Prizes for Innovation in African Agriculture: A Framework Document

Version 1.0

William A. Masters

Department of Agricultural Economics,
Purdue University

Center on Globalization and Sustainable Development,
The Earth Institute at Columbia University

www.earth.columbia.edu/cgsd/prizes

This work was funded by a generous grant from the Adelson Family Foundation.

Prizes for Innovation in African Agriculture: A Framework Document

Table of Contents

Acknowledgements

This document was made possible by the Andrew Adelson and the Adelson Family Foundation, as well as the guidance and support of Jeffrey Sachs and Richard Nelson at Columbia University. Thanks are also due to Hamilton Boardman for research assistance.

The proposal has benefited from discussion in departmental seminars at Purdue, Rutgers, and Columbia, as well as international conferences in Montreal, Zurich, New York and Ravello, Italy. At these meetings, particularly important advice and endorsements of the basic idea were received from Dana Dalrymple (USAID), Simeon Ehui (World Bank), Bob Evenson (Yale), Anil K. Gupta (Ahmedabad, India), Michael Kremer (Harvard), Phil Pardey (Minnesota), Richard Nelson (Columbia), George Norton (Virginia Tech), Rob Paarlberg (Wellesley), Prabhu Pingali (FAO), Per Pinstrup-Andersen (Cornell), Carl Pray (Rutgers), Vern Ruttan (Minnesota), Jeffrey Sachs (Columbia), Pedro Sanchez (Columbia), Eugene Terry (Sierra Leone/Kenya) and Brian Wright (Berkeley). Numerous other suggestions and endorsements were received by email, notably from Walter Alhassan (Ghana), Julian Alston (U.C. Davis), Jock Anderson (World Bank), Alain de Janvry (Berkeley), Bruce Gardner (Maryland), Oumar Niangado (Mali), and James G. Ryan (Australia).

The methods used in the proposal to assess the value of research originate in a decade-long series of grants to Prof. Masters at Purdue University from the Africa Bureau of USAID, to develop and apply practical methods of measuring the impacts on agricultural innovations in West and Central Africa – particularly through a series of seven workshops hosted by the Institut du Sahel (INSAH) in various countries, training African researchers to document the economic impacts of their own technologies. Personal thanks for their contribution to that effort are due to Jeff Hill of USAID; M.S. Sompo-Ceesay and then Idriss O. Alfaroukh, the Directors-General of INSAH; Touba Bedingar and then Samba Ly, the Agricultural Research Officers of INSAH; and the more than 60 workshop participants-- particularly the repeat participants who most shaped this work, from Benin (Soulé Midingoyi), Burkina Faso (Souleymane Ouedraogo, Laraba Illy, and Gaspard Vognan), Cameroun (Charles Njomaha), Cape Verde (Alfesene Baldé), Chad (Namba Yallah, Dehala Gandoua, and Komna Ngawara), Guinea Bissau (Sirajo Seidi) Mali (Alpha Oumar Kergna, Bakary Sékou Coulibaly, and Dramane Mariko), Mauritania (Ould Moctar Ould Sidi Bah), Niger (Germaine Ibro and Jean-Pierre Atindehou), Sénégal (Amadou Abdoulaye Fall and Moustapha Deme), Sierra Leone (James Edwin) and Togo (Kossi Sedzro).

Both the prizes proposal and impact-assessment work in Africa benefited from collaboration with a number of valued colleagues at Purdue, notably John Sanders, Jess Lowenberg-DeBoer, and Wallace Tyner; and graduate students Monica Fisher, Diakalia Sanogo, Mamadou Sidibé, Jeffrey Vitale and Anne Williams.

Executive Summary

This document details a new mechanism for donors to support sustainable economic development in Africa, through the creation, adaptation and dissemination of new technologies that can improve nutrition, raise living standards, and reduce environmental degradation.[1] Current spending in this area is on the order of one billion dollars per year, mainly through grants, contracts and government budgets. The new approach would offer an additional one to ten million dollars per year, as prize payments to innovators in proportion to the gains generated by farmers when their new technologies are adopted.

The proposal would invite individuals, organizations and partnerships to apply for prize awards, as soon as they could collect enough data from field experiments and farm surveys to document the value of their innovation after its adoption. Payments would be a fraction, initially 20 percent, of any measurable benefits that accrue to the public. 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 – and then, after a prize is paid, it publicizes the achievement and makes it easier for others to imitate. This results-based incentive would complement donors' other ways of funding innovation, and would also promote market development by allowing innovators to retain intellectual property rights, while receiving partial compensation for the benefits of adoption that cannot be recovered through product sales or technology licensing.

Many outside donors are keenly interested in funding innovations to help African farmers, and yet local innovators have little incentive to develop and spread the new technologies they most need. Innovations that help the poorest farmers improve nutrition, living standards and the environment are not much rewarded by sales and licensing revenues, while the grants and contracts offered by donors are difficult to tie to those outcomes. Offering prizes would bridge that gap for all techniques whose benefits can be measured through controlled experiments and farm surveys. Similar data are sometimes collected for impact studies and cost-benefit analyses;[2] the proposed prize mechanism would give innovators an incentive to collect more of this information and use it to set priorities and monitor success.

---

[1] The proposal was first sketched in W.A. Masters (2003), "Research Prizes: A Mechanism to Reward Agricultural Innovation in Low-Income Regions", *AgBioForum* 6(1&2, November): 71-74. A longer and more detailed version is forthcoming in *International Journal of Biotechnology*, and is available by download from www.earth.columbia.edu/cgsd/prizes or by email from wmasters@ei.columbia.edu.

[2] Examples of such studies and their results are in W.A. Masters, T. Bedingar and J.F. Oehmke (1998), "The Impact of Agricultural Research in Africa: Aggregate and Case Study Evidence," *Agricultural Economics*, 19(1-2): 81-86.

The availability of prizes would complement rather than replace other funding mechanisms. The private sale of new technologies would become all the more attractive, since innovators could be partially compensated for the spillover benefits they generate. Donor grants and contracts would still be needed to support projects whose results cannot be measured, and some donors would use information from the prize program to provide more direct support for prize-winning approaches. The prize mechanism itself would be attractive primarily to donors who prefer a market-type mechanism, through which they can reward success without having to pick winners ahead of time, monitor their grantees' use of funds, or be subject to the lobbying pressure of people who are selling ideas rather than results.

The proposal calls for the creation of a prize secretariat which would publicize the rules, verify the data submitted by prize applicants, adjudicate disputes, and authorize the payment of prizes, subject to the criteria established by donors. Each donor's prize funds could target specific regions or kinds of technologies, and be announced as a line of credit available to prize applicants for a specific period of time. In this way, the system could be funded on a pay-as-you-go basis, without a trust fund or endowment, with multiple donors targeting different technology domains.

The prize authority's guidelines as to how the data should be collected and combined to measure economic gains are drawn from standard textbook techniques,[3] building on the author's experience teaching African agricultural research personnel to conduct economic impact assessments of their innovations. We draw on the lessons learned from a vast professional literature, and personal experience leading a series of seven workshops in West Africa from 1994 through 2002, through which over 60 African scientists conducted over 30 case studies of various new technologies.[4]

The approach offers an efficient, equitable approach for donors to support sustainable poverty alleviation in Africa. The approach targets agriculture, mainly because innovations in that sector are relatively easy to measure using verifiable data from field trials and household surveys. And agricultural innovations target the poor, mainly because poorer people spend a larger fraction of their resources growing agricultural products or buying them from others. Without innovations to help farmers produce more output on their fixed land area, rural population growth will continue to drive

---

[3] J.M. Alston, G.W. Norton and P.G. Pardey, 1995. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting* (Ithaca, NY: Cornell University Press).

[4] Details on these workshops are provided in a website/CD-ROM by W.A. Masters and S. Ly, 2002. *Ateliers INSAH-Purdue sur l'Impact Economique de la Recherche* (Bamako, Mali: Institut du Sahel), which is available on-line at : www.agecon.purdue.edu/staff/masters/ImpactCD/ImpactInfo. This site includes the original training manual developed for the initial workshops, W.A. Masters (1996), *L'Impact Economique de la Recherche Agricole: Un Guide Pratique*, with spreadsheet exercises. (Bamako, Mali: Institut du Sahel).

down Africans' living standards and give them no choice but continue depleting their limited natural resources.

In the extreme, a donor concerned with African poverty in general could offer to fund prize awards for *any* agricultural improvement. In reality, donors have narrower objectives. Our framework allows each donor to specify their targets—and have confidence that their funds will be paid out in a transparent and accountable manner, in proportion to the gains actually achieved in the targeted area. Different donors, by aiming for different areas, would complement each other. And offering prizes would add leverage to other funding mechanisms, by offering a separate, additional incentive in proportion to results achieved.

At the start of the prize program its principal function would be to reward *past* successes, to channel additional income to those institutions and partnerships that have proven themselves capable of generating needed innovations and documenting their value. Only after some years would the prizes have a significant incentive effect on new work, first to induce institutions to do the kinds of trials and surveys needed to document social value, and then to ensure that promising technologies are actually disseminated, and finally to allocate R&D resources to make more promising technologies. In each of these roles, the prizes would be an incremental source of funding, aimed at complementing rather than replacing other funds.

In essence, the proposed prize secretariat offers a contracting device that helps extend the market for innovations, allowing donors to reward innovators in proportion to the public-domain benefits that they generate. Doing so would complement the other ways in which donors and innovators already do business, helping the entire innovation system expand and work more efficiently – while the prize secretariat itself becomes a vibrant marketplace for innovations that donors want to pay for, that researchers can develop, and that African farmers desperately need.

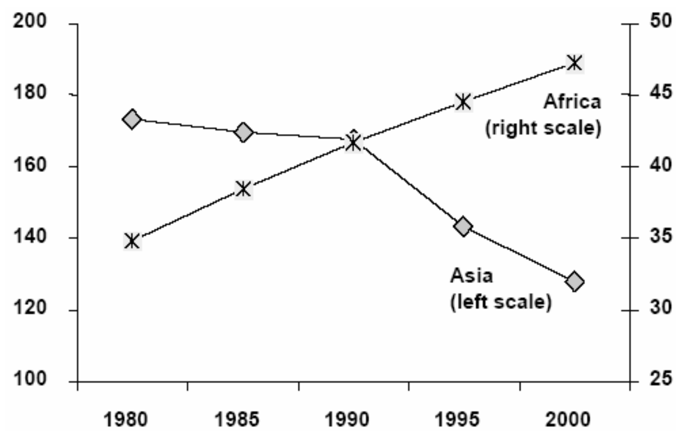
1. Motivation: Why this new funding mechanism is needed

The poorest Africans are increasingly impoverished. They have no choice but to live in rural areas, and current funding mechanisms are not delivering the new agricultural technologies they desperately need to feed themselves and improve their living standards.

1.1 Why more agricultural technology?

Figures 1 illustrates the problem: Africa is the only region in the world in which malnutrition is getting worse. While other low-income regions have successfully begun to eliminate extreme poverty, Africa is going in the wrong direction. Africans have little access to the food that is so abundant elsewhere, and little to sell in exchange.

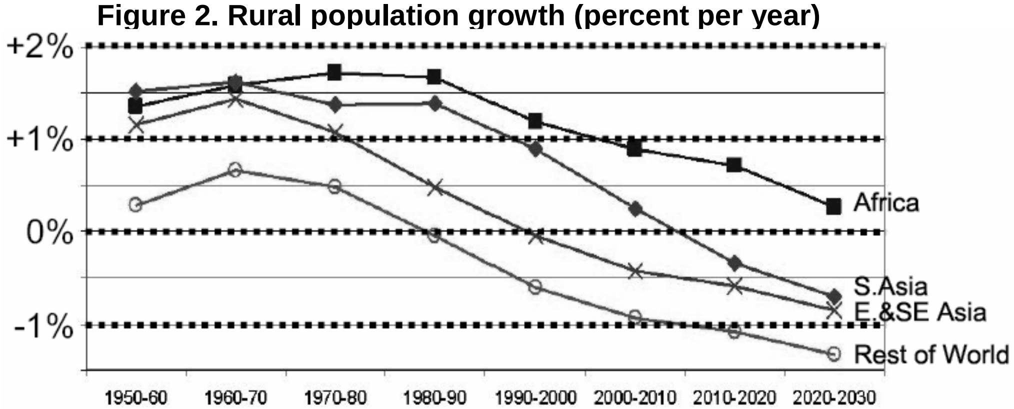
Figure 1. Number of stunted children (millions)



Source: M. de Onis et al. (2000), "Is Malnutrition Declining?" *Bulletin of the World Health Organization* 78(10): 1222-33.

Figure 2 illustrates a cause of the problem: Africa has the world's fastest *rural* population growth. This implies a decline in the amount of land and other agricultural resources available per worker, so unless productivity rises, real incomes must fall. One reason why Asia has been more successful at poverty alleviation is that it has been able to reduce its rural population growth much more quickly than Africa– thus requiring less farm productivity growth to maintain or raise income per farmer. In East and Southeast Asia, the rural population growth rate has already turned negative, allowing an increase in the amount of land and other farm resources per worker.

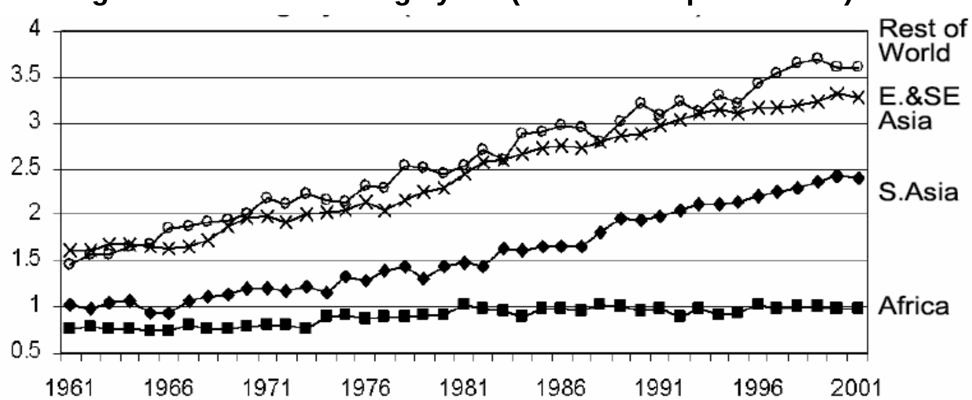
Figure 2. Rural population growth (percent per year)



Source: FAOStat estimates.

Figure 3 illustrates another, closely related reason for the impoverishment of rural Africans: far from keeping up with rural population growth, the continent's productivity levels have actually stagnated, while those of Asia have climbed rapidly. Africa was bypassed by the green revolution: new seed varieties and fertilization techniques which led to continually rising yields in Asia simply were not suited for Africa. Among the key differences are more severe moisture constraints due to lower irrigation and rainfall levels, and less favorable relative prices for fertilizer due to lower population density and higher transport costs.

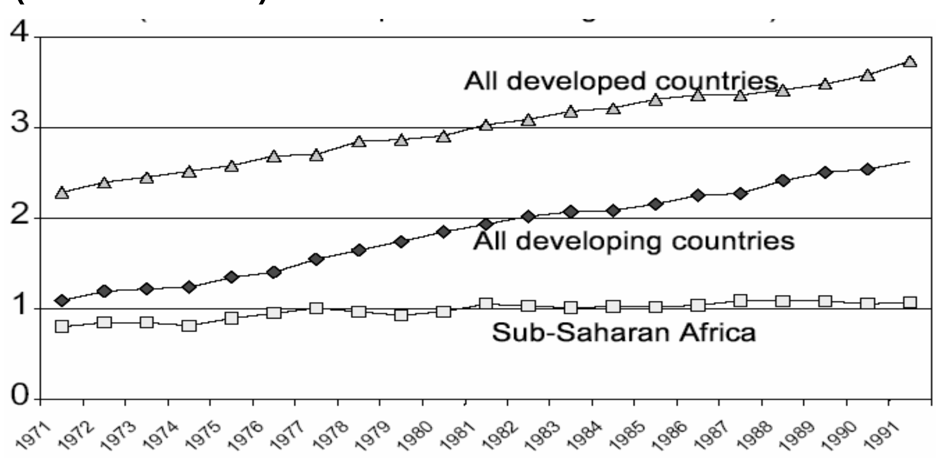
Figure 3. Cereals average yield (metric tons per hectare)



Source: FAOStat estimates.

It has been possible to raise crop yields and productivity under African conditions, but not by simply importing Asian techniques: locally adapted innovations are needed. And Africa has simply had less of the public research needed to develop appropriate techniques, as illustrated in Figure 4.

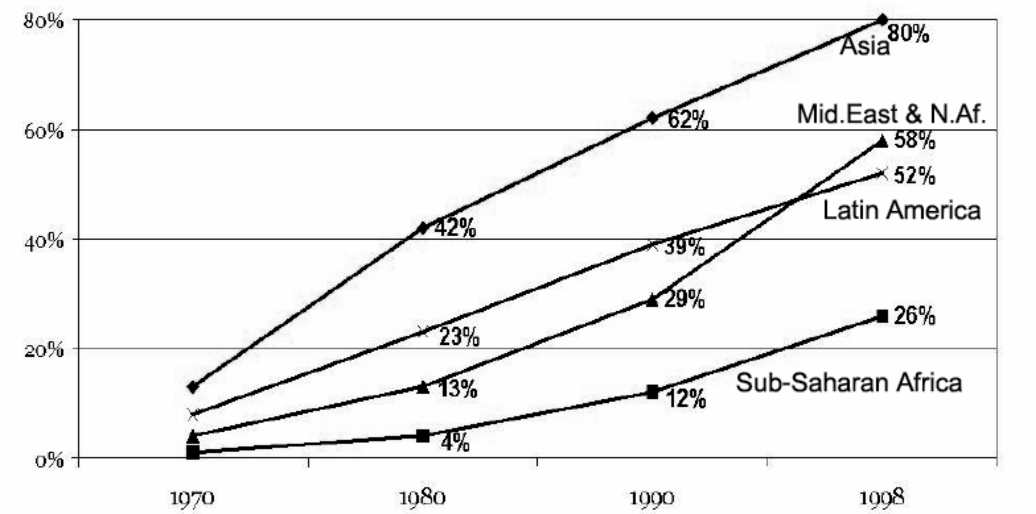
Figure 4. Public research expenditure per unit of agricultural land (1985 PPP dollars)



Source: Calculated from IFPRI and FAOStat file data

Figure 5 reveals the consequence of Africa's low research intensity: Africa is about 25 years behind Asia in adoption of new crop varieties. Africa is just starting its agricultural technology adoption process, so yield gains are localized and often offset by the yield drag caused by expansion of cropping activity into lower-fertility soils. At a comparable point in South Asia's adoption process, in the mid-1970s, its yields had barely begun to rise. The start of new variety adoption in Africa is encouraging, but the continent's adoption curve is a full generation behind that of Asia.

Figure 5. Adoption of new varieties (percent of cropped area)



Source: Calculated from data in R.E. Evenson and D. Gollin, 2003. *Crop Variety Improvement and its Effect on Productivity*. Cambridge, MA: CABI.

For Africa to overcome its rapid rural population growth and unusually harsh environment, it will to find better ways of generating and disseminating locally appropriate innovations.

1.2 Why more donor funding?

The development and dissemination of the new techniques African farmers need is inherently a public-sector problem. Eliciting almost any kind of innovation requires government action, either to enforce patent rights or to fund public institutions. And patent rights stimulate only those innovations that are marketable, that generate benefits for adopters who in turn can pay the innovator. Many important innovations are not marketable, particularly for agriculture in very low-income settings, in part because their benefits spill over from adopters to other farmers and consumers, and also because the poorest potential adopters have little capital with which to pay for a risky new investment.

For non-marketable innovations, philanthropic or government funding is needed. And since the benefits from public-sector innovations are, by their nature, spread widely particularly among the poor, they tend to attract little lobbying support: there is consistent under-investment in public innovation, and therefore above-average levels of economic return on the investment that does occur.

A large academic literature documents the history and impact of public agricultural innovation systems. National institutions aimed specifically at agricultural research, technology development and dissemination to farmers were first built in the United States and Japan in the late 19th century. The technologies they generated are widely credited with sustaining broad-based economic development in those countries, and similar public R&D systems were instituted in many other countries throughout the 20th century (Hayami and Ruttan 1985).

The impacts of agricultural R&D are relatively easy to measure, using experimental evidence on input-output relationships, farm survey data on the adoption of new techniques, agricultural census data on aggregate performance, and budgetary information on the costs of research. With abundant data and keen interest in the question, a large number of studies have estimated the benefit-cost ratios and economic rates of return attributable to public research programs: a recent survey found 1,821 distinct estimates, averaging 65 percent per year (Alston, Marra, Pardey, and Wyatt, 2000).

Public agricultural research has yielded high economic returns in all kinds of environments, but it is particularly effective at alleviating poverty in the lowest-income settings. For example, the amount of public agricultural R&D investment needed to permanently pull one person out of poverty has been estimated at only $144 in Africa and $180 in Asia – much less than in other regions (Thirtle, Lin and Piesse, 2003), where the poor are less likely to be farmers, and spend a smaller fraction of their income on food.

Public investment in agricultural innovation not only pays for itself, but provides gains that are often well targeted to the poorest people. New technology can raise the value of their labor and land, and reduce the real cost of achieving better nutrition. These benefits are difficult to capture in a marketable innovation, and a large fraction of benefits spill out to consumers and to other producers. This is particularly true in low-income countries with weak legal systems and where farmers have limited access to markets or credit, but even in the U.S. with the world's most stringent intellectual property protection and fully commercialized markets, the developers of Round-Up Ready® soybeans for example are estimated to have captured only 37-44% of total gains (Moschini, Lapan and Sobolevsky 2000).

The relatively large spillover effects of agricultural technologies leaves a special role for *public* innovation systems. On average these have very high rates of return, but their success is by no means guaranteed – in particular, targeting the funds is very difficult, and so funding is actually mobilized only when governments or philanthropic donors have confidence that a particular approach is buying what farmers need. Case studies reveal a wide variety of approaches that work, and some that don't (Meinzen-Dick, Adato, Haddad and Hazell 2003). To have the greatest possible impact, it is necessary to develop a wide range of new institutional arrangements adapted to various circumstances (Byerlee and Echeverria 2002). For example, intellectual property clearing houses help innovators exchange ideas that are already patent protected (Graff and Zilberman 2001), and direct grants to public initiatives underwrite promising new lines of research (Conway and Toenniessen 1999).

1.3 Why introduce a prize program?

Our proposal aims to supplement patent protection and direct grants with a third kind of mechanism: innovation prizes. There is a long history of using prizes alongside patents and grants, because they complement each other: like patents, prizes reward innovators only in proportion to proven results; like grants, they reward innovations that are publicly valued but not privately marketable.

Modern economic analysis of the incentive effects of innovation prizes began with Wright (1983) as well as Nalebuff and Stiglitz (1983). These analyses reveal an important role for prizes to elicit certain kinds of innovations, achieving results that cannot be obtained through patent protection or direct grants. During the 1980s and 1990s, the role of prizes was eclipsed by an explosion of new patent protections in the U.S. and elsewhere, as well as the steady growth of direct grants for innovative activity. But certain kinds of innovation were seen to lag, leading to a resurgence of interest in prize mechanisms.

The rediscovery of prize incentives was led by Kremer (2001), proposing a way to stimulate pharmaceutical research on malaria, tuberculosis, and other relatively-neglected diseases. A number of other economists and legal scholars have also written on this issue in recent years (Calandrillo 1998, Shavell and van Ypersele 2001, Davis 2002, Abramowicz 2003, Hollis 2004), focusing mainly on attempts to influence public policy towards pharmaceutical research (e.g. Weisbrod 2003). The application of prize mechanisms to tropical agriculture was initiated by Kremer and Zwane (2002).

Our framework for prize awards builds on previous work, putting together our analyses of agricultural technology with the broader literature on research incentives, in the light of actual historical experience with a wide variety of prize mechanisms. The next section surveys that experience, drawing key lessons for our proposal.

2. History: Lessons from past prizes and achievement awards[5]

Prizes have long been offered as incentives in economic organization, helping their sponsors to elicit efforts that are not easily rewarded in other ways. Prizes are widespread in academia, but they are also common in industry, the arts, and any endeavor in which the marketplace fails to provide enough incentive to meet public needs. A few prizes attract substantial media attention, such as Nobel or MacArthur awards, but many very effective prizes are known only to the small community of interested colleagues and competitors for whom the incentive is most relevant.

To inform our proposal, we are concerned particularly with prizes for the development of new technologies, offered in formal programs using explicit criteria to disburse significant amounts of funding. The modern history of such prizes generally begins with the Longitude Prize, offered by the British government in 1714. A popular book (Sobel 1995) recently drew attention to it, and a prize for space flight is currently making headlines (Ansari Xprize 2004), but in between there have been many other prize programs that also offer useful lessons. No comprehensive history of research prizes has yet been written, so our survey is drawn from a wide range of sources, providing valuable guidance in creating and administering a new prize system.

2.1 Types of prizes

A recent report by the National Academy of Engineering (Bloch et al., 1999) contains a useful taxonomy and brief survey of the different types of prizes that might be used to foster innovation. Some prizes are awarded on a *best entry* basis, chosen from among all applications received by a certain date. Other prizes are given a *first achiever* basis. Some are given once only, while others are repeated; some involve fixed sums, while others vary with the achievement level. Most generally, however, they distinguish between prizes aimed at *recognition*, and those aimed at *inducement*.

Recognition awards are intended to confer prestige on subjectively-defined achievement. They may be awarded late in life for past accomplishments, such as the Nobel prizes, or awarded early to recognize future promise, such as the Intel (formerly Westinghouse) awards, or some combination of the two, such as the MacArthur Fellowships. Criteria may include scores on standardized tests and other screening devices, but the award itself is a subjective decision. To limit lobbying pressure, the nomination and selection process is often conducted in private, and there is typically no recourse in the event of a dispute.

Inducement prizes, in contrast, are intended to guide innovation in a specific direction, towards some objective criterion for which the award is given. By definition, inducement prizes involve the public announcement of the criteria and of the decision-making

[5] This section is co-authored with Hamilton Boardman.

process. To gain credibility and attract applicants, prize sponsors may commit to third-party assessments and dispute resolution procedures.

Both kinds of prizes offer the public prestige of winning a difficult contest, as well as the direct material benefit of reward itself. Recognition awards often include fellowship and scholarship funds intended to cover the costs of future work, and inducement prizes may aim to provide a sufficient monetary award to offset the costs having participated in the contest, but in practice applicants for these prizes apply a far larger level of effort than would be justified by the material reward alone. The size of the material reward is important, but so is the information produced by publicizing the prize and announcing its winner.

Indeed, perhaps the best operational definition of a prize as opposed to a contract is the level of publicity associated with tendering the offer and making the award. The effectiveness of publicizing an award as a way to elicit effort has helped fuel a rapid expansion in the use of prizes: a current listing is available as in a two-volume, several thousand-page directory (Webster, 2004), and at one count, there was a fivefold expansion in the number of prizes during the 1970s and 1980s (Zuckerman 1992, as cited in Bloch 1999).

Our concern is with inducement prizes, since our goal is to elicit the particular kinds of innovation that African farmers most need. For our purposes, a key distinction among inducement prizes is whether they target *a pre-specified technological hurdle*, such as traveling a particular distance, or whether they are paid proportionally to a more complex function, such as *the economic value of the innovation*.

Inducement prizes for a specific technology tend to have sharper criteria, with less room for favoritism -- but the hurdles they specify are often arbitrary, making the achievement of less value to the donor or the public than a more complex prize criterion might be. Inducement prizes that are proportional to value can be tailored more closely to desired achievements, but require more checks and balances to maintain the trust of donors and competitors for the prize. Our proposal is proportional to value, but has much to learn from prizes for specific technologies.

2.2 Inducement prizes for specific technologies

All inducement prizes, by definition, pre-specify and publicize their selection criteria. The sponsors of such prizes know what they want, and try to design objective criteria that can direct prize applicants' efforts towards meeting that goal, as opposed to pursuing other objectives or trying to sway the judges. Such efforts sometimes fail but they often succeed, offering useful lessons for our proposal.

The Longitude Prize

The most important and influential inducement prize was given by the British government for a reliable method to measure longitude at sea. During the 16th and 17th centuries, travel and transport across the Atlantic and Indian Oceans grew rapidly, but sailors still relied on "dead reckoning" to guess their location, keeping careful logs of the direction and estimated distance traveled to the East or West. Increasingly, military campaigns and commercial fortunes were lost when captains misjudged and found themselves in the wrong place, at the wrong time.

On May 25th 1714, a group of naval captains and merchants petitioned the British Parliament for a solution; on July 8th of that year, the Longitude Act was passed. It offered three levels of prizes: £10,000 for a method accurate to within one degree of latitude, £15,000 for a method accurate to within two-thirds of a degree, and £20,000 for a method within half a degree. The Longitude Act was not the first prize established by a European government for a solution to the longitude problem–Spain, the Netherlands, and several Italian city-states had done so before–but the British prize was by far the largest ever offered (Sobel, p. 8).

To manage this unprecedented prize offer, Parliament established the Board of Longitude and laid out detailed criteria by which a successful method would be judged. The Board, which answered to Parliament, comprised twenty-two of the country's most eminent sailors, politicians, and scholars (Quill 1966, p.6). Included on the Board, as ex-officio members, were the Astronomer Royal, the First Lord of the Admiralty, the Speaker of the House of Commons, the First Commissioner of the Navy, and the Savilian, Lucasian, and Plumian professors of mathematics at Oxford and Cambridge Universities (Sobel, p. 54).

In addition to providing authoritative judgments about the success of any method brought before the Board, the Act authorized the Board to provide working capital to sustain promising lines of work. The Board could disburse up £2000 to cover the costs of developing or testing a particular method if five or more of the commissioners agreed. Furthermore, if a method failed the criteria established for the three prize levels, the Board could offer a lesser prize if the method was still considered to be of use to the public (Quill 1966, pp. 226-227). As it happened, the Board remained in existence of over 100 years, during which time it used its power to disburse over £100,000 for lesser awards and for development (Sobel, p. 54).

The Longitude Act required that the efficacy of any method presented to the Board be tested on one of Her Majesty's ships as it sailed from Great Britain to a port in the West-Indies chosen by the Board (Sobel, p. 55). The Act allowed for half the prize to be given out if the Board agreed that the method was reliable within 80 geographical miles of the shore and the other half only when the complete trial had been concluded (Quill 1966, p. 227).

The Act certainly created a stir and spurred many to begin work on various solutions to this problem. But it was only after 23 years that the members of the Board were sufficiently interested in a proposal brought to their attention to meet for the first time in 1737 (Quill 1966, p. 7). Many different ideas for solving the problem were proposed over the years, ranging from the bizarre to the impracticable.

Two competing methods were thought to hold out the most promise. One was the lunar distance method, by which sailors might compare the local time at which a star disappeared behind the moon with a table containing the predicted time of that passage at a known location (Sobel, p. 23). All that was needed was for an accurate table with these predictions to be published, but making such a table was an immensely complex undertaking.

The other proposed solution was to develop a clock that could keep accurate time at sea. Such a clock would be set to the time of a known longitude, and by observing the sun's apex in the sky, the local time could be determined. Sailors could then use the difference between the two times to figure the longitude of their current location. In the 18th century, the most accurate clocks relied on the regular swing of a pendulum, which was easily thrown off by the rolling motion of a ship upon the waves. In order to qualify for the highest level of the longitude prize, the clock would have to gain or lose no more than three seconds a day over the course of its prescribed voyage to the West Indies (Sobel, p. 58).

The proposal that piqued the Board's interest in 1737 was the work of a carpenter and clockmaker from rural England, John Harrison. Harrison's first sea-clock was met with enthusiasm by the members of the Board of Longitude. Harrison, however, seemed only to see the defects of his work. Rather than requesting a trial of this clock, he instead asked that he be given two years and £500 to build a second, more accurate chronometer. The Board agreed to Harrison's request, on strict conditions – and over the following years it granted a total of £2750 in subsidies for production of the four subsequent clocks that Harrison would produce (Quill 1963, p. 153).

Harrison did not request a test to win the prize until 1760, when he presented his fourth model, the H. 4, a radically smaller pocket-watch design. By this time the composition of the Board had changed. The new Astronomer Royal, Nevil Maskelyne, was a strong supporter of the lunar distance method and had spent much of his life working to perfect it (Sobel, p. 112). Other members of the Board also favored the astronomical approach, and seemed to look down upon the idea that a simple machine could do a better job of finding longitude than the stars and heavens (Sobel, p. 99).

Harrison's initial attempt at testing never even made it to the West Indies: he was told to proceed to Portsmouth and await instructions from the Board, which never came. The Board consisted of members all of whom had other full careers to attend to and who were not paid for their work on the Board. Furthermore, the Board lacked any clerical staff, thus contributing its disorganization (Quill 1966, p. 85-86).

Harrison actually tested the H. 4 in 1761. After the voyage, his calculations showed that the H. 4 had performed well within the limits required for the full £20,000 prize. But the Board was not fully satisfied, in part because Harrison's calculations included a steady rate of gain or loss. Harrison argued such that nothing in the Longitude Act would prohibit this adjustment. In the end, the Board awarded £2500 and promised another test (Quill 1963, p. 154).

The second test was organized for 1764, allowing Harrison's rate adjustment. The Board recognized the H. 4's accuracy, but immediately levied further conditions. A new act of parliament was passed, awarding Harrison half the full prize, on condition that he explain how the H. 4 was constructed and turn the watch over to the Admiralty. The remaining £10,000 was to be paid against two additional clocks, which would be tested over a twelve month period.

Harrison managed to construct only one more clock, the H. 5, without the benefit of the original or his drawings which he had been required to turn over to the Board. At this point, he was over 80 years old; he appealed directly to King George III, who agreed to test it over a ten week period. Parliament ultimately awarded him £8750, which brought his total award to £18,750. So Harrison never collected the whole prize, even though, by all measures he probably should have after the completion of the first test (Quill 1963, pp. 155-157).

The Alkali Prize

The French government made several important prize offers in the 18th century, to spur innovations that were deemed critical to national interests, and yet were not being elicited by either patent protection or direct public funding. These prizes were offered both before and after the Revolution; while none drew as much attention as the Longitude prize in England, the French awards were of critical importance to industrial development – and offer valuable lessons for later new prize offerings.

The most important of the 18th century French prize offers was for the production of alkali to be used in soap, glass, and textiles (Kiefer, p. 45). These soda compounds were mainly potassium carbonate (potash), typically drawn from wood ash, and sodium carbonate (known popularly as 'barilla'), drawn from the ash of burned seaweed (Reilly, p. 288). Obtaining these materials became increasingly difficult, from either within Europe or by trade with North America due to the British blockade of French ships (McGrayne, p. 5-6).

In response to the scarcity of alkalis, in 1775 France's King Louis XVI offered a prize of 2,400 livres for a method of making artificial soda from common salt – a resource of which France had a plentiful supply. The prize was administered by the Académie des Sciences in Paris and sought to "to discover the simplest and most economical method of decomposing sea salt on a large scale, in order to secure from it the alkali" (Kiefer, p.

45). The prize helped spur research not only in France, but also in England as well as other countries. Several chemists developed potential solutions to the problem and applied for the prize, however, none were found to be sufficiently efficient and inexpensive to be a replacement for potash (Reilly, p. 288-289).

The process that should have won the prize was developed by a man of humble origins named Nicolas Leblanc. Leblanc, a surgeon who was employed by the Duke of Orleans, had become interested in chemistry, and spurred by the prize offer, decided to turn his attention to the soda problem. The process he developed involved mixing common salt, sulfuric acid, limestone or chalk and coal or charcoal to create a "black ash" from which soda ash could be washed (Kiefer, p. 46). While the process met the requirements of the prize, he was never to receive it.

Before Leblanc could make a proper claim for the prize, the French Revolution intervened and led to the closing of the Académie des Science. Leblanc lost all hope of collecting the prize. He pushed forward in trying to build an enterprise to manufacture soda ash, but suffered a series of setbacks at the hands of the revolutionary government. When his benefactor, the Duke of Orleans, was executed in 1793, Leblanc lost control of his factory at St. Denis and was forced to publish his process so any and all could copy his methods. Nearly penniless, Leblanc committed suicide in 1806.

It wasn't until 1855 that Leblanc received proper recognition for his work. In that year Napolean III awarded an equivalent sum of prize money to Leblanc's heirs (Kiefer, p. 46, 49). Leblanc's process for making soda ash became the primary source of sodas for most of the next one hundred years, and is often noted as the birth of the modern chemicals industry.

This prize was by no means the only motivating factor drawing attention to the soda problem. The hope of gaining a patent monopoly on the use of a particular process, given the scarcity of soda at the time, was probably worth far more. However, this prize did at least succeed in drawing Leblanc's attention to the problem, and, like other prizes, served as a useful tool for the government of the time to signal the value and importance of pursuing particular avenues of research.

The Food Preservation Prize

Returning from his Italian campaign of 1800 and concerned about the condition of French industry, Napoleon established the Society for the Encouragement of National Industry which was run by the government and empowered to offer prizes of up to 100,000 francs to encourage industrial development (Burke, p. 234). The Society, which remains in operation today, was made up of four topical committees of experts – on mechanical arts, technical arts, economics, and agriculture – which were charged with reviewing developments in each field for dissemination in the Society's regular bulletin as well as establishing prizes and the methods of evaluation for those prizes (Cotte).

One of the early prizes offered by the Society was established in response to the logistical problems that Napoleon had faced during the Italian campaign. With Italians unwilling to accept the currency of the French government, there were problems buying food to feed the army. Upon the creation of the Society, a prize in the amount of 12,000 francs was announced for a reliable method of preserving food – if the army couldn't buy or seize food, it could bring it with them. The navy was likewise interested in such an innovation, since given the political climate of the day, many of the foreign ports where they usually procured goods had been blockaded.

The winner of the prize was a confectioner and son of wine makers, Nicolas Appert, who, even before the prize was announced, had dabbled with the idea of preserving food in champagne bottles. He discovered that when those bottles were placed in boiling water for some length of time, depending on the particular food, the food would keep for a great period of time. A report on Appert's preservation techniques was presented to the Society in 1809 and the following year, the Society awarded him the 12,000 franc prize on the condition that he publish his techniques (Burke, pp. 234-235).

The Early Aviation Prizes

The most famous and arguably most important prizes of the 20th century were for achievements in aviation. The first of these was established in 1900 by French financier Deutsch de la Meurthe who offered 100,000 francs (then roughly $20,000) to anyone who could fly an airship the 11 kilometers from the offices of the Aéro-Club de France to the Eiffel Tower and back (Hallion 2003, p. 91). The award was won in October of 1901.

By the start of WW I, over 50 different prizes were offered, sponsored by newspapers as well as philanthropists, rewarding feats in speed, duration, altitude and the completion of certain routes (Maryniak, pp. 8-10). During 1911, it is estimated that well over $1 million in aviation prizes were awarded, mainly in Europe (Villard, p. 127, 135, as cited in Maryniak, p. 11).

Although prizes were important to the development of aviation, they were not the only factor: even more money was available from other sources. The Wright Brothers built their first planes with an eye towards both patent protections and government contracts, and with the onset of WWI government funding for military applications became dominant. This was followed in the early twenties by further government efforts supporting civilian uses, including the establishment of air mail routes and national passenger airlines (Davis and Davis, pp. 8-11).

The Orteig Prize and the Spirit of St. Louis

The most important modern aviation prize is that which motivated Charles Lindberg to fly from New York to Paris in 1927. The award was offered by Raymond Orteig, an entrepreneur who had come from France to New York in 1912, where he became the owner of two prominent hotels frequented by French airmen (Ranfranz). In May 1919, he sent a letter to the President of the Aero Club of America in which he offered a prize of $25,000 to the first aviator from any of the Allied countries to fly non-stop New York to Paris, or vice versa. He stipulated that it could be won with either a sea- or land-plane, but it must be a "heavier than air" machine. The offer was to be valid for five years (Berg, p. 91).

At the time, the 3,600 mile distance from New York to Paris was over twice the distance that had ever been covered by an airplane in a single flight (New York Times, May 30th 1919). By the expiration of Orteig's offer in 1924, not a single flier attempted the crossing (Corn, p. 17). Orteig reorganized the prize, lifting the deadline and opening it to aviators from any nation. The management of the prize remained with the Aero Club, which had recently become the National Aeronautical Association.

By 1926 interest in the prize and the challenge of a non-stop transatlantic crossing had risen within the aviation community (Berg, p. 91). When Charles Lindbergh finally set off on his winning flight on the morning of May 20, 1927, at least three previous attempts had failed, and at least two other entrants were preparing to try. The NAA required a $250 registration fee and 60 days notice. Lindbergh chose to fly earlier, and after his success the NAA chose to ignore its 60-day rule, awarding Lindbergh the full $25,000 purse (Berg, p. 110, 159).

Upon receiving the prize money, Lindberg noted that the prize had drawn both his own attention and that of other aviators to the challenge, and that no "such challenge, within reason, will ever go unanswered" (Berg, p. 159). In all, nine different competitors worked toward winning the prize, spending a combined total of $400,000 in their efforts. Lindbergh was one of only two entrants who endeavored to win the prize with an investment of less than the prize amount (Maryniak, p. 12).

The huge success of Lindbergh's flight and the publicity that surrounded his flight launched a new round of prizes, including $25,000 for a California to Hawaii non-stop, $30,000 for a similar flight to Tokyo, and $33,000 offered by the National Aeronautic Association for a series of transcontinental flights (Berg, p. 143). These prizes helped not only to advance the technologies involved, but also perceptions of aviation safety and social roles: numerous prizes were offered for women fliers, helping to launch the careers of Amelia Earhart and other pioneers.

The Kremer Prize for Human Powered Flight

The prizes described above all targeted technologies with important commercial applications, providing additional incentives for endeavors that were primarily funded by commercial markets or government contracts. Some prizes, however, have focused on more speculative or aesthetic achievements. Here we consider those aimed at realizing the promise of Leonardo da Vinci's famous illustrations of human powered flight.

In 1933, Polytechnische Gesellscaft in Germany offered 5,000 marks for a human powered aircraft that could fly a 500 meter course. Though the award was raised to 10,000 marks two years later, the prize went unclaimed. Similar prizes were offered in Italy and the U.S.S.R., but were also never won. In 1960, British industrialist Henry Kremer offered a prize of £5,000 for flying around a one mile-long figure-eight course while remaining at least ten feet above the ground – and it wasn't until 1977 and an increase in the prize purse to £50,000 that the prize was finally claimed by a group led by designer Paul B. MacCready, Jr (Carlson, pp. 117-118).

The challenge of human flight went unfulfilled for so long in part because of the difficulty of the challenge. To remain aloft with the mere 400 watts of power that even the best trained athletes can deliver over a sustained period of time, the aircraft that won the Kremer prize needed a wingspan of 29 meters, yet had to weigh no more than a small hang glider. It was only with the development of new materials such as Mylar and Kevlar that such an aircraft became a possibility (Davis and Davis, p. 13).

Kremer's first award spawned a series of others, first for £100,000 to cross the English Channel, and then other challenges. Engineers and adventurers have continued to develop human-powered aircraft capable of great speeds and distances. Human-powered flight has attracted little commercial or government funding beyond the prize money, but has demonstrated and improved key technologies used in other applications such as lightweight batteries and military drones.

Prizes for Space Travel: the CATS Prize and the X Prize

Unlike the development of aviation, the early years of space travel were funded almost exclusively by government contracts. Commercial applications have since led to substantial private investment in communication satellites, but launch vehicles remain very costly and human spaceflight remains prohibitively expensive.

Two notable recent prizes have aimed to spur the development of lower-cost techniques: the Cheap Access to Space (CATS) Prize, which ended unclaimed in 2000, and the X Prize, which appears likely to be claimed by the end of 2004. Moreover, in June of 2004 a Presidential commission established to review the future of the American space program recommended that the U.S. government offer prizes to encourage commercial space development, including the possibility of offering a $1 billion prize for another manned mission to the moon (Aldridge, pp. 34-35).

The CATS prize was offered in November 1997 by the Space Frontier Foundation, promising $250,000 for the first group to launch a two-kilogram payload at least 200 km in to space, $50,000 for the first competitor to reach at least 120km. The prize was offered for a period of only three years, and its rules forbade the use of government funding in any way. Five teams competed, and though none came close to reaching either of the targets, several of the groups involved continued to be involved in space flight attempts.

The X Prize was established in 1995 by Peter Diamandis, aiming to help launch the beginning of a space tourism industry. Like the CATS prize, it requires that each entry be privately financed and built. To win, a re-usable aircraft must reach an altitude of 100 km twice in a 14-day time period, with no more than 10% of the vehicle's non-propellant weight replaced between flights. Each flight must carry at least one full-grown adult, with space and ballast enough to represent two passengers. The crew must return to earth in good health and the vehicle must be "substantially intact" – both criteria to be judged by the prize review board.

The prize has drawn competitors from around the world. As of June 2004, more than 20 teams from seven different countries had registered with the prize board to compete (Ansari X Prize, Factsheet). A cursory glance at the various designs submitted by these teams reveals a wide diversity in approaches to the prize challenge. Launch methods range from traditional land-based rocket powered launches, to horizontal take-offs from runways, to air launches from secondary airplanes or balloons. Similar diversity exists in landing techniques, from glider-based runway landings to parachute descents to land or water, and in propellants used (X Prize, Team Summary).

On June 21, 2004, the first test flight that exceeded the 100km limit with a pilot on board was completed by Scaled Composites, a team led by noted aircraft designer Burt Rutan and backed by Microsoft co-founder Paul Allen. Indeed, according to Allen, that team alone has already spent more than $20 million – twice the prize purse – on its attempt (Schwartz).

The X Prize foundation has announced that the prize offer will expire at the end of 2004 if no team wins the prize (Schwartz). However, given the success of the Scaled Composites test flight, the X Prize is widely expected to be won before that expiration date. Furthermore, the prize sponsors have developed plans to continue their goal of encouraging private spaceflight by holding an annual X Prize Cup – a series of competitions and races in which teams will be able to compete for cash prizes in a number of different categories, such as highest altitude, fastest turnaround time, and maximum number of passengers carried (X Prize, Cup Fact Sheet).

Prizes for Math and Computer Science

Beyond physical achievement, in recent years a vast new crop of prizes have been offered for feats and innovations in the fields of computer science, nanotechnology, and mathematics. Offered by a variety of organizations, they seek to spur interest in overcoming various barriers that have been observed in these fields.

A striking example is the International Computer Go Championship, sponsored by Acer and the Ing Chang-Ki Wei-Ch'i Education Foundation. It offers a prize of $1.6 million for any computer program that can beat a human at the game of Go. As of yet, no one has even tried to capture the prize, however, the Foundation also sponsors annual "best of" competitions for the best program at the game (Bloch, p. 29, and American Go Association).

Another example is the $100,000 prize offered since 1990 by Dr. Hugh Loebner, for the first computer that could pass what is known as the Turing Test. In 1950, British mathematician Alan Turing proposed that a machine could be said to think like a human, if the machine's responses were indistinguishable from those of a human. Loebner offered the prize for any computer that can pass this test; it has not been won, but Loebner also sponsors an annual contest for "the *most* human response" from a computer. This prize consists of $2000 and a bronze medal.

The Rockefeller Foundation Prize for STD Testing

An important precedent for our proposal is the 1994 Rockefeller Foundation prize for a low-cost way to test for gonorrhea or chlamydia. These two sexually-transmitted diseases are associated with the transmission of HIV. They are easily cured once diagnosed, and a test to facilitate early diagnosis was thought to be enormously valuable but insufficiently profitable to be developed by private pharmaceutical firms.

In 1994, the Rockefeller Foundation offered a $1 million prize for such tests, specifying strict criteria in an attempt to elicit techniques that could be used widely and inexpensively throughout the developing world. Among the requirements were that the test be 99% accurate, use little electricity, cost less than $0.25, be storable in tropical climate conditions for up to six months, use non-invasive samples like urine, and provide results immediately in a way that health workers with only a primary education and two hours or less of training could get reliable results (Kremer 1998, p. 1164, and Mabey, p. 397).

Although over 40 different rapid tests for syphilis, gonorrhea, and chlamydia are available on the market, mostly in developed countries, the Rockefeller Prize was never claimed, nor was it renewed after the offer expired in 1999 (Mabey, p. 397). Kremer and others have argued that the criteria laid down by the Foundation were too strict and offered little room for trade-offs in the criteria (Kremer, p. 1164). It is also possible that the prize period was too short, and no intermediate awards were offered to build the reputation of the prize approach in this area – and that the prize amount was too small, relative to the other rewards available to the researchers and laboratories using these technologies.

The Honeybee Network in India

[to be completed]

2.3 Inducement Prizes Proportional to Value

The inducement prizes considered so far all had pre-specified targets and rewards. They often involved a schedule of payments for different achievements, but each hurdle and each amount was written down *ex-ante*, and did not vary in proportion to the perceived value of the invention after its deployment. Such prizes rely entirely on the prize sponsor to define what is to be invented, and to compute the amount to be paid ahead of time. The resulting targets and payments were sometimes visionary, leading to new techniques that were soon widely used, but they were also often arbitrary, leading to beautiful but useless accomplishments – or to no award at all. And even when prize-winning techniques found widespread use, their adaptation and diffusion was done in the context of marketable products or government contracts.

Using prizes to reward adaptation or diffusion of non-marketable products requires specifying some way to measure value, using *ex-post* information about willingness to pay for the results of the innovation being rewarded. Such a prize system was used as a substitute for patents in Soviet Union, and as a complement to them in the United States.

Soviet Incentive Awards for Innovation

Soon after the start of central planning, the Soviet Union saw the importance of innovation and sought to create special incentives for it. In 1931, the Committee for Inventions established specific monetary awards to be paid for specific techniques, proportionally to the cost savings achieved after three years of use. The committee could grant some payments earlier, and also award non-monetary benefits such as priority for housing and admission to elite schools (Hughes 1945, p. 292).

In order to be considered for an award, an inventor needed first to certify its novelty by applying for an Authorship Certificate (Hughes 1946, p. 416). Payments were then made against a detailed schedule based on the cost savings achieved. Improvements on existing techniques were rewarded at roughly half the rate of new inventions. Innovations in clerical procedures received one-quarter of the invention awards, while those inventions which reduced imports or boosted exports could receive a bonus of up to 100 percent of the base award. By 1940, at least 112 million rubles worth of rewards were paid out.

The Soviet Union's innovation awards did not eliminate the old style patent, but in the controlled economy patents were of little value – and Soviet patent application fees were the highest in the world. As a consequence, the period from 1933 to 1940 saw a substantial dwindling in the number of patents issued. To accelerate the pace of innovation, the Soviet Union expanded its awards system in 1942, increasing the amount of the awards while also allowing for smaller awards, as well as clarifying the procedure for verifying the originality and authorship of an innovation (Hughes 1946). In the end, of course, such awards were unable to overcome the destructive effects of central planning and political repression. Living standards continued to fall, and the Soviet Union was dissolved in 1991.

Atomic Energy Act Patent Compensation Awards

In the United States, innovations are rewarded principally through commercial markets -- but where markets are limited, prize payments have also been used. The Atomic Energy Act of 1946, for example, aimed to reward innovations whose only buyer was the Federal government. The act specifically prohibited the patenting of certain innovations, thereby preventing the disclosure of information that might be used to produce atomic weapons, and established the Patent Compensation Board to make payments to private-sector inventors in lieu of patent rights. Similar payments would be made to the owners of existing patents whose technologies were to be used in government programs.

In setting payment levels, the Patent Compensation Board was instructed to consider the cost of developing the invention, the extent to which that cost had been financed by the government, the actual usefulness of the innovation, and any other arguments offered by the inventor (42 U.S.C. 2187). The legislation also allowed for special prizes for "any especially meritorious contribution to the development, use, or control of atomic energy."

In practice, the Board did not commit itself to any particular way of measuring usefulness. Its payments came to be seen as relatively small, and not closely tied to the value of each innovation. Most famously, for example, the Board gave Robert H. Goddard only $1 million for the use of his patents on liquid rocket engines, and it awarded only $300,000 to Enrico Fermi in compensation for his patent on the production of radioactive isotopes (Scherer, p. 458). Prize payments had little incentive value in eliciting subsequent innovations, and atomic technology remained the province of government labs and contracts.

The Super-Efficient Refrigerator Program

Environmental benefits were the target of an interesting U.S. prize offer, known as the Super-Efficient Refrigerator Program (SERP). The program originated in the 1980s, when many electrical utilities offered subsidies to induce customers to install new, more energy-efficient appliances. Then, under the Montreal Protocol, the U.S. government committed itself to phasing out the use of CFCs in refrigerators and air conditioners – although alternative cooling technologies without CFCs were more expensive and less energy efficient. The need for new refrigerator technologies had become even more pressing, and a consortium of utilities and environmental advocacy groups was formed to pool the utilities' consumer subsidies, and offer them as a single prize to the first appliance manufacturer capable of marketing a "super-efficient" refrigerator (Davis and Davis, p. 14).

The contest offered a variety of payments, including some on a per-unit basis for each refrigerator sold to the public (Bloch, p. 27). Contest judges examined the marketing and sales plans of the entrants as carefully as they did the technical aspects of the refrigerator – and entrants had to certify that the wholesale cost of the refrigerator was no more than the cost for a less efficient unit of similar size, in an attempt to ensure the firms did not subsidize sales just to win the prize.

The Whirlpool Corporation won the SERP prize in 1994, less than a year after requests for proposals had been sent to 14 interested manufacturers. Its entry significantly exceeded it the requirements for the prize, cutting energy use by over 30%. By 1995, Whirlpool had succeeded in cutting that energy use further – to 40% better than the federal regulations. Actual payment, however, was to be calculated based on the number of units sold: Whirlpool had to sell 250,000 refrigerators by 1997. As energy prices fell in the mid-nineties, consumer interest in energy efficient appliances was thin and Whirlpool ended production of the refrigerator even before the deadline had expired. It was reported that sales were at least 30% below expectations (Davis and Davis, p. 15).

The SERP program showed that a large prize can attract attention to a given problem, and that tying the collection of prize money to sales of the product can help ensure that it finds its way in to the marketplace. But such an endeavor can still face problems if the formula used to compute value is flawed – or if the prize is intended to reward something that, in the end, turns out to have a low value (Bloch, p. 28). In the case of SERP, the value of energy-efficient appliances depends not only on the current price of energy, but also on the timing of government regulations. As it happened, new rules on energy efficiency were to have gone in to effect in 1998, but this deadline was pushed back after lobbying by other appliance manufacturers – thus limiting the number of units that Whirlpool could sell before the SERP deadline (Davis and Davis, p. 16).

2.5 A Few Lessons from Past Prizes

From the brief history of prizes reviewed here, we can glean several key lessons about where, when and how prizes have succeeded:

1. Prizes are a last resort. Successful prizes arise only when a government or philanthropic donor sees a pressing need for particular kinds of innovation, beyond what is provided in the marketplace or can be procured by direct contracting with salaried researchers. If the desired innovations can be marketed to the public or procured by contract, then doing so is almost certain to be faster and more effective than offering prizes. That being said, in a surprising number of instances, donors have wanted a kind of innovation that they could not obtain by other means – and it has proven well worthwhile to establish prizes.

2. Prize programs are temporary. Successful prizes often lead to successor prizes in the same line, but as soon as that line of research becomes well established, it eventually generates either marketable products or the possibility of procurement by contract. Prize schemes may last for several decades, but they do not displace patents or public research institutions which have lasted for centuries.

3. Prize programs cannot stand alone. Even the most well-endowed prizes attract entrants whose work is funded from other sources. Often, much of the work was done for other reasons, even before the prize was offered. In any case, entrants typically choose to invest more than they expect to win, in pursuit of the prestige and reputation associated with the award.

4. Prize programs are about *information.* When governments, philanthropists, or others can know what they want and from whom, it is usually better for them to procure it directly from the market or by contract. Announcing a prize is useful only when the donor knows only the problem, and is looking for information about what or who can best provide the solution. The prize publicizes the problem through its award criteria, and elicits information about possible solutions from the prize entrants. Once that information about what and who can solve the problem becomes public knowledge, markets and contracts can take over.

5. Prize programs are created by donors for end-users. Most prize programs are created by donors unilaterally, as the most cost-effective way to procure something they know they want. Occasionally, groups of end-users come forward to ask a donor to create a prize program for them, but this occurs only when end-users are unusually well-organized and well-informed about the potential benefits of some new technology. It is even less common for the innovators themselves to ask for a prize program. Those who could create a new technology typically ask for grants and contracts to pursue their line of work, partly because they genuinely believe that their organization's approach is the best way to get results, and partly because that is the only way to obtain guaranteed funding. Even if a prize program were established for the kinds of results they produce, they cannot know in advance whether they would win.

5. Prize programs are fragile institutions. The creation of a prize requires donors to put resources behind a set of prize criteria, not knowing who or what will win. This requires a high degree of faith in the awards mechanism, in a context where potential prize winners are also asking for direct grants and contracts to fund their particular approach. The two mechanisms are complementary in retrospect, after prizes have helped identify successful approaches that then attract more support, but *ex-ante* they are competing alternatives. Donors who must choose what fraction of their funds, if any, to put behind the prize mechanism face a difficult decision. They must place their trust in a set of criteria that are specific enough to state a known problem, and yet flexible enough to find an unknown solution -- and they must offer enough funds to attract innovators' attention, without starving potential prize-winners of the working capital they need to make progress.

With those lessons in mind, we now turn to our specific proposal.

3. Proposal: How to do prizes for innovation in African agriculture

This framework document aims to help donors provide improved technologies for African farmers, by offering a new kind of incentive for innovation. In this section, we outline the key features of the proposal, then explain in more detail how it would work.

3.1 An informal summary

When discussing this or any new proposal, it is often useful to have a one-sentence summary of the idea. Here it is: we propose that donors pay innovators proportionally to the economic value of new technologies needed by African farmers.

How do we know this a *good* idea? We know that African farmers desperately need new techniques. We know that many different kinds of innovators are already working in Africa. And we know that donors want to pay for the innovators' work to reach farmers and meet their needs. What we *don't* know is which techniques, from which innovators, are most likely to be successful. The only way to answer that question is for innovators on the ground to make local trials, to identify the best solutions to local farmers' problems. Since local farmers are poor and lack the capital or institutions to pay for enough local innovation, donors must step in – and an efficient way to do that is to pay innovators proportionally to how well farmers' needs have been met.

Is this the *only* solution? Of course not: Most of the incentives for innovation are provided by the marketplace. Even impoverished farmers and consumers buy and sell many things, and donors achieve results mainly through grants and contracts. The prize offers a payment *in addition to* these other flows of funds, targeting a specific criterion that would not otherwise be aimed for, so as to complement other activities and help them work better. On balance, it seems likely that a prize mechanism is likely to carry a small but very influential fraction of all funding for agricultural innovation, and to appeal to a very specific subset of donors: in particular, those who want to see results on the ground, without championing a particular way of achieving that result.

3.2 Design questions and program structure

The approach proposed in this framework evolved from decades of work by thousands of researchers; the proposal can perhaps best be described as answers to a series of fundamental questions.

Design question #1: *Novelty* – What's new in this proposal?
Agricultural technologies are well known as a way to alleviate poverty, and prizes are well known as a way to obtain desired technologies. What's new here is to adapt prizes to the technological needs of African farmers. Our proposal specifies a new target to aim for, and a new way to measure how well that goal is met so as to compensate innovators accordingly.

Design question #2: *The target* – What does this proposal aim to achieve?
Past prize systems have typically specified a specific technological hurdle, such as flying a certain distance or addressing a particular disease. This works well for industry and health, where a single problem has a single solution. But agriculture has no equivalent to the airplane or the blockbuster drug. Very few agricultural technologies are developed once in a factory or laboratory and then work everywhere for a long time, or can be adapted by the end-user to their needs.

In agriculture, even the most widespread technologies actually consist of thousands of locally-adapted and temporarily-useful applications, each one requiring a substantial R&D effort at a particular place and time. This variation is perhaps most obvious in farmers' seeds, where a widely-used kind of plant such as hybrid maize actually consists of thousands of location-specific and soon-obsolete variants, each one developed by specialized crop breeders at each place and time. Such genetic improvement is usually outside the reach of individual farmers, because it requires large-scale controlled experiments – which may also be needed to find improved agronomic techniques involving fertilization, irrigation and pest control as well as other innovations involving livestock or marketing.

To develop and disseminate the technologies that African farmers need, an effective search process is both global and highly localized: it consists of drawing ideas and materials from all over the world, and conducting local tests to find what works best in a particular place, under a specific set of biological and economic constraints. In effect, each step builds a wider variety of tools from which farmers can choose.

An effective search process is also cumulative as well as timely: each step builds on what was done before, and creates something new that will soon be obsolete. In agriculture even more than in other domains, each breakthrough is temporary, because pests and diseases are constantly evolving, because improvements that alleviate one constraint soon encounter another, and because a research system that develops one good technique may soon develop an even better one.

In summary, the target of successful agricultural innovation is not a particular technology, but rather a growing portfolio of technologies, each filling a particular niche and soon replaced by something better. That portfolio consists of locally-adapted varieties of crops and livestock, timely pest and disease control strategies, appropriate fertilization and irrigation practices, and effective marketing institutions.

Design question #3: *Measurement*– How can the criteria be specified?
The target may be broad, but recent experience with hundreds of impact assessments for agricultural research, technology development and extension programs allows us to define a specific approach to computing an innovation's value, based on purely observable criteria. Agricultural economists and other researchers have so much experience with impact assessment for agricultural R&D in part because the data are readily available, so the question offers a convenient laboratory for student theses and

paper projects, and in part because there is an important argument to be made in which empirical research has a distinctive role to play: R&D is a public investment characterized by persistent under-investment and excess returns, which can be documented only through impact assessment.

As with any scientific effort, each researcher's contribution to impact assessment aims to distinguish itself from previous work, and different analysts becomes champions of slightly different methods. The impact-assessment field has seen fierce arguments over methodology, functional forms, parameter estimates, data quality, and many other dimensions of the measurement problem. But faced with the policy question of how to design a prize system – as opposed to the academic question of how to write a research paper – a large number of distinguished researchers can probably agree on the broad lines of an appropriate criterion.

The target criterion for prize payments is unlikely to be perfect – as one economist advising on the design of this proposal put it, it would be an astonishing surprise to get it right on the first try. It may be desirable to start with more than one way to earn prizes, and certainly necessary to establish a mechanism by which to learn from experience and adjust the criteria as needed. Even after experimentation and learning-by-doing, however, no economic institution offers perfectly aligned incentives. Revenues from marketable patents, for example, are only roughly in line with their underlying economic value, if only because of transaction costs and distortions in any market that is not characterized by perfect competition. Realistically, no prize criteria can ensure that winners hit the bulls-eye. Our goal is to help innovators aim in the right direction, towards the economic value of adopted technologies.

Our criteria for this prize system are, in a sense, analogous to the criteria used in awarding patents and other licenses. In those cases, applicants must submit particular kinds of data, collected in ways that can be verified by examiners and subject to challenge by others, offering a dispute-resolution procedure to rule on special cases and a legislative procedure, if needed, to change the rules. Patent applications must demonstrate novelty and usefulness, and drug-approval applicants must show safety and efficacy. In our case, applicants must show economic value.

Design question #4: *Data* – What are the criteria for awarding prizes?

This framework calls for prize criteria based on three kinds of variables: *experimental results,* measuring the changes in quantities of inputs and outputs associated with using the new technique as opposed to whatever else farmers might be doing; *adoption surveys,* measuring the extent to which the new technique is used; and *market prices*, measuring the local value of the inputs and outputs concerned. The applicant must submit a portfolio documenting their methods and results in these three areas, and an agreement on attribution of effort among any partners associated with the development and deployment of the new technology. These data aim to ensure that the prize amount is proportional to the sum of quantities times prices, and is then divided fairly among those who contributed to the effort.

Controlled experiments can be used to document many kinds of quantity change, showing how a new technology might raise yields, save time, reduce pesticide use, improve food quality, or do anything else that can be replicated in an experimental setting. Asking for data from controlled experiments allows a wide range of solutions to farmers' problems to be considered and compared in a transparent and accountable manner. Of course not all innovations can be subject to controlled experiments, but the approach allows a wide range of important innovations to be rewarded proportionally to their value.

Farm surveys will observe the net result of many kinds of diffusion processes – the technology may be sold in markets, supported by credit and risk-sharing programs, explained through education and extension, or simply spread from farmer to farmer. Again, using farm survey data ensures that applicants' claims are readily verifiable through re-surveys and comparisons with other data. Not all changes can be documented through farm surveys, but the approach will capture a wide range of important innovations.

Finally, market prices reflect the local scarcity of many kinds of things, from food, land and labor to credit and transportation services, firewood and water. As before, not all values are captured in market prices, but the approach is transparent and verifiable, and captures the main things that are of greatest importance namely the total quantity of food and other staples that a farm family can afford to consume.

Design question #5: *Effectiveness* -- Who would respond to prize incentives?
Many researchers are already working in Africa with potentially-valuable innovations, including national and international institutes, universities, NGOs, farmers, input suppliers, and agro-processors. Each of these enterprises was built and is sustained with revenues from either market sales or public grants and contracts.

The prize system is unlikely to replace local innovators' other sources of core finance and working capital. Even at their most successful, the function of prizes is mainly to help lubricate the market for innovations, providing some resources directly to successful groups and also complementing other flows. With a prize program in place, donors and investors could have additional confidence in their enterprises, knowing that success is more likely to be rewarded. Donors, investors and innovators will also have more information about what strategies have worked well elsewhere, as will farmers who can use that information to demand more appropriate innovations for themselves.

The unique virtue of a prize program is to provide rewards *ex-post*, letting other institutions provide the working capital. The prize secretariat would have no comparative advantage in becoming yet another funding agency for research; donors should use a different mechanism for that. But the prize secretariat would have a strong advantage in providing technical assistance and small grants for experimental data and farm surveys, to build capacity in the new skills needed to produce high quality applications. By offering that assistance, prizes would be more likely to reach innovators who happen to be good at R&D or diffusion, but are perhaps not very skilled at documenting their work.

Offering technical assistance and small grants for data analysis and farm surveys will no longer be necessary only these criteria are well accepted for innovation programs. Innovators will collect and analyze similar data as a routine matter, because that will be the only way for them to know if they are succeeding. But many innovators do not now collect this type of data, and they are not funded in proportion to their success on the ground. Funding occurs for other things: either marketable innovations (pursuing sales as opposed to adoption), or through grants and contracts (pursuing proposals as opposed to results). Indeed, this failure to pursue economic gains for farmers is why there is a need for the proposed prizes.

Design question #6: *Additionality* -- Would prizes pay for new work?
The earliest prize-winning applications could be for innovations that have already been adopted, with the only additional effort needed to win prize funds being the documentation of impacts. Some donors might wish to support such retroactive prizes, simply to draw immediate attention to these achievements, to channel funds to the successful groups, to inspire imitators and establish confidence in the prize mechanism.

Other donors might prefer to look forward, for example specifying prizes for technologies that were first described, released or disseminated after the prize announcement. In such cases the awards would go first to new techniques that happened to be "on the shelf", with the prize offer providing stimulus mainly to the dissemination effort and the alleviation of adoption constraints.

Over time, the prize award would help to pull technologies from further up the research pipeline, encouraging individuals and institutions to anticipate potential results, solve farmers' problems and thereby win prize awards. Prize awards would, as always, also play an important role in publicizing successes, encouraging innovators to pursue proven strategies and encouraging donors to provide direct contracts for successful lines of work.

In the long run, the principal achievement of the awards would be to raise the profile of the prize criteria, to have more innovations developed in pursuit of results measured by controlled experiments and adoption rates. This achievement would put the whole prize scheme out of business, as market mechanisms or public funding would be pursuing the same goal, and prizes would no longer elicit any additional work. In the meantime, however, neither markets nor existing grant-making systems are reliably generating enough successful technologies. Large excess returns from spillovers are readily observable in the data, which is why the proposed prize system is needed now.

Design question #7: *Compatibility* -- Would prizes conflict with patents?
The purpose of the prizes is to provide partial compensation for the spillover benefits of adoption. Initially, the reward would be computed at 20 percent of the public benefit

that remains, after subtracting the cost of inputs and other farm expenses associated with adoption. Prize applicants retain any intellectual property rights they may have, whether these are patents or other barriers to imitation. Prize applicants can continue to sell or restrict use in any way. Indeed, the only restriction is that applicants cannot receive two prizes for the same data: they can request another prize for the same technology, deployed in another location or for another purpose, but that becomes, in effect, a separate prize.

The prize can be understood as a licensing payment for the public-domain benefits of adoption: a reward for spillover effects. It is not a license for private use, or a property right of any sort. Indeed, the question of how the innovation should be marketed or diffused remains the innovator's choice. The only difference is that, with the prize in place, there is some compensation for those benefits of adoption that are not captured through product sales.

Because the prize offers a relatively small share of gains from adoption, technologies that are marketable will be marketed. When the seller can fully exclude free-riders, they will not leave enough measureable gains from adoption in the public domain to justify a prize application. But technologies suitable for African farmers typically generate large spillover benefits. Even inputs that are readily sold in the market, such as vegetable seeds or inorganic fertilizers, generate economic gains that are not recovered by the seller. And many new techniques, such as improved millet seeds or virus-resistant potato plantings, are often best distributed by simply giving them away. With the prize in place, programs can choose whether to sell or give away, knowing that that whatever public benefits they can generate could earn them some cash return, to the extent that they can be verifiably documented.

Design question #8: *Attribution* -- Would the right innovators get paid?
Technological innovation is a cumulative process: each innovation is built of previously-available components, produced earlier in time and often by other people. The question of who should be rewarded for each step is a matter of dynamic efficiency as well as fairness.

At any one place and point in time, whoever adds the last element to deploy a new technique might want to claim all the credit, effectively taking all previous components for granted. At another extreme, whoever produced the "first" or most basic component might want to claim all the credit. Neither attribution rule is sustainable, as they would allow no further incentive to create new components. Indeed, no fixed attribution of any kind can be optimal, since prespecifying the rule throws away the possibility of an appropriate reward to something genuinely new.

In practice, actual attribution systems balance the supply and demand for each component in the usual way -- by negotiation. Eliciting the fastest and most effective flow of innovations relies on making that negotiation easy, so that the most appropriate components can be assembled and deployed as quickly as possible. For marketed technologies, the attribution problem is solved through the payment of royalties, subject to challenge and adjudication in court. Injustices and inefficiencies do occur, but routinized negotiation and dispute resolution systems help limit the degree to which valuable technologies are withheld from the market for any sustained period time.

The prize framework proposed here would solve the attribution problem in a similar way, through the formation of ad-hoc partnerships to share prizes and relying on subsequent dispute resolution to ensure fairness. Indeed, prize-sharing may be a particularly easy way to facilitate coordination among institutions involved in new technologies, because prize money is easy to subdivide. The costs are irrelevant to the award, so there is no need for the harmonized accounting practices needed in other kinds of joint ventures. As a result, there is no obstacle to creating partnerships among NGOs, for-profit firms, individuals and various government agencies or local government bodies.

To facilitate negotiation, the prize secretariat need only require that each application be accompanied by an attribution agreement, stating what share of the prize each party expects to receive. When the application is made public, a comment period (e.g. 90 days) is opened to invite other parties to examine the data. Anyone who believes they contributed significantly to the innovation can then approach the partnership and request a share, possibly adding additional data to the application – which could help raise the total amount of the prize.

If the partnership rejects the claim and maintains its original application, the challenger can submit their data independently, letting the prize secretariat adjudicate between them, possibly offering awards to both. In addition, a dispute-resolution procedure is offered, as applicants and challengers can appeal to a panel of experts convened by the prize secretariat. The basic structure of the appeals process could be made similar to that used to challenge or appeal patent claims or FDA approvals.

Design question #9: *Time-consistency* -- Would prize-giving be fair?
A key factor in the success and durability of the prize secretariat is the fairness of its operations. If innovators don't trust the secretariat, they won't bother to submit applications. And if donors don't trust it, they won't use it to offer prize money.

The approach proposed in this framework document is for the secretariat's constitution and initial procedures be dictated by an impartial advisory board, and then have operational oversight and dispute resolution be handed over to an elected supervisory board. In particular, with 12 elected supervisors, if donors choose four, researchers choose four, and four are agreed upon by both, then each could serve four-year terms and there could be an election each year for one seat in each category. With a ban on participating in any decision involving one's own prize fund or prize application, the result would be a secretariat whose board of supervisors has a consistent interest in keeping prizes fair from year to year.

The board of supervisors would hire the executive secretary, who in turn would be responsible for donor relations and staffing. The supervisors would also provide adjudication for dispute resolution, by the formation of 3-person panels whose decisions could be appealed to the full body. And of course the board could also choose to revise the rules, by majority or supermajority voting.

It is expected that supervisors would be working on a very part-time basis, as if they were outside directors of a private firm. They would receive compensation for time spent on the secretariat and in the dispute-resolution panels. Money management would not be a significant part of the supervisors' responsibility, as donors could disburse their prizes directly to recipients, or place funds in escrow with a third party such as the World Bank. The supervisors would, however, be expected to assist the executive secretary in fund-raising to support the secretariat itself, for operating costs and technical support or small grants to prize applicants, and to underwrite lines of credit for prize awards.

Design question #10: *Magnitude* -- How big might prizes become?
The proposed mechanism would cost on the order of $500,000 per year to implement, on the basis of an executive secretary and two staff economists, based at a U.S. university but traveling heavily. Their tasks would focus on publicizing prize offers, assisting groups to apply, and adjudicating awards. An additional $200,000 per year might be spent on further technical assistance and small grants to support prize applications.

That level of fixed costs could be justified with as little as $1 million per year in prize disbursals, but it seems likely that once core funding is secured and the secretariat is established, other donors would also find the mechanism attractive and would underwrite additional lines of credit for prizes in their area of interest. The same secretariat could readily handle up to $10 million per year in disbursals.

For example, one might expect to see the following purely illustrative examples, targeting technologies for:

(a) cotton farmers, underwritten by the textile, garment or retail industries;
(b) cocoa or coffee growers, underwritten by confectioners and food manufacturers;
(c) food quality or quantity, underwritten by nutrition-oriented philanthropies;
(d) the poorest regions, underwritten by DfID and others; or
(d) specific target countries, underwritten by USAID and others.

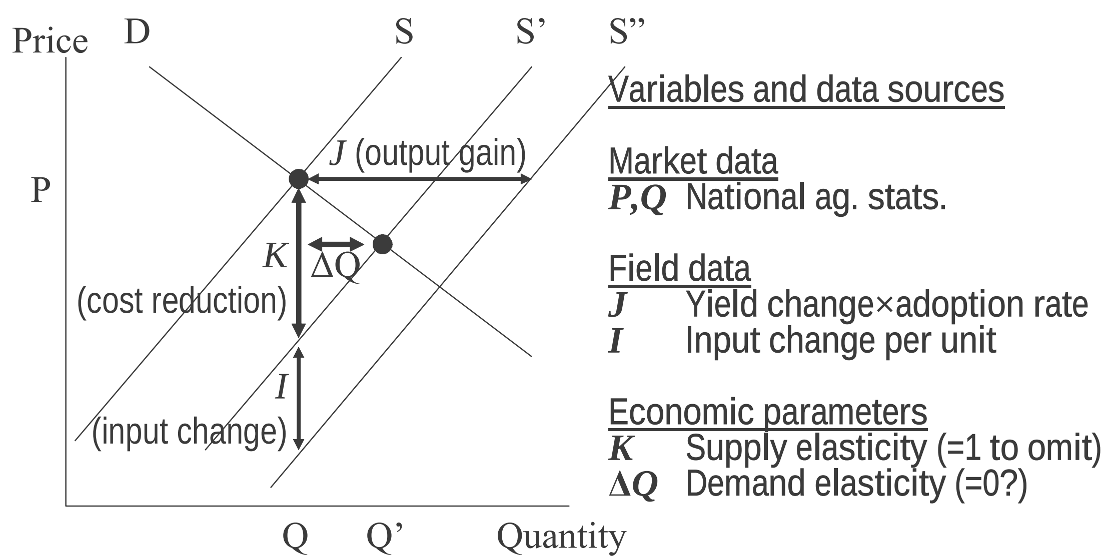
Once a prize secretariat was established and gained a successful track record, however, it seems likely to benefit from strong scale and reputation effects, so that other donors would be attracted into using that same framework.

3.3 Underpinnings of the proposal: impact assessment methodology

Add details – The approach consists of estimating the spillover economic surplus gain from adoption of a given technology in a given market for a given time period, including a projection of continued adoption 3 years forward. In summary, this requires estimating, in each period for which a prize is claimed:
(a) an output and input change per unit of production (*j*) using controlled experiments;
(b) an adoption rate (*a*) and local prices for output (*P*) and inputs using a farm survey;
(c) total production in the adoption domain (*Q*) using survey or census data;
(d) the change in output supply from adoption (*J*) by combining (a), (b) and (c);
(e) the change in input costs from adoption (*I*), by combining (a), (b) and (c).

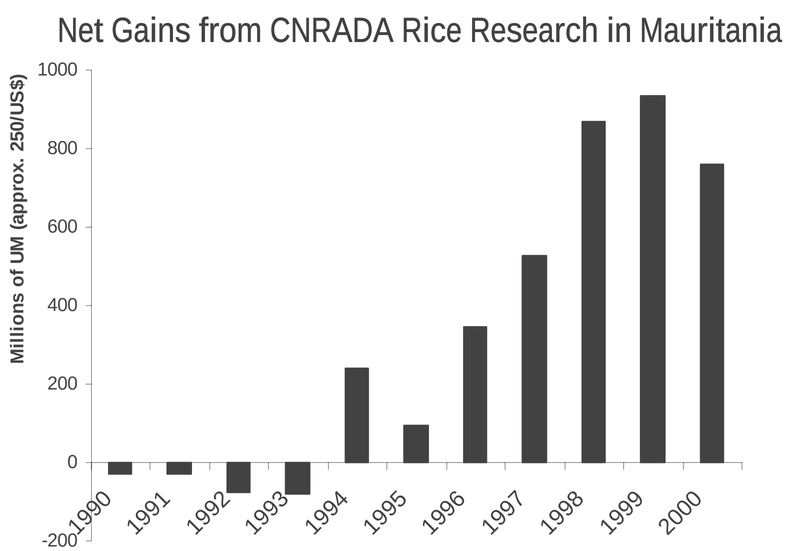
All of these data are locally verifiable by random site visit from the prize secretariat staff. Having subtracted the change in input costs (*I*) that include payments for marketed inputs as well as labor or other non-marketed inputs, the resulting economic-surplus calculation can be interpreted as spillover economic surplus gain if we assume that the supply elasticity = 1 and demand elasticity = 0. Relaxing this assumption would have the advantage of giving deservedly greater weight to innovations that raise productivity where supply is more inelastic, but it has the disadvantage of relying on data that are not easily verifiable, so on balance it is preferable to use the simpler rule. A forward projection of 3 additional years of continued benefit is desirable, however, to limit the frequency with which a given research program would need to apply for prizes.

Figure 1. Data needed to estimate annual value of an innovation



3.4 An example calculation

Add details – These data were collected and analyzed for an impact study of public investment, in a way that is similar to how prize proposals might be assembled. Data collection and analysis was completed by a Mauritanian scientist, using about $2500 in funding and the methods taught in the INSAH-Purdue workshops on impact assessment. The rate of return on Mauritania's investment in importing, testing and disseminating improved rice varieties from Senegal was found to be 68% and the Net Present Value of the program was about US$14 million. If these data had been submitted as a prize application in 2002, and then verified by a site visit and confirmation survey, they might have led to an award on the order of $3m. to be shared amongst various agencies in Mauritania and Senegal.



Source: Bah, Moctar Sidi (2001), « Impact économique de la recherche et de la vulgarisation sur le riz irrigué en Mauritanie ». Paper presented at the INSAH-Purdue workshop on the economic impacts of agricultural research, 22-26 July 2002. Available online at
http://www.agecon.purdue.edu/staff/masters/ImpactCD/Etudes/EtudesInfo.htm

Bibliography

Analysis of Prizes and Patents

Abramowicz, Michael (2003). "Perfecting patent prizes." *Vanderbilt Law Review* 56 (1, January): 114-263.

Bloch, Erich, Paul G. Kaminski, David C. Mowery, Daniel M. Tellep and Robert S. Walker (1999), *Concerning Federally Sponsored Inducement Prizes in Engineering and Science: Report of the Steering Committee for the Workshop to Assess the Potential for Promoting Technological Advance through Government-Sponsored Prizes and Contests*. Washington, D.C.: National Academy of Engineering (November). http://books.nap.edu/books/NI000221/html/R1.html Last accessed August 8, 2004.

Calandrillo, Steve P., (1998). "An Economic Analysis of Intellectual Property Rights: Justifications and Problems of Exclusive Rights, Incentives to Generate Information, and the Alternative of a Government-Run Reward System." *Fordham Intellectual Property, Media & Entertainment Law Journal* 301(9, Autumn).

Davis, Lee N, and Jerome Davis (2004). "How Effective Are Prizes as Incentives to Innovation? Evidence From Three 20th Century Contests." Draft paper: http://www.druid.dk/ocs/viewpaper.php?id=114&cf=1 Last accessed August 8, 2004.

Davis, Lee N, (2002). "Should We Consider Alternative Incentives for Basic Research? Patents vs. Prizes". Draft paper: http://www.druid.dk/conferences/summer2002/Papers/DAVIS.pdf Last accessed August 8, 2004.

Graff, G., & Zilberman, D. (2001). "An intellectual property clearinghouse for agricultural biotechnology." *Nature Biotechnology*, 19(12): 1179-1180.

Hollis, Aidan, (2004). "An Efficient Reward System for Pharmaceutical Innovation." http://econ.ucalgary.ca/hollis.htm.

Horrobin, D. F., (1986). "Glittering prizes for research support." *Nature* 324:221.

Kremer, Michael, (1998). "Patent Buy-Outs: A Mechanism for Encouraging Innovation." *Quarterly Journal of Economics* 113(4, November): 1137-1167.

Kremer, Michael, (2001). "Creating Markets for New Vaccines," in Adam Jaffe, Joshua Lerner and Scott Stern, eds., *Innovation Policy and the Economy* (Volume 1). Cambridge: The MIT Press.

Kremer, Michael and Alix Peterson Zwane, (2002). "Encouraging technical progess in tropical agriculture." http://are.berkeley.edu/courses/envres_seminar/zwane.pdf

Lerner, Josh, (2002). "Patent protection and innovation over 150 years." NBER Working Paper no. 8977. Cambridge, MA: NBER.

Macfie, R. A., (1869). *Recent Discussions on the Abolition of Patents for Inventions*. London: Longmans, Green, Reader, and Dyer.

Macfie, R. A., (1883). *Copyright and Patents for Inventions, vol. II., patents.* Edinburgh: T. & T. Clark.

MacLeod, Christine, (1988). *Inventing the Industrial Revolution*. Cambridge: Cambridge University Press.

Malchup, Fritz and Edith Penrose, (1950). "The Patent Controversy in the Nineteenth Century." *The Journal of Economic History* 10(1, May): 1-29.

Nalebuff, Barry J. and Joseph E. Stiglitz, (1983). "Prizes and Incentives: Towards a General Theory of Compensation and Competition." *Bell Journal of Economics* 14(1, Spring): 21-43.

National Academy of Engineering, (1999). "Concerning Federally Sponsored Inducement Prizes in Engineering and Science." http://www.nap.edu/books/NI000221/html/ Last accessed June 20, 2004.

Scotchmer, Suzanne, (1991). "Standing on the Shoulders of Giants: Cumulative Research and the Patent Law." *Journal of Economic Perspectives* 5(1, Winter): 29-41.

Shavell, Steven and Tanguy van Ypersele, (2001). "Rewards versus Intellectual Property Rights." *Journal of Law and Economics*, XLIV (October): 525-548.

Wright, Brian D, (1983). "The Economics of Invention Incentives: Patents, Prizes, and Research Contracts." *The American Economic Review* 73(4, Sept): 691-707.

Weisbrod, Burton (2003). "Solving the Drug Dilemma." *Washington Post* (Aug. 22: page A21). http://www.washingtonpost.com/wp-dyn/articles/A29306-2003Aug21.html

The role of agricultural innovation in sustainable economic development

Alston, Julian M., Michele C. Marra, Philip G. Pardey and T.J. Wyatt (2000), "Research returns redux: a meta-analysis of the returns to agricultural R&D." *The Australian Journal of Agricultural and Resource Economics,* 44(2, June): 185-215.

Byerlee, Derek and Ruben G. Echeverria (2002). *Agricultural research policy in an era of privatization*. Wallingford, UK: CABI.

Hayami, Yuhiro and Vernon W. Ruttan (1985). *Agricultural Development: An International Perspective*. 2nd ed. Baltimore: Johns Hopkins University Press.

Meinzen-Dick, Ruth, Michelle Adato, Lawrence Haddad and Peter Hazell (2003), "Impacts of Agricultural Research on Poverty: Findings of an Integrated Economic and Social Analysis." EPTD/FCND Discussion Paper No. 111/164. Washington DC: IFPRI.

Moschini, GianCarlo, Harvey Lapan and Andrei Sobolevsky (2000). "Roundup ready soybeans and welfare effects in the soybean complex." *Agribusiness*, 16: 33-55.

Thirtle, Colin, Lin Lin and Jenifer Piesse (2003), "The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America." *World Development*, 31(12, December): 1959-1975.

Background on methodology for agricultural impact assessment

Textbooks and training materials

J.M. Alston, G.W. Norton and P.G. Pardey, 1995. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting* (Ithaca, NY: Cornell University Press).

Masters, William, 1996. *The Economic Impact of Agricultural Research: A Practical Guide, with spreadsheet exercises.* Also available in French. Distributed by CD-ROM and website: http://www.agecon.purdue.edu/staff/masters/ImpactCD/Manuel/ManuelInfo-English.htm

Selected publications using the proposed methodology

Ahmed, Mohamed, William Masters and John Sanders (1995), "Returns from Research in Economies with Policy Distortions: Hybrid Sorghum in Sudan", *Agricultural Economics* 12: 183-192.

Bedingar, Touba and William Masters (1999), "The Impact of Agricultural Research: A Synthesis of Findings and Policy Implications for the Sahel", *Les Monographies Saheliennes* No. 9 (Institut du Sahel, Bamako, Mali), 36 pages.

Edwin, James and William Masters (1998), "Returns to Rice Technology Development in Sierra Leone", *Etudes et recherches sahéliennes/Sahelian Studies and Research* (Institut du Sahel, Bamako, Mali), no. 1 (June): 67-74.

Fisher, Monica, William Masters and Mamadou Sidibé (2000), "Technical change in Senegal's irrigated rice sector: impact assessment under uncertainty", *Agricultural Economics*, 24(2): 179-197

Masters, William, Touba Bedingar and James F. Oehmke (1998), "The Impact of Agricultural Research in Africa: Aggregate and Case Study Evidence", *Econonomics*, 19(1-2): 81-86.

Masters, William and Samba Ly (2002), "INSAH-Purdue Workshops on the Economic Impact of Agricultural Research in the Sahel: Compilation of Results." CD-ROM. West Lafayette, IN and Bamako, Mali: Purdue and INSAH. Also online, at: http://www.agecon.purdue.edu/staff/masters/ImpactCD/ImpactInfo.htm

History of specific prize programs

Personal Recognition Prizes

Kreeger, Karen Young, (1999). "Eye on the Prize: The Influence of Awards on Careers." *The Scientist* 13(23, Nov):24.

Encyclopædia Britannica, (2004). "The Nobel Prize." Encyclopædia Britannica Online. http://search.eb.com/eb/article?eu=57415 Last accessed Aug 6, 2004.

MacArthur Foundation, (2004). "2003 MacArthur Fellows Program Overview." http://www.macfdn.org/programs/fel/fel_overview.htm Last accessed Aug 6, 2004.

Science Service, (2004). "About the Intel STS." http://www.sciserv.org/sts/about Last accessed Aug 6, 2004.

Zuckerman, Harriet (1992). "The Proliferation of Prizes: Nobel Complements and Nobel Surrogates in the Reward System of Science," Theoretical Med., 13:217–31.

Webster, Valerie J., ed. (2004), *Awards Honors & Prizes* (24th ed., 2 vols.). Farmington Hills, MI: Gale Group.

Longitude Prize

Andrewes, William J. H., ed., (1993). *The Quest for Longitude*. Cambridge, MA: Collection of Historical Scientific Instruments, Harvard University.

Quill, Humphrey (1966). *John Harrison the Man who found Longitude*. London: Baker.

Quill, Humphrey, (1963). "John Harrison, Copley Medalist, and the £20,000 Longitude Prize." *Notes and Records of the Royal Society of London* 18(2, Dec): 146-160.

Sobel, Dava (1995). *Longitude*. New York: Walker and Company.

18th & 19th Century French Prizes

Burke, James, (1978). *Connections*. Boston: Little, Brown and Company.

Cotte, Michel, (2001). "La diffusion de l'innovation durant la première industrialisation. Les actions publique et associatives, les revues périodiques." Paper for the International Festival of Geography, Saint-Dié des-Vosges. http://xxi.ac-reims.fr/fig-st-die/actes/actes_2001/cotte/article.htm

Gillispie, Charles C., (1957). "The Discovery of the Leblanc Process." *Isis* 48(2, June):152-170.

Kiefer, David, (2002). "It was all about alkali." *Today's Chemist* 11(1, Jan):45-46,49.

McGrayne, Sharon Bertsch, (2002). *Prometheans in the Lab*. New York: McGraw-Hill.

Reilly, Desmond (1951). "Salts, Acids, & Alkalis in the 19th Century. A Comparison between Advances in France, England & Germany." *Isis* 42(4, Dec):287-296.

Aviation Prizes

Berg, A. Scott, (1998). *Lindbergh*. New York: G. P. Putnam's Sons.

Corn, Joseph J., (2002). *The Winged Gospel: America's Romance With Aviation*. Baltimore: John's Hopkins University Press.

Hallion, Richard P., (2003). *Taking Flight: Inventing the Aerial Age from Antiquity Through the First World War*. New York: Oxford University Press.

Maryniak, Gregg, (2001). "When will we see a Golden Age of Spaceflight?" Draft article. http://www.xprize.org/papers/XP-CATO-Maryniak.5Mar01.doc

The New York Times. "Puts up$25,000 for Paris Flight" p. 1. May 30, 1919.

The New York Times. "Feel Paris Flight Will Soon be Made" p. 2. May 31, 1919.

The New York Times. "Mail Pilot Files Entry for Paris Flight" p. 16 March 1, 1927

Ranfranz, Patrick, ed. "Raymond Orteig-$25,000 prize." *Charles Lindberg: An American Aviator*. http://www.charleslindberg.com/plane/orteig.asp

Villard, H.S., (1987) *Contact: The Story of the Early Birds*. Washington: Smithsonian.

Human Powered Flight

Carley, William M., (1972). "MIT Students Have An Idea, but Will It Get Off the Ground?" *The Wall Street Journal* (Dec. 1):1.

Carlson, Shawn, (1997). "The Lure of Icarus." *Scientific American* (October): 116-119.

Downie, Leonard, (1979). "Pedal-Driven Plane Flies Channel." *Wash. Post* (June 13):A1.

Space Prizes

Aldridge, E. C. "Pete", Jr., Chairman, (2004). "A Journey to Inspire, Innovate, and Discover." Report of the President's Commission on Implementation of United States Space Exploration Policy, (June). http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf Last accessed July 25, 2004.

Ansari X Prize. http://www.xprize.org Last accessed June 25, 2004.

Schwartz, John, (2004). "Manned Priveate craft Reaches Space in a Milestone for Flight" New York Times, June 22, 2004. http://www.nytimes.com/2004/06/22/science/space/22PLAN.html Last accessed June 25, 2004.

Space Frontier Foundation. "The Cheap Access to Space (CATS) Prize." http://www.space-frontier.org/Projects/CatsPrize/ Last accessed July 25, 2004.

Rockefeller Foundation Prize for STI Diagnostics

Mabey, David, Rosanna W. Peeling, and Mark D. Perkins, (2001). "Rapid and simple point of care diagnostics for STIs." *Sexually Transmitted Infections* 77:397-398.

Super Efficient Refrigerator Program

Clinton, William J. and Albert Gore, Jr. (1993) *The Climate Change Action Plan*. "Case Study: The Super Efficient Refrigerator Program" http://www.grico.org/USCCAP/case_kitchen.html Last accessed August 3, 2004.

Results Center, The, (1994). *Super Efficient Refigerator Program Profile #106*. http://sol.crest.org/efficiency/irt/106.pdf Last accessed August 4, 2004.

Math and Computer Science Prizes

American Go Association. "The Ing Chang-Ki Education Foundation." http://www.usgo.org/ingfoundation/index.html Last accessed August 4, 2004.

Loebner Prize, (2004). "Loebner Prize Home Page." http://www.loebner.net/Prizef/loebner-prize.html Last accessed August 6, 2004.

US Atomic Energy Act Patent Compensation Board

Lee, Sabing H., (1997). "Protecting the Private Inventor Under the Peacetime Provisions of the Invention Secrecy Act." *Berkeley Technology Law Journal* (12:2) http://www.law.berkeley.edu/journals/btlj/articles/vol12/Lee/html/reader.html

Riesenfeld, Stefan A., (1958). "Patent Protection and Atomic Energy Legislation." *California Law Review* 46:40.

Scherer, F. M., (1980). *Industrial market structure and economic performance* (2nd Ed). Chicago: Rand McNally College Pub. Co.

Sinnot, John P., (1988). *World patent law and practice*, Vol. 2M. New York: Matthew Bender.

42 U. S. C. §2187

Code of Federal Regulations: Title 10, part 780

Soviet Innovation Incentive Awards

Hughes, Francis, (1945). "Soviet Invention Awards." *The Economic Journal* 55(218/219, June-Sept): 291-297.

Hughes, Francis, (1946). "Incentive for Soviet Initiative." *The Economic Journal* 56(223, Sept):415-425.

Annex: summary table of major prize awards, 1714-present

Prize	Goal	Period	Prize Amount	Source of Funding	Disbursal Authority	Winner
Longitude Prize	Reliable way of finding longitude at sea.	1714-1773	Up to £20,000	Government of the United Kingdom	Longitude Board	John Harrison
French Alkali prize	Artificial means of producing alkali soda.	1775 – 1789	2400 livres	Government of France	Académie des Sciences	None – regime was overthrown in 1789
Napoleonic Prize for Bottled Food	Technique for preserving food in bottles.	1802-1809	12,000 francs	Government of France	Society for the Encouragement of National Industry	Nicolas Appert
Various aviation prizes	Various aviation feats.	1901-1940	Millions of dollars	Various	Various	Various
Wolfskehl Prize	Proof of Fermet's last theorem.	1908 – 1997	£30,000	Paul Wolfskehl	Göttingen Academy	Andrew Wiles
Orteig Prize	New York to Paris non-stop flight.	1919-1927	US $25,000	Raymond Orteig	National Aeronautical Association	Charles A. Lindbergh
Polytechnische Gesellscaft Prize for Human Powered Flight	500m controlled human-powered flight.	1933 – 1935	5,000 – 10,000 marks	Polytechnische Gesellscaft	Polytechnische Gesellscaft	Not won.
Kremer Prize for Human Powered Flight	One mile figure-eight controlled human-powered flight.	1959-1977	£5,000-£50,000	Henry Kremer	Royal Aeronautical Society	Paul B. MacCready, Jr. and team.

Annex: summary table of major prize awards, 1714-present

Prize	Goal	Period	Prize Amount	Source of Funding	Disbursal Authority	Winner
Kremer Prize for Human Powered Flight	Human-powered flight across the English Channel.	1959-1977	£100,000	Henry Kremer	Royal Aeronautical Society	Paul B. MacCready, Jr. and team.
Rockefeller Foundation Prize for Rapid STD Diagnostic Test	Rapid and inexpensive point of care STD diagnostic test.	1994-1999	US $1,000,000	Rockefeller Foundation	Rockefeller Foundation	Not won.
X Prize	Commerically developed manned flight to 100 km altitude.	1995-present	US $10,000,000	The New Spirit of St. Louis Foundation	Ansari X Prize Foundation	No winner so far.
FCC Pioneer Preference Program	Development of communications services.	1991-1997	Telecommunications spectrum (worth, probably, hundreds of millions of dollars)	U.S. Federal Communciations Commission	FCC	Various telecommunications companies.
Super Efficient Refrigerator Program	Highly efficient, CFC free refrigerator.	1994-1997	$30,000,000	24 Utilities which created the S.E.R.P.	S.E.R.P. Board	Whirlpool Corporation
CATS Prize	Inexpensive commercial launch of payload in to space.	1997-2000	$250,000	Anonymous Donor	Space Frontier Foundation	No winner.

Annex: summary table of major prize awards, 1714-present

Prize	Goal	Period	Prize Amount	Source of Funding	Disbursal Authority	Winner
International Computer Go Championship	Computer program that can beat human at the game Go.	Late 1990s – present	$1.6 million	Ing Chang-Ki Wei-Ch'i	Ing Chang-Ki Wei-Ch'I Foundation	No winner so far.
Loebner Prize	Computer that can pass the Turing test.	1990	$100,000	Dr. Hugh Loebner	Dr. Hugh Loebner	No winner so far.
Electronic Frontier Foundation Cooperative Computing Challenge	New large prime numbers.	1999 – present	$50,000 - $250,000	Anonymous Donor	Electronic Frontier Foundation.	One winner for a 1 million+ digit prime number. ($50,000).
Feynman Prizes	Feats in nanotechnology	1996 – present	$250,000	Foresight Institute	Foresight Institute	No winner so far.
Millennium Math Prizes.	Seven unsolved problems in mathematics	2000 – present	$7 million ($1 million each)	Clay Mathematics Institute	Clay Mathematics Institute	No winners so far.