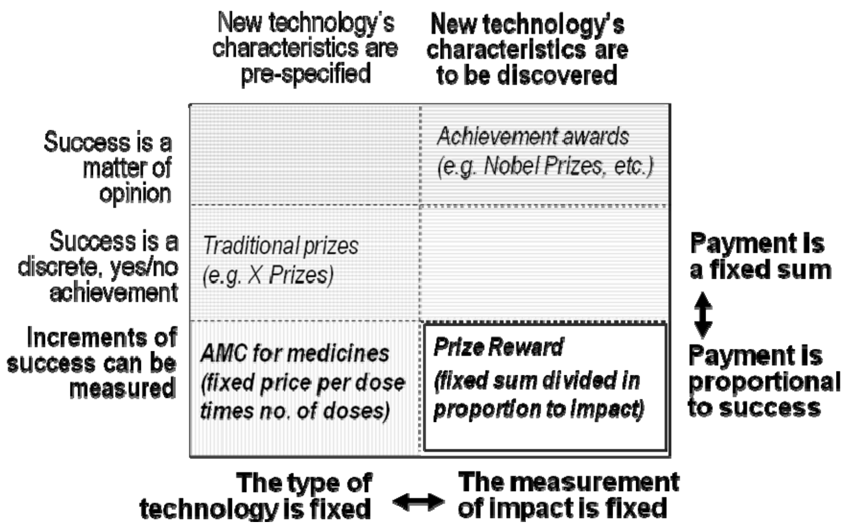
Can careful prize designs overcome these limitations? If contests were designed to offer ex-post rewards for incremental achievements of a more varied nature, they could potentially overcome these constraints and benefit funders more than the traditional winner-take-all prize strategy. Such prize rewards could overcome the zero-sum problem of patent races for narrowly-defined achievement, and elicit efforts toward or information about relative success using a much wider range of technologies. To promote a successful competition, however, these prize rewards would have to retain the three characteristics described above: a feasible but difficult objective, a clearly measurable goal, and prizes that are disbursed in a predictable manner by an impartial authority.

In the following section, we look inside the universe of ex-post prizes by examining a new typology of conditions and assessing which prize designs might be most useful in each case. This typology shows how the new category, called "prize rewards," differs from other prize designs, and helps identify the circumstances under which this category would be likely to be a cost-effective incentive mechanism.

4. A TYPOLOGY OF PRIZE MECHANISMS: CONTEXT AND MOTIVATION FOR A NEW DESIGN

Figure 4 (below) presents a typology of prize contests. The key characteristics of the technology are shown on the horizontal axis, while methods of measuring success are shown on the vertical axis. This classification includes some blank cells that represent combinations of characteristics for which no examples are available at this time. The bottom-right cell shows the characteristics that apply to the new prize rewards concept that was first introduced in Masters (2003, 2005).

Figure 4. A new typology of prize design



The top row shows one of the oldest kinds of prize, in which success is measured subjectively as a matter of expert opinion. The example shown is the Nobel Prizes, but readers will be familiar with many juried contests of this type. Almost every organization offers some kind of meritorious service or achievement award. These types of prizes are useful for promoting many kinds of desirable innovation that cannot be objectively measured.

The second row applies to prize contests where success is measured as a discrete event. These yes/no achievements are typically structured as either first-to-achieve contests or as best-entry competitions. The prizes may include first, second and third place awards, all of which are defined as lump sum, winner-take-all payments. The example shown is the X Prizes, but this category applies to almost all traditional prizes shown in Figures 1 and 2.

The third row applies to prizes in which increments of success can be measured, and therefore may be rewarded incrementally. The example shown is the new AMC for vaccines, but an earlier case would be the SERP for energy-efficient refrigerators, in which companies able to sell additional units would receive additional payments. This feature of some prizes is crucial to overcoming the zero-sum conflict in patent races, by making the competition a positive-sum game with incremental rewards for incremental efforts made to expand the market.

An especially interesting combination of characteristics arises in the bottom-right corner of Figure 4, which shows prizes in which the funder chooses a continuous measure of impact, and pays proportionally to success. In these contests, the characteristics of winning technologies remain to be discovered based on the contestants' innovative efforts, and those efforts are rewarded incrementally. To combine these characteristics, the sponsor of a proportional prize rewards contest could offer a fixed sum to be divided among numerous contestants, in proportion to their success along the chosen measure of impact.

5. IMPLEMENTATION OF PROPORTIONAL PRIZES: PRIZE REWARDS FOR AFRICAN AGRICULTURE

As shown in our typology of prize mechanisms, proportional prize rewards could be a useful mechanism for spurring innovation wherever funders have an objective and verifiable measure of impact, and recognize that the goal could be achieved by a variety of innovators using various techniques that succeed to varying degrees. Many fields might offer such circumstances. For example, one might consider prize rewards for innovation in education, where improvements in students' test scores might be a criterion used for proportional rewards to teachers and schools, thereby identifying and rewarding the most successful educational techniques. Energy efficiency could also be rewarded in this way, with prize rewards proportional to increases in the efficiency of transportation, heating and cooling, or other tasks.

With proportional prizes, a key concern is whether the impact measure really gauges incremental success in a useful way, and whether the characteristics of successful technologies are truly unpredictable. If these criteria are not met, it is preferable to offer traditional prizes, or to use other funding mechanisms. However the stated criteria seem to arise occasionally, in particular with regard to the innovations needed to raise productivity in African agriculture.

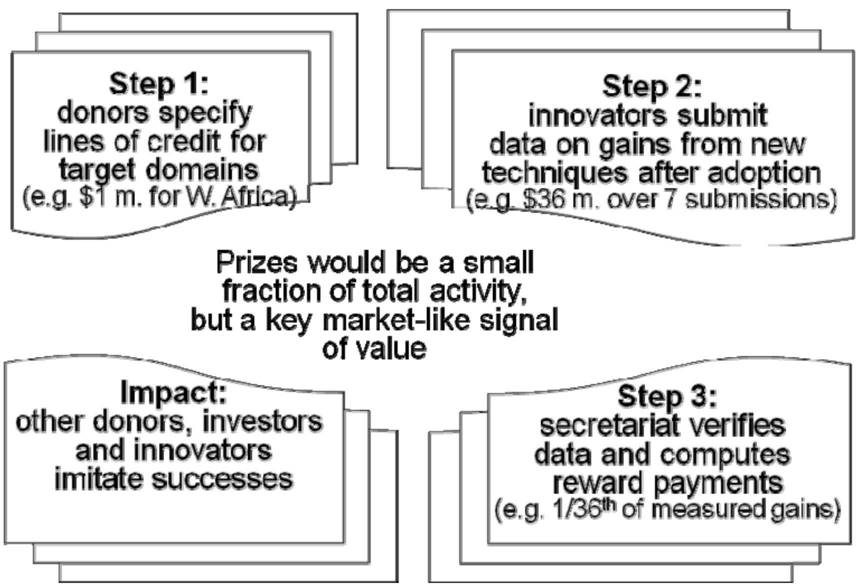
As documented in Masters (2005), the limitations of existing funding mechanisms have left the productivity levels of African agriculture well below those of other regions. Low productivity is a significant cause of continued poverty and malnutrition. The United Kingdom's Commission on Intellectual Property Rights (2002) concluded that developing countries cannot rely simply on patent protection, and there is a need for a better system that orients research toward the needs of poor farmers. Kremer and Zwane (2005) suggest an approach modeled on the AMC, which presupposes that agriculture offers vaccine-like opportunities for a "one disease, one cure" type of technology. We argue that most agricultural innovation falls in the bottom-right rather than the bottom-left cell of Figure 4, because value creation can be measured ex-post more easily than it can be predicted ex-ante.

The value created by new agricultural techniques is highly measurable, because innovations can be subject to randomized field trials that measure unit gains between the old and new techniques, farm surveys may be used to measure the number of new versus old units in use, and market observations may be used to identify the prices at which outputs and inputs are being bought and sold. The observed quantities times prices can then be used as a reasonable measure of value creation in each year, and the discounted total value over time allows us to compute the value created by a new technology in a particular region over a given time period. This value creation is economically measurable, even though it is not entirely captured in financial profits for the seller. Much of the gain accrues to consumers in the form of lower prices, and to the technology's imitators in the form of technology spillovers. Of course the details of measurement are open to question, but in principle, value creation is observable and auditable after the fact, and is clearly linked to the innovation's value for society. Furthermore, the same measurement approach can apply to a wide range of technologies, whenever and wherever they are used, and whatever their mode of operation, as long as the technology affects the quantities of observable outputs and inputs having prices that can be inferred from observable market prices. In many cases, the item itself may be produced and consumed on the farm without actually being bought or sold, but an upper or lower bound on its value can be approximated by the price of a substitute product on local markets.

Agricultural technologies that create value are very diverse and often quite hard to predict. A funder may believe that disease resistance, drought tolerance, fertilizer response, yield variability, product quality, storage losses or other characteristics are particularly important, but the feasibility and performance of a breakthrough in any area remains unknown until it is actually observed on farms. Agricultural productivity relies on interactions among dozens of useful species, against a myriad of biological, physical and social constraints. Even blockbuster breakthroughs, such as semi-dwarf wheat, hybrid maize, or transgenic sources of insect resistance, require endless localized adaptation. In general, improvements that overcome one constraint soon encounter another. There is no equivalent to the "one problem, one solution" paradigm that often applies in other fields. Productivity growth is driven by the continuous deployment of many locally-adapted innovations, each of which is soon replaced by something better.

For all of these reasons, improvement in African agriculture is a good candidate for implementation of proportional prizes. The way this might work is represented in Figure 5, as a sequence of four steps forming a virtuous circle to leverage other investments and accelerate innovation.

Figure 5. Implementation of the prize rewards approach



The first step shown in Figure 5 consists of donors offering a fixed sum of money, for example $1 million per year, to be divided among those responsible for developing and disseminating the most successful new technologies observed on farmers' fields in West Africa. Note that such a sum would be a tiny fraction of what is now being spent on grants and contracts in this domain. Masters (2005) documents the evolution of total expenditure on African agricultural R&D, which is now over $1 billion per year.

The second step occurs when innovators, responding to the funder's offer, assemble data on their technologies to document an application for prize rewards. These data are defined as at least one controlled experiment showing output and input quantities using the new technology, at least one farm survey showing the use extent of the new technology, and market prices showing the value of each output or input. As described in Masters (2006), this experimental dataset is typically needed to guide the R&D process itself, and the farm survey and price data are needed to guide dissemination. These data are entirely observable, they refer to real events, and reporting them does not require any of the ex-ante projections or accounting and management skills needed for forward-looking proposals. The submitted prize applications are then audited, and the verified data are used in simple spreadsheets that multiply quantities times price to estimate the total value added. In the example shown in Figure 5, a total of seven applicants might come forward with data documenting a total impact of $36 million. (These numbers are not arbitrary; they are discussed in more detail below.)

The third step occurs when the submitted data are subjected to on-site audits by the prize secretariat, and the donors disburse payments to the winning portfolio of techniques in proportion to the verified impact of each. To ensure the accuracy of applicants' data, the prize authority must send analysts to inspect the experiment sites, interview technicians regarding the validity of controlled experiments, and interview local farmers regarding the validity of adoption data. The cost of such audits depends on the number of site visits and the intensity of the auditing effort. A balance must be struck between award amounts and audit costs; the prize sponsor should spend just enough on audits to ensure the credibility of their awards. In the example shown, if the entire $36 million in measured gains is accepted by the secretariat, each of the seven innovators would receive $1/36^{th}$ of their technology's measured gains in "prize rewards." In essence, they would be given a 2.8 percent royalty on the value created by their innovation.

The impact of the intervention is felt in a fourth step, when other investors, innovators and adopters use the information disclosed in prize announcements to scale up and spread the winning techniques. Some of the winning technologies might involve excludable technologies, such as hybrid maize or vegetables for export; these would be scaled up commercially by for-profit firms. Other winning technologies could exist inherently in the public domain, such as a new storage or organic pest-control technique; these would be scaled up by public or NGO agencies through government or philanthropic support.

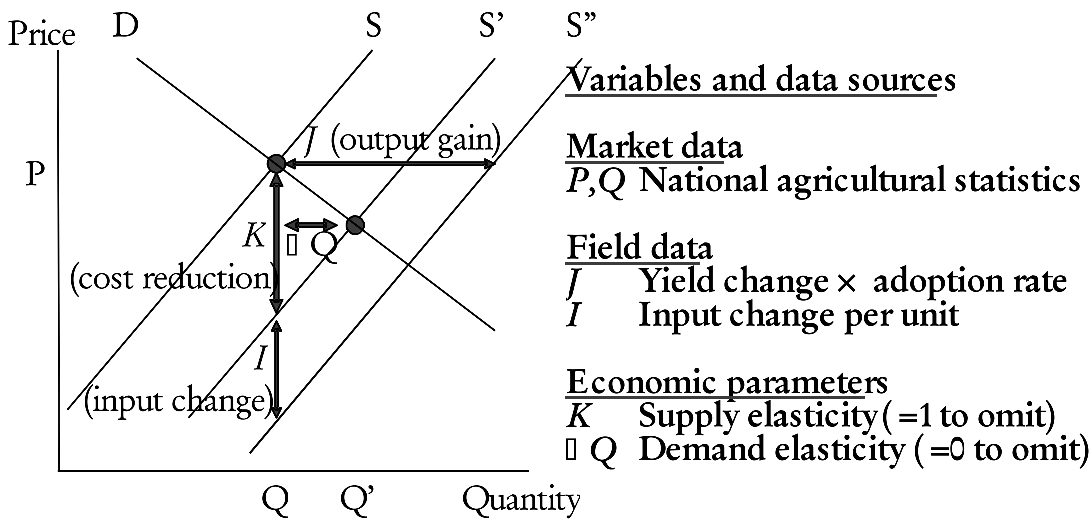
Proportional prizes could be awarded for achievement towards any kind of observable goal that is subject to cardinal measurement. In the case of agricultural innovation, step two of the described cycle calls for measuring the net present value of social gains from technology adoption. This can be done readily using a standard impact assessment methodology refined in training workshops for African research managers, as detailed online at www.agecon.purdue.edu/staff/masters/impact.

Figures 6, 7 and 8 below illustrate our approach for measuring the value of agricultural innovations in Africa. For each kind of observation, we show the letter used on the figure, and how the estimate would be obtained for entry in a spreadsheet whose formulas follow the calculations shown in the figures. The only variables needed to estimate value are:

a) an output and input change per unit of production, which roughly corresponds to a "yield change" but can involve any kind of quantity to be measured using controlled experiments;
b) an adoption rate and local prices for output and inputs, shown as *P* on Figure 6, to be obtained using a household survey among actual and potential adopters;
c) total production in the adoption domain (*Q)* which can be obtained from survey or census data;
d) the change in output supply from adoption (*J*), obtained by combining a), b) and c); and
e) the change in input costs from adoption (*I*), also obtained by combining a), b) and c).

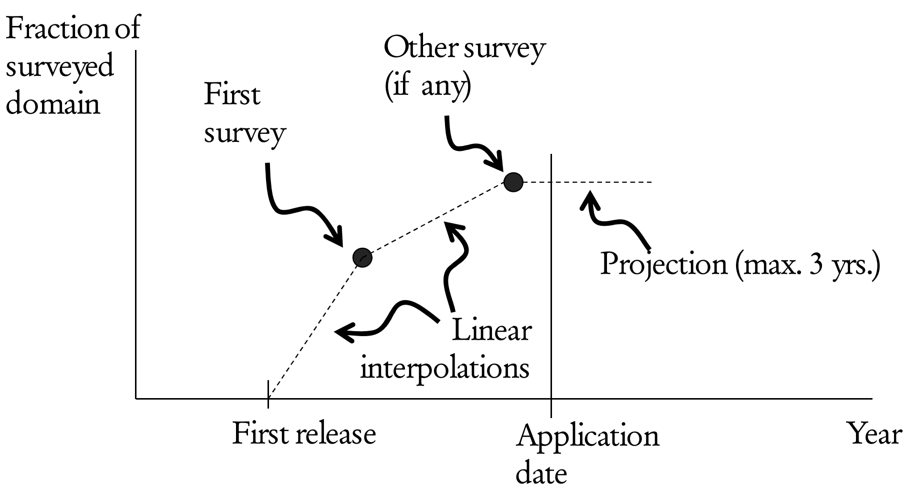
Note that each variable may be verified locally through random site visits by the prize secretariat staff. Figure 6 illustrates how these data relate to a standard supply-demand diagram, and how they permit the computation of net cost reduction (shown as *K* on the diagram). Having subtracted the change in input costs (*I*), including payments for marketed inputs as well as labor or other non-marketed inputs, the value of *K* over all *Q* is proportional to the economic surplus gain accruing to farmers and consumers. The value of *K* times Q is exactly equal to economic surplus gain when supply elasticity is unity and the demand elasticity is zero. Using other elasticities would have the advantage of giving deservedly greater weight to innovations that raise productivity where supply is more inelastic, but would have the disadvantage of relying on data that are not easily verifiable; thus, in order to maintain transparency in this context, it is preferable to use the simpler rule by which total estimated gains are equal to the area *K* times *Q*.

Figure 6. Data needed to estimate the annual value of an innovation



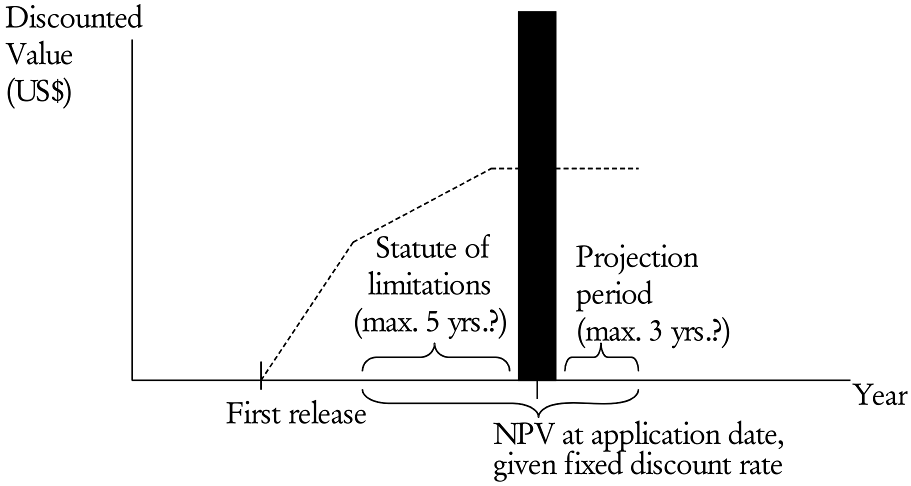
The data discussed so far refer to a single year. However, it could be desirable to allow forward projection of three additional years of continued benefit, to limit the frequency with which a given research program would need to apply for prizes. Similarly, it might be useful to include a "statute of limitations" disallowing benefits for innovations that were initially disseminated more than five years prior to the date of application, in order to limit claims for historical events. Thus, prize applicants would typically be making a single application for up to eight years of adoption benefits, the magnitude of which might be estimated with just one or two farm surveys, as illustrated in Figure 7 below.

Figure 7. Data requirements to infer adoption rates



The annual data presented in Figures 6 and 7 would have to be aggregated into a single year, as illustrated in Figure 8.

Figure 8. Computation of net present value as of application date



An example of the results of these calculations is presented in Table 1 below, showing an entire dataset that might be used in application for prize rewards. The example provides a concrete illustration of a particular set of prize rewards that might result from the four-step process illustrated in Figure 5. The results shown were compiled using the same data definitions and spreadsheet calculations that would be required for the prize application, with data drawn from many of the groups who would be likely to apply. These calculations were done as part of a series of workshops in which West African researchers were invited to present their own data on their most successful technologies, using the impact-assessment methodology described in Masters (1996) and Masters and Ly (2002).

Table 1. Example set of prize rewards for West African agriculture

Example technology	Measured Social Gains (NPV in US$)	Measured Social Gains (Pct. of total)	"Royalty" Payment (US$)
1. Cotton in Senegal	14,109,528	39.2%	392,087
2. Cotton in Chad	6,676,421	18.6%	185,530
3. Rice in Sierra Leone	6,564,255	18.2%	182,413
4. Rice in Guinea Bissau	4,399,644	12.2%	122,261
5. *Zai* in Burkina Faso	2,695,489	7.5%	74,904
6. Cowpea storage in Benin	1,308,558	3.6%	36,363
7. Fish processing in Senegal	231,810	0.6%	6,442
Total	$35.99 m.	100%	$1 m.

Note: With payment of $1 million for measured gains of about $36 million, the implied royalty rate is approximately 1/36 = 2.78 percent of measured gains.

The data in Table 1 represent the researchers' measurements of their own program's impacts. In order to qualify for prize rewards, the data would be subjected to audit, and might prove to differ from the estimates. However, the researchers' estimates suggest that the largest source of gains in this portfolio came from cotton improvement in Senegal. This innovation involved the introduction of a set of seed varieties and related pest-control techniques developed by the Senegalese Institute for Agricultural Research (ISRA), a national research agency, and disseminated through public-private partnerships in the 1990s. The data show that these efforts generated about $14 m. in value creation over eight years. These gains were spread among smallholder farmers, input suppliers and cotton buyers. If all of the data in Table 1 were to survive audit, the gain would correspond to 39.2 percent of total measured gains, meaning that the ISRA and its partners would receive a royalty-like payment of $392,087 from this round of prize rewards. Those responsible for the other techniques shown on the table would receive smaller payments, as shown in the right-hand column.

A key feature of the prize rewards approach is its similarity to a real marketplace, in that all qualified groups and individuals receive payment, but the amounts vary according to how well the various buyers' needs are met. In this case, the values shown in Table 1 can be seen as the market share or portfolio weight of each innovation, measuring the degree to which it contributes to the prize sponsor's overall objective of creating value in African agriculture. In the case shown above, each innovation earned its place in a different way, and the costs of achieving the gains varied widely. Future investors seeking to scale up each prize-winning innovation must consider the cost of replication. In this case, the top four innovations involve genetic improvement, which typically has a large fixed cost but low marginal cost. However, yield improvement through the selection of new varieties is not the only channel for agricultural innovation. The other three prize winners involve other kinds of technological change: the dissemination of *zai* microcatchments for soil and water conservation in Burkina Faso, the use of sealed containers for cowpea storage in Benin, and improved techniques for artisanal fish processing in Senegal using cinderblock ovens (*fours parpaing*).

The data needed to document success typically include information from controlled experiments conducted during the development phase, combined with information from household and market surveys used to monitor dissemination. The assembly of these data requires cooperation between the R&D institution conducting the controlled experiments (such as a government or private research agency) and a dissemination agency with associated field staff (such as a local NGO or farm input supplier). However, the prize reward application requires only outcome data, meaning that it is relatively easy to form the necessary partnerships, usually through an agreement to share data in exchange for sharing the resulting prize payment. As in other negotiations, the result is likely to be a simple division that splits the award into halves, thirds or other fractions. Such payments would be much simpler to manage than the payments involved in traditional donor-funded projects, and would typically be a small fraction of the total revenue of the prize-winning organizations. Many entities, including international agricultural research centers and multinational companies, might contribute data to a prize application without claiming a share of the payment, simply to demonstrate the impact of their work. As with all of the prizes described herein, the applicants are generally far more concerned with the reputation gained by winning rather than the actual prize money itself. The cash is an important signal of value, however, and would come to the recipient as unrestricted revenue. In this way, the gain parallels the income from sale of a product– or, more precisely, royalties received on the social gains from technology adoption.

The payments in Table 1, following the steps shown in Figure 5, could spark a virtuous circle in which prize rewards might be offered repeatedly year after year. The rewards would remain a small fraction of total innovation funding, yet would be extremely valuable as long as each year's winning portfolio of successful innovations included surprises that were not predictable ex-ante, and that subsequently attract investment because they won a share of the prize. The proportionality of the awards is important, with each year's prize allocation acting similar to market shares or portfolio weights. Even receipt of a small prize can help an innovation be scaled up, if replication can be achieved at a correspondingly low cost. The wide range of innovations shown in Table 1 demonstrates how a prize program could showcase all kinds of new technology throughout the food and agricultural sector. The only constraint for eligibility is that gains be measurable, as described above.

6. CONCLUSIONS

This paper provides a history and typology of innovation incentives, thereby identifying a combination of circumstances under which alternative mechanisms and particularly a new kind of prize payment could help accelerate and guide the innovation process. The new approach involves royalty-like prize rewards that would be paid in proportion to measured impact. This mechanism allows a donor to pay only for results, without pre-specifying who or what is likely to be most successful. The example given shows how this approach would work for agricultural technologies in Africa. Similar instruments could potentially be developed to spur innovation in other sectors, such as to improve outcomes in education or raise energy efficiency.

In summary, the effectiveness of innovation funding depends on choosing the right instrument for each situation—and perhaps, in some situations, developing a new instrument that is specifically suited to the task. Prizes are distinctive in that they are additional and temporary sources of funding, they are used when needed to elicit additional effort, and they can reveal the most successful approaches for reaching a particular goal. For this reason, a relatively small amount of funding in a well-designed prize program can help guide a much larger flow of other funds, complementing rather than replacing other institutional arrangements.

APPENDIX

Table A.1. Dataset of major technology prizes, 1700-2007

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
1	Spanish Longitude Prize	Discovery of a method to find longitude at sea	1567 - ?	6000 gold ducats + 2000 ducats/year for life	$328,000[a] + $109,500/year for life =$2,500,000 assuming a 20-year life span.	King of Spain	King of Spain	No known winner
2	British Longitude Prize for Determining Longitude at Sea	Reliable way to find longitude at sea	1714-1773	Up to £20,000	$2,087,000 [b]	Government of the UK	Longitude Board	John Harrison
3	Premium for an Invention to Stop the Progress of Fires	Best invention for stopping the progress of fires	1734-1761	20,000 crowns		Government of Sweden	Government of Sweden	Dr. Godfrey
4	Prize for Sugar from Native Plants	Extract sugar from native plants	Second half of 18th century	20 ducats	$57[c]	Dutch Society for the Encouragement of Agriculture	Dutch Society for the Encouragement of Agriculture	R.J. Brouwer
5	Prize for Producing Alkali Soda	Artificial means of producing alkali soda	1775–1789	2,400 livres	$13,000[d]	Government of France	Académie des Sciences	None – regime was overthrown in 1789
6	Prize for Food Preservation Techniques	Technique for preserving food in bottles	1795-1810	12,000 francs	$44,000[e]	Government of France (Napoleon)	Society for the Encouragement of National Industry	Nicolas Appert
7	Prize for a Flax Spinning Machine	Invention of the best machine for spinning flax	1810-1813	$1,000,000 livres	$3,731,000[e]	Government of France (Napoleon)	Government of France (Napoleon)	Philippe de Girard (never received)

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
8	Art of Piercing or Boring Artesian Wells Prize	Best manual, or practical and elementary upon the art of piercing or boring Artesian wells with the miner's or fountaineer's augur, from 25 meters to 100 meters depth, and deeper if possible	1818-1821	3,000 francs	$11,000[e]	Society of Encouragement of National Industry in France	Society of Encouragement of National Industry in France	Mr. Gamier
9	Prize for Propelling Vessels Without a Paddle Wheel	Best suggestion on propelling vessels without paddle wheels	1825	100 guineas	$10,500	A British company	A British company	Samuel Brown
10	Turbine Prize	Development of a large scale commercial hydraulic turbine	1823-1827	6,000 francs	$26,500 [c]	French Society for the Encouragement of Industry	French Society for the Encouragement of Industry	Benoit Fourneyron
11	Apple and Pear Prize	Improve the fruits from apple and pear trees	1826-1847	1,000 francs	$4,500[e]	Royal Horticulture Society of Paris	Royal Horticulture Society of Paris	Unclaimed
12	Army Corps of Engineers Navigable River Prize	Develop a machine capable of removing obstacles to navigation	1829	$1,000	$22,500	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers	John Bruce
13	Liverpool & Manchester Railway Locomotive Prize	Build a locomotive weighing less than six tons that could pull a load of 20 tons at 10 miles per hour	1829	£550	$59,500	Liverpool & Manchester Railway	Liverpool & Manchester Railway	George and Robert Stephenson, and Henry Rooth
14	Premium for a Substitute for Quinine	Artificially prepare the sulphate of quinine	1849 - ?	4,000 francs	$25,500[f]	Society of Pharmacy of Paris	Society of Pharmacy of Paris	No known winner
15	"Self-righting" Lifeboat prize	Best design for a "self-righting" lifeboat with eight desired features	1849	100 guineas	$13,500	Duke of Northumberland	Duke of Northumberland	James Peake
16	Substitute for Guano Prize	Discovery of a manure equal in fertilizing properties to Peruvian Guano	1852 - ?	£1,000	$132,000	The Royal Agricultural Society of England	The Royal Agricultural Society of England	No known winner

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
17	Breant Prize	Cure for cholera	1854 - now	100,000 francs	$593,500 [f]	French Royal Academy of Sciences Montyon Prize fund	French Royal Academy of Sciences	Unclaimed
18	Screw Propeller Reward	Invention of a screw propeller for the Royal Navy	1855	£20,000	$2,353,000	British Government	British Government	A group of five private claimants
19	Manley Marble-Sawing Prize	Best new marble-sawing machine	1856 - ?	$10,000	$245,250	M. M. Manley	M. M. Manley	No known winner
20	Prize for Destruction of the Bothrops Lanceolatus	Destroy this serpent, endemic to the island of Martinique	1859 - ?	1,000 francs	$5,900[f]	Societe d'Acclimatation	Societe d'Acclimatation	No known winner
21	The Billiard Ball Prize	Find a suitable substitute for ivory to make billiard balls	1863-1865	$10,000	$165,650	Phelan & Collander	Phelan & Collander	John W. Hyatt
22	Prizes for Decortication China Grass	Design a machine that could separate the fiber from the stems and bark of freshly cut China Grass	1869 and 1881	£5,000 (1869) and £5,000 (1881)	$494,500 (1869) and $491,500 (1881)	Indian Government	Indian Government	Unclaimed
23	Phylloxera Prize	Find a cure for the wine blight (Phylloxera)	1870 - ?	20,000 francs from 1870 to 1874 then 300,000 francs	$75,000 from 1870 until 1874 then $1,287,500 [f]	French Department of Agriculture	French Department of Agriculture	Unclaimed – problem was circumvented by grafting onto resistant rootstock
24	Wisconsin Prize for Mechanical Substitute for Horses and Other Animals	Machine propelled by steam or other agent able to complete a 200-mile route at no less than 5 mph and to plow and pull loaded wagons	1875-1878	$10,000	$189,450	State of Wisconsin	State of Wisconsin	Two crews split part of the prize
25	The Orloff-Davidoff Prize	Cure or prevention of cattle plague	1894 - ?	10,000 rubles		Count Orloff-Davidoff	Imperial Institute of Experimental Medicine, St. Petersburg	No known winner

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
26	Chicago Times-Herald Motor Prize	Development of a practicable, self propelling road carriage	1895	$5,000	$124,000	Chicago Times-Herald	Chicago Times-Herald	J. Frank Duryea
27	Francois Joseph Audiffred Prize for a Tuberculosis Remedy	Finding a curative or preventive remedy against tuberculosis	1896-1921	24,000 francs	$139,700[f]	Académie de Medecine of Paris	Académie de Medecine of Paris	Unclaimed
28	French Society for the Encouragement of Industry Prizes	Series of four prizes	1896	21,000 francs at least	$122,200[f] at least	French Society for the Encouragement of Industry	French Society for the Encouragement of Industry	Various
29	Deutsch Prize	Fly between Aero-club de France and Eiffel Tower and return in less than 30 min	1900-1901	100,000 Francs	$582,000 [f]	Henri Deutsch de la Meurthe	Henri Deutsch de la Meurthe	Alberto Santos-Dumont
30	Deutsch-Archdeacon Prize	Fly a heavier-than-air vehicle along a 1-km circular course	1903-1907	50,000 francs	$277,700[f]	Ernest Archdeacon and Henry Deutsch de la Meurthe	Ernest Archdeacon and Henry Deutsch de la Meurthe	Henry Farman
31	Texas Boll Weevil Eradication Prize	Invention of a practical remedy or device for eradicating the boll weevil	1903-1904	$50,000	$1,181,700	State of Texas	State of Texas	Unclaimed
32	Scientific American Prize	First airplane in America to fly 1 km	1908	$2,500	$56,500	Scientific American magazine	Scientific American magazine	Glenn Curtiss
33	Wolfskehl Prize	Proof of Fermat's last theorem	1908–1997	100,000 gold-marks	$590,500[g] (actually awarded only DM75,000 = $54,500)	Paul Wolfskehl	Göttingen Academy	Andrew Wiles
34	The Daily Mail English Channel Prize	Fly across the English Channel	1909	£1,000	$111,500	The Daily Mail	The Daily Mail	Louis Bleriot
35	Milan Committee Prize	Fly across Alps from Switzerland to Italy	1910	160,000 lire	$665,500 [h]		Milan Committee Prize	Gorges Chavez

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
36	Automobile Clubs Prize for a Cheap Alternative to Gasoline	Best fuel other than gasoline capable of being used in internal combustion engines	1913 - ?	$100,000	$2,100,000	International Association of Recognized Automobile Clubs	International Association of Recognized Automobile Clubs	No known winner
37	Daily Mail Trans-Atlantic Prize	Cross the Atlantic non-stop	1913-1919	£10,000	$1,022,500	The Daily Mail	The Daily Mail	John Alcock & Arthur Brown
38	Hearst Prize	Cross continental US in 30 days	1919	$50,000	$582,500	William Hearst	William Hearst	Unclaimed
39	Orteig Prize	Fly non-stop from New York to Paris (or vice versa)	1919-1927	$25,000	$291,500	Raymond Orteig	National Aeronautical Association	Charles A. Lindbergh
40	England-to-Australia Air Race	Flight from England to Australia in less than 30 days	1919-1920	10,000 pounds	$563,000[i]	Australian Government	Australian Government	Ross Smith and Keith Smith
41	Soviet Incentives Award	Trigger innovative research	1931-1942 mainly, officially - 1991	112 m. rubles until 1940	$165,755,500 [j]	Soviet Union	Committee for Inventions	Many
42	Polytechnische Gesellscaft Prize for Human Powered Flight	500-m controlled human-powered flight	1933 – 1935	5,000 to begin with – raised to 10,000 marks	$23,500 in 1933 then $59,000 in 1935	Polytechnische Gesellscaft	Polytechnische Gesellscaft	Unclaimed
43	Kremer Prize for Human Powered Flight	One-mile figure-eight controlled human-powered flight	1959-1977	£5,000 offered at beginning - £50,000 prize awarded	$97,000	Henry Kremer	Royal Aeronautical Society	Paul B. MacCready, Jr. and team.
44	Kremer Prize for Human Powered Flight	Human-powered flight across the English Channel	1959-1979	£100,000	$1,942,500	Henry Kremer	Royal Aeronautical Society	Paul B. MacCready, Jr. and team.
45	Kremer Prize for Human Powered Flight	Human-powered flight on a 1.5-mile triangular course in under 3 minutes	1959 - now	£20,000	$388,000	Henry Kremer	Royal Aeronautical Society	A team from MIT

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
46	Kremer Prize for Human Powered Flight	Human-powered flight on a 26-mile long course in under an hour	1959 - now	£50,000	$971,000	Henry Kremer	Royal Aeronautical Society	Unclaimed
47	Kremer Prize for Human Powered Flight	Human-powered flight challenge stressing maneuverability	1959 - now	£100,000	$1,942,500	Henry Kremer	Royal Aeronautical Society	Unclaimed
48	Feynman Prizes	Development of first motor less than 1/64th of an inch on every side	1959	$1,000	$6,900	Richard Feynman	Richard Feynman	William McLellan
49	Fredkin Prize	First computer chess program to beat a reigning world chess champion	1980-1997	$100,000	$244,500	Edward Fredkin	Edward Fredkin	IBM's Deep Blue Chess team
50	Sikorsky Prize	Design and fly a human-powered helicopter for at least 60 seconds at a height of 3 m	1980-now	$20,000	$48,950	American Helicopter Society	American Helicopter Society	Unclaimed
51	Armand Hammer Cancer Prize	Find a cure for some form of cancer in the following decade	1981-1991	$1,000,000	$2,217,100	Armand Hammer	Armand Hammer	Unclaimed
52	Loebner Prize	Computer that can pass the Turing test	1990 - now	$100,000 Grand Prize + $25,000 + $2,000 each year for "most human-like computer"	$193,000 + 3,000 each year	Crown Industries, Inc.	Dr. Hugh Loebner and The Cambridge Center for Behavioral Studies	No winner so far for the main prize
53	RSA Factoring Challenge	First person to factorize one of the listed semi-prime numbers	1991-2007	from $100 to $200,000	$296,050	RSA Laboratories	RSA Laboratories	Some winners
54	Feynman Grand Prize	100-nm robot arm and 50-nm computing device that demonstrates ability to build nano tech computer	1996-now	$250,000	$349,000	Foresight Nanotech Institute	Foresight Nanotech Institute	Unclaimed
55	Super Efficient Refrigerator Program	Highly efficient, CFC-free refrigerator	1994-1997	$30,000,000	$40,810,000	24 Utilities comprising SERP	SERP Board	Whirlpool Corporation

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
56	Rockefeller Foundation Prize for Rapid STD Diagnostic Test	Rapid and inexpensive point of care STD diagnostic test	1994-1999	$1,000,000	$1,360,500	Rockefeller Foundation	Rockefeller Foundation	Unclaimed
57	Ansari X PRIZE	Commercially developed manned flight to 100-km altitude, twice in two weeks	1996-2004	$10,000,000	$12,849,000	Ansari Family	X Prize Foundation	Mojave Aerospace Ventures
58	Budweiser Cup	First non-stop balloon flight around the globe	1997-1999	$1,000,000	$1,256,000	Anheuser-Bush Corporation	Anheuseur-Bush Corporation	Bertrand Piccard and Brian Jones
59	CATS Prize	Inexpensive commercial launch of payload into space	1997-2000	$250,000	$314,000	Anonymous Donor	Space Frontier Foundation	Unclaimed
60	International Computer Go Championship	Computer program that can beat human at the game of Go	Late 1990s – now	$1,600,000	$1,979,000	Ing Chang-Ki Wei-Ch'i	Ing Chang-Ki Wei-Ch'i Foundation	Unclaimed
61	Beal's Conjecture Prize	Proof of Beal's Conjecture	1997 - now	$100,000	$125,500	Andrew Beal	Andrew Beal	Unclaimed
62 63	Electronic Frontier Foundation Cooperative Computing Challenge	New large prime numbers	1999 – now	$50,000 - $250,000 (total $550,000)	$60,500-$303,000 ($666,000 total)	Anonymous Donor	Electronic Frontier Foundation	One winner for a million-digit prime number ($50,000)
64	Goldcorp Challenge	Best gold prospecting methods or estimates	2000-2001	$575,000	$673,000	Goldcorp	Goldcorp	Australian team
65	Millennium Math Prizes	Seven unsolved problems in mathematics	2000 – now	$7,000,000 ($1 m. each)	7 x $1,170,500	Clay Mathematics Institute	Clay Mathematics Institute	Unclaimed
66	InnoCentive.com, NineSigma.com	Finding answers to problems that need specific solutions	2001-now	Various amounts	Various Amounts	Individual companies	Individual companies	Many

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
67	DARPA Grand Challenge	Improve robotics in vehicles	2003-now	$1m. (2003), $2 m. (2005), $3.5 m.(2007)	$1,096,000 (2003 prize); $2,064,500 (2005 prize); $3,500,000 (2007 prize)	United States Department of Defense	Defense Advanced Research Projects Agency	Stanford Racing team (2005)
68	Methuselah Mouse Prize	Demonstrate slowing of ageing process on mouse	2003-now	Increasing. Currently at $4,500,000	$4,500,000	Various Donors	Methuselah Foundation	Many
69	Territory Government's Great Cane Toad Trap Competition	Design a trap to catch the highly poisonous Cane Toads	2004-2005	$16,000 + $1,000 for each of the other 5 finalists	$22,500	The Northern Territory Government and the Pest Animal Control Cooperative Research Center in Canberra	The Northern Territory Government and the Pest Animal Control Cooperative Research Center	Paul Baker
70	NASA Centennial Challenges	Improvements in space exploration	2004-now	Various prizes, total around $6.5 million	Various - Total around $6,500,000	Spaceward Institute and Florida Space Research Institute	Spaceward Institute and the Florida Space Research Institute	Many
71	Grainger Challenges	Development of economical filtration devices for the removal of arsenic from well water in developing countries	2005	1st place: $1,000,000 2nd place: $200,000 3rd place: $100,000	1st place: $1,032,500; 2nd place: $206,500; 3rd place: $103,000	National Academy of Engineering	National Academy of Engineering	Abul Hussan
72	Windows-on-a-Mac Prize	Reliable and duplicatable way to boot Windows XP on a Mac with an Intel processor	2006	$14,000	$14,000	Colin Nederkoorn	Colin Nederkoorn	BootCamp
73	Neuros OSD Bounties	Currently seven bounties on creation of applications for use on the OSD	2006-	$500-$1000	$500-$1000	Neuros OSD	Neuros OSD	No known winner

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
74	Archon X PRIZE for genomics	Successful sequencing of 100 human genomes in 10 days	2006-present	$10,000,000	$10,000,000	Dr. Craig Venter and the X Prize Foundation	X Prize Foundation	Unclaimed
75	Prize4Life Prize	Finding a verifiable biomarker that could allow early diagnosis of ALS (Lou Gehrig's disease)	2006-2008	$1,000,000	$1,000,000	Prize4Life	Prize4Life	Unclaimed
76	The Netflix Prize	Improve the company's recommendation system by 10%	2006 - now	$1,000,000	$1,000,000	Netflix	Netflix	Unclaimed
77	Wolfram's Turing Machine Research Prize	Prove or disprove Wolfram's conjecture that a particular 2-state, 3-color "Turing machine" could function as a universal purpose computer	2007	$25,000	$25,000	Stephen Wolfram	Stephen Wolfram	Alex Smith
78	Wearable Power Prize	Design a wearable electric power system providing 96 hours of equipment operation at less than half the current weight (almost 20 lbs)	2007 - now	1st place $1,000,000 2nd place $500,000 3rd place $250,000	$1,750,000	US Department of Defense	US Department of Defense	Unclaimed
79	Prize for Faster Airport Security Technology	Deploy security land technology in an airport to increase throughput by 15% or more	2007 - now	$500,000	$500,000	Clear	Clear	Unclaimed
80	Open Architecture Prize	Design a computer lab adapted to local needs that can be built in communities around the world	2007 - now	$250,000	$250,000	Advanced Micro Devices and Architecture for Humanity	Advanced Micro Devices and Architecture for Humanity	Unclaimed
81	Bright Tomorrow Lighting Prizes	Invention of energy-efficient lamps (three categories)	2007 - now	$20,000,000 total for the three categories	$20,000,000	US Government	US Secretary of Energy	Unclaimed

Table A.1. Continued

	Prize	Goal	Period	Prize Amount	Value (2006 US$)	Source of Funding	Disbursal Authority	Winner
82	The Orbital Demonstration Prize	Space flight vehicle completing at least three Earth orbits at minimum altitude of 400 km with a minimum capacity of three people	2007 - now	approx $100,000,000	$100,000,000	Aeronautics and Space Prize Act	Aeronautics and Space Prize Act	Unclaimed
83	Advance Market Commitment	Development of a new vaccine for pneumococcal disease	2007 - now	$1.5 billion in the fund; payments depend on sales	$1.5 billion	Canada, Italy, Norway, Russia, UK and Gates Foundation	World Bank	Not disbursed yet
84	Virgin Earth Challenge	Commercially viable design that results in the removal of anthropogenic, atmospheric greenhouse gases	2007 - now	$25,000,000	$25,000,000	Virgin Group	Virgin Group and a committee of five judges	Unclaimed
85	Unlock the Value Prize	Increase the silver yield of the Barrick Gold Corporation's Veladero mine in Argentina	2007 - now	$10,000,000	$10,000,000	Barrick Gold Corporation	Barrick Gold Corporation	Unclaimed
86	Bigelow Space Prize	Transport a five-person crew into orbit for 60 days, twice	2004-2010	$50,000,000	$53,361,500	Bigelow Aerospace	Bigelow Aerospace	Unclaimed
87	Google Lunar X PRIZE	Land a robot on the surface of the Moon, travel 500 meters over the lunar surface, and send images and data back to the Earth	Announced in 2007, to be awarded in 2010-2014	First prize $20 m. (falls to $15 m. in 2013); second prize $5 m.; $5 m. in bonuses.	$30,000,000 then $25,000,000 on Jan 1, 2013	Google	X Prize Foundation	Unclaimed
88	Automotive X PRIZE	Production-capable vehicle that exceed 100 MPG equivalent	2007-2009	$10,000,000	$10,000,000	X Prize Foundation	X Prize Foundation	Unclaimed
89	PETA in vitro meat prize	Produce commercially viable in vitro chicken	2008-2012	$1,000,000	$1,000,000	People for the Ethical Treatment of Animals (PETA)	People for the Ethical Treatment of Animals (PETA)	Unclaimed

Notes: All sources are listed in references. Shaded prizes are not shown in Figures 1 and 2. When currency conversions are necessary, we convert into US dollars before applying inflation to determine current values of prizes. Exchange rates are from Officer (2007a, 2007b), except as noted below. The 2006 values in US dollars are determined using the CPI time series available online at www.measuringworth.com (Officer and Williamson, 2006) for the time period 1790-2006.
In the conversions from 18th and 19th century currencies into dollars, we use the value of gold in the coins as a lower bound on the currency value.

Table A.1. Notes Continued

a) One Spanish ducat weighs 0.1125 troy ounce in gold which equals 3.4969 g or 0.12335 ounce of gold. Using a value of gold of $20.97 per ounce between 1837 and 1933, we determine that 1 Spanish ducat = $2.404 in 1790.
b) From Officer and Williamson (2006), £4.25 corresponded to one ounce of gold in 1717. Hence, £20,000 weighed 4,705 ounces in gold. With a gold price of $19.49 per ounce in 1790, the prize is equivalent to $91,717 in 1790 and $2,086,938 in 2006.
c) One Dutch ducat weighed 3.51 grams of gold = 0.1238 g of gold. Based on the earliest dollar value of gold that we were able to find, $19.49 per ounce of gold, 1 Dutch ducat = $2.413 in 1786.
d) Based on the Louis d'Or "au bandeau", French coin worth 24 livres from 1726 until 1785. The coin weighed 8.158 g in gold (Aubin, 2001). Based on a gold price of $19.49 per ounce in 1790 (earliest date available), 1 livre = $0.2336 in 1790.
e) From 1803 until 1928, 1 franc germinal = 0.3225 g of gold. With a gold price of $19.39 per ounce from 1803 until 1833 and 28.35 g per ounce, this gives 1 franc = $0.2206 between 1803 (used as the reference year for 1802) and 1833. CPI inflation for US dollars can then be applied
f) From 1803 until 1928, 1 franc germinal and then 1 franc-or = 0.3225 g of gold. With a gold price of $20.67 per ounce between 1837 and 1933 and 28.35 g per ounce, we have 1 franc (germinal/or) = $0.235 from 1837 until 1933.
g) 100,000 gold-marks weighed 35.8423 kg or 1264.279 ounces of gold in 1908 (Barner, 1997). The price of gold in 1908 was $20.67 per ounce. Using this information, 100,000 gold-marks = $26,132 in 1908, and $509,621 in 2006 using CPI as an indicator for inflation (Officer and Williamson, 2006).
h) We use the earliest available exchange rate for Italian lire to US dollar, which was for 1913.
i) The exchange rate used for the Australian pound in 1919 is that for the earliest year available (1928). In 1928, 1 US dollar = 0.207 Australian pounds
j) The exchange rate in this case is 9.73 rubles = 1 dollar, as estimated based on purchasing power parity. This value is used because it has been shown that the official rate of 5 rubles = 1 dollar is overvalued and that courtesy rate from Soviet authorities to foreign agencies on USSR soil was actually as low as 12 rubles = 1 dollar at some points in time (Baran, 1947).

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IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org

IFPRI ADDIS ABABA

P. O. Box 5689
Addis Ababa, Ethiopia
Tel.: +251 11 6463215
Fax: +251 11 6462927
Email: ifpri-addisababa@cgiar.org

IFPRI NEW DELHI

CG Block, NASC Complex, PUSA
New Delhi 110-012 India
Tel.: 91 11 2584-6565
Fax: 91 11 2584-8008 / 2584-6572
Email: ifpri-newdelhi@cgiar.org