Promoting Innovation to Solve Global Challenges

Opportunities for R&D in agriculture, climate change, and health

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A Report to the German Marshall Fund of the United States
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1 Introduction

Technological innovations arguably have an important role to play in addressing global challenges such as poverty, climate change, and the current food crisis. A variety of public policies exist which aim to increase incentives for innovation. Such policies can be broadly classified into two categories: "push" programs and "pull" programs. Push programs subsidize research inputs through means such as government subsidies to university-based research, or tax credits for research and development (R&D) investments. Pull programs, on the other hand, increase the rewards for developing specific products by committing to reward successful innovations conditional on their development.

Push programs and pull programs each have advantages and disadvantages. In practice, R&D systems in high-income countries utilize a combination of up-front push funding together with pull mechanisms that reward successful innovation. In the United States, for example, government organizations such as the National Institutes of Health (NIH) support basic research, while private sector firms are incentivized to translate the results of basic research into usable products by the promise of market protection that is generated by Intellectual Property Rights (IPR) systems such as patents and copyrights. For R&D needs that are specific to low-income countries, fewer R&D incentives are in place—particularly few for pull-type incentives.

IPR systems such as patents are one type of pull incentive. The core idea of patents is to provide incentives for innovation by allowing patent owners to sell their products at a monopolist price, above manufacturing costs, thereby allowing patent owners to make a profit sufficient to recoup the costs of their R&D investments. One advantage of this type of IPR is that it creates a rough link between rewards and value—in the sense that a patent owner who creates a "better" product (in the sense of being more desirable to consumers) will typically be able to realize higher sales (and thus, higher profits) than if the same patent owner had put less effort into creating a product with characteristics desired by consumers. However, a disadvantage of this type of IPR is that the creation of these incentives comes at the cost of restricting access to innovations. That is, because patents make goods more expensive to consumers, at the margin some goods will not be used even when the social value would exceed the cost of production.

Alternative reward mechanisms can potentially mitigate this trade-off between promoting innovation and maximizing access to innovations once they are developed. In this paper, we focus on several examples of how such alternative aid mechanisms could be applied to the context of development aid to benefit low-income countries. Innovative pull mechanisms can complement the set of more traditional foreign aid mechanisms, resulting in an expanded and more flexible set of tools for addressing development policy goals. Many such pull programs could be implemented by multi-donor collaborative efforts, such as the Advance Market Commitment (AMC) mechanism that is being supported by Italy, the United Kingdom, Canada, Norway, and Russia together with the Bill & Melinda Gates Foundation. Experimentation with various forms of pull mechanisms would be valuable and greater cooperation among American, European, developing country, and other policymakers in designing and implementing such mechanisms could accelerate learning and help inform public policy decisions to address global challenges.

This paper discusses various aspects of alternative reward mechanisms that can promote R&D but restrict access to less than "traditional" IPR systems. In Section 2, we discuss how such mechanisms could either be voluntary for IPR holders, and thus supplement existing IPR systems, or be

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mandatory, and thus substitute for existing IPR systems. In Section 3, we discuss various types of potential triggers for rewards: fulfillment of technical specifications set *ex ante* (Section 3.1), measures of *ex post* use such as willingness-to-pay or impact (Section 3.2), and *ex post* decisions made by a judging committee (Section 3.3). We argue that a combination of these features will often be desirable, and that the ideal balance is likely to depend on the technological setting. We then discuss three examples of cases in which such pull mechanisms may be successfully applied: vaccines for so-called "neglected" diseases concentrated in low-income countries (Section 4), agricultural innovations appropriate for low-income tropical country climates (Section 5), and technologies to address climate change and global warming (Section 6). Section 7 concludes and emphasizes the potential role for experimentation with alternative pull mechanisms in developing new tools for encouraging innovations.

2 Voluntary versus mandatory institutions

Public policies to provide additional pull incentives could either be voluntary (supplementing the IPR system that is currently in place) or be mandatory (being alternative to the IPR system that is currently in place). To clarify these options, it is worth reviewing an example of each of these types of pull programs.

One type of voluntary pull incentive is a patent buyout mechanism. As discussed in Kremer (1998), an example of the application of such a patent buyout mechanism is the case of the Daguerreotype process for photography, invented by Louis Jacques Mande Daguerre in 1837. In 1839, the French government purchased the patent for the Daguerreotype photography process and subsequently made the technique freely available in the public domain. Following this patent buyout, Daguerreotype photography was rapidly adopted worldwide and the technology was greatly improved.

Such a patent buyout corrects the under-provision of R&D without imposing monopoly pricing, while also allowing private firms to determine the direction of research themselves (as is the case under the current patent system). Patent buyouts can also be helpful in addressing the so-called "patent thicket" problems that arise in cases where it is overly costly for firms to make investments in improving a particular technology due to concerns about (real or potential) conflicts with existing patents. Kremer (1998) proposes a price mechanism for patent buyouts in which the private value of patents is determined using an auction.

An example of a mandatory pull incentive is a proposal for a Medical Innovation Prize Fund. As an example of such a prize fund proposal we mention the proposal described by Love (2005). In this proposal, the patent system would be in place through the process of product development and market approval. However, rather than rewarding new products through market exclusivity, generic companies would be allowed to freely compete and developers of new products would be financially rewarded through payments from the Medical Innovation Prize Fund. Love (2005) proposes that such payments could be based on the incremental health benefits of new products.

Voluntary programs such as the patent buyout mechanism would supplement the current IPR system, and thus increase the total available incentives for R&D (since if the price in a voluntary program was set low enough such that firms would realize lower revenue if they chose to participate than they would realize if they chose not to participate, presumably firms would select out of participating in the voluntary pull program). Mandatory programs such as the Medical Innovation Prize Fund proposal would be alternative to the current IPR system, and whether the incentives provided by such an alternative system would be higher or lower than the level of incentives provided by the current IPR system would be a function of the design of the prize fund proposal.

An issue arising with mandatory programs is that of how to apportion credit across multiple, collaborating firms. Typically, many patents and pieces of work go into a single innovative product. Under the current IPR system, a variety of contracts are undertaken across organizations to apportion rewards to individual firms which contribute to a given product, such as licensing agreements. In such contexts, a mandatory system would need to address how the financial payments provided under such a system would be divided across firms.

The remainder of this paper focuses on voluntary pull mechanisms which would supplement the current IPR system.

3 Potential triggers for rewards[1]

In an ideal world, pull programs would credibly commit to reward appropriate innovations, but at the same time would not commit sponsors to have to pay for innovations that end up not being useful or desirable.

In designing pull programs, a central design issue is the choice of what will trigger reward payments. In an ideal world, pull programs would credibly commit to reward appropriate innovations, but at the same time would not commit sponsors to have to pay for innovations that end up not being useful or desirable. Alternative triggers for reward payments are one way in which these goals can be traded off. In this section, we discuss three potential triggers for reward payments: fulfillment of technical specifications set *ex ante* (Section 3.1), measures of *ex post* use such as willingness-to-pay or impact (Section 3.2), and *ex post* decisions made by a judging committee (Section 3.3).

To motivate the discussion, we look at the example of a prize offered by the British government to encourage the development of a method for determining longitude. In 1707, English navigators on a fleet of five ships misjudged longitude and ran aground about twenty miles from the English shore. Many similar tragedies occurred over this time period due to mariners' inability to determine longitude while at sea, and in this case over two thousand lives were lost. To attempt to find a solution to this "Longitude problem," the British government offered a prize of £20,000 for a method of determining longitude within a half of a degree.

The Board of Longitude expected astronomers and mathematicians to develop a solution through celestial observations of the positions and motions of heavenly bodies, but in fact the solution was developed by a clockmaker named John Harrison. The clockmaker developed a timepiece that was sufficiently accurate to determine time at the port of departure even on rolling ships—specifically, by comparing time at the port of departure to local time (which is easily ascertained in good weather by observing the sun), longitude could be determined. It took 12 years to prove the worth of the chronometer and reward the inventor with his prize. In her popular book on the subject, Sobel (1996) argued that these delays were unnecessary; others have argued that the Board of Longitude was justified in requiring these tests.

Several lessons can be drawn from this example. On the one hand, this example suggests that such prizes can in fact stimulate research and the development of important products. On the other hand, the difficulty the clockmaker had in collecting his prize arguably suggests that it is very important to think carefully about what reward triggers are most appropriate for a given situation. Prizes seeking to induce innovation should specify solutions and not methodologies, and in places where committees are used to determine reward payments clear conditions and the process for judging the merits of candidates should be well specified in advance.

Below, we discuss three potential triggers for reward payments in more detail. We argue that a combination of the design features—fulfillment of technical specifications set *ex ante* (Section 3.1), measures of *ex post* use, such as willingness-to-pay or impact (Section 3.2), and *ex post* decisions made by a judging committee (Section 3.3)—will often be desirable, but that the way they should be balanced is likely to depend on the technological setting.

3.1 *Ex ante* technical specifications

One reward trigger mechanism with a long history—for example, for prizes offered in the fields of mathematics and aviation—is that of offering rewards for fulfillment of a set of technical specifications that are defined *ex ante*.

An example of such a prize in the field of mathematics is the Wolfskehl Prize, which was established in 1908 to reward the first person to prove Fermat's Last Theorem—a famous mathematical puzzle that had been posed in the 17th century. The prize initially attracted amateurs—none of whom succeeded—but little attention from serious mathematicians, who reportedly considered the problem to be intractable. Finally, in 1997, the prize was awarded

[1] Many of the examples in this section are drawn from Kremer and Glennerster (2004).

to Princeton professor Andrew Wiles for his proof of Fermat's Last Theorem.

An example from the field of aviation is the series of Kremer prizes, established in 1959 by Henry Kremer to encourage innovation in human-powered flight. The first Kremer Prize of £50,000 was awarded in 1977 for the human-powered aircraft to fly a figure eight. Two later Kremer prizes for human-powered flight were also awarded, and several others remain as yet unawarded.

In 1919, a New York hotel owner offered another aviation prize of $25,000 for the first person to fly across the Atlantic, nonstop between Paris and New York. Although numerous pilots attempted and failed, 25-year-old Charles Lindbergh designed and supervised the construction of the "Spirit of St. Louis," complete with huge fuel tanks, longer wings, and a new location for the seat. The novel design led to his famous first solo flight across the Atlantic in 1927.

Aviation prizes have also been offered in more recent times. The Ansari X Prize offered a $10 million prize for the first nongovernment organization to launch a reusable manned spacecraft into space twice within two weeks. The prize was awarded in 2004, and similar subsequent prizes were later announced—including the Archon X Prize in 2006, the Automotive X Prize in 2006, and the Google Lunar X Prize in 2007.

Fulfillment of technical specifications is likely very appropriate for contexts such as mathematical prizes in which sponsors can very clearly describe in advance what they are looking for (as for vaccines, as discussed in Section 4), or in contexts such as aviation prizes in which sponsors are primarily looking to spur a successful demonstration project as opposed to spurring the development of a commercially viable product. In other cases, such as for the Post-It Note or the GUI (Graphical User Interface) technology, sponsors likely could not have described the product specifically enough in advance to have had this type of reward trigger be useful. For many types of technologies, choosing to solely use fulfillment of technical specifications as a basis for reward payments (rather than combining this reward trigger with another type of mechanism) through attempting to write down completely exhaustive technical specifications *ex ante* might result in projects specifications that are either too tight or too loose, and which are not sufficiently flexible to spur innovation on the desired product.

3.2 Metrics of *ex post* use, willingness to pay, or impact

One issue with basing pull mechanism reward payments solely on technical specifications set *ex ante* is that products may be developed which in a strict sense meet the technical specification but for some reason are not desirable to consumers. The Kremer prizes for human-powered flight, for example, were primarily intended to provide incentives for demonstration projects—not for the production of commercially useable products. Although demonstration projects may be the explicit goal of some pull programs, for pull programs that aim to spur the development of products desirable to consumers it may often be useful to base reward payments at least in part on some measure of *ex post* valuation of the product by consumers.

One issue with basing pull mechanism reward payments solely on technical specifications set ex ante *is that products may be developed which in a strict sense meet the technical specification but for some reason are not desirable to consumers.*

An example of how reward payments can be based on *ex post* use will be covered in Section 4, in the context of AMCs for vaccines for diseases concentrated in low-income countries. It is worth noting that although basing reward payments in part on some measure of *ex post* use can be useful in many contexts, several features of vaccines ease the implementation of this mechanism. For example, in many contexts, measuring *ex post* use may not be straightforward. In the case of vaccines used in low-income countries, these vaccines are largely purchased through a centralized system (namely, through UNICEF), where the use of vaccines can be tracked relatively easily. In other technological contexts, such measures may often not be available.

3.3 *Ex post* discretion by a committee

An alternative payment trigger for pull programs is to give a committee discretion to award payments *ex post*. It is worth noting that using *ex ante* technical specifications as a reward trigger will almost always need to be combined in practice with some sort of committee to decide when the technical specifications have been met; the question is just how much discretion such a committee should have. For example, a committee with full discretion is used to award the Nobel Prizes; other cases use committees but give them more limited discretion within bounds set *ex ante*.

Although rewards based completely on *ex post* discretion by committee may be appropriate for awarding Nobel Prizes, in most settings it may be useful to combine committee decisions with either fulfillment of some technical specifications set *ex ante* (thus providing some scope for *ex post* judgment within some specifications set in advance) or to combine committee decisions with a market test mechanism. One broad issue that can arise in the context of *ex post* discretion by committee is that a committee may have incentives to reward based on different criteria *ex ante* relative to *ex post*. For example, *ex ante* the committee may want to reward innovation, but *ex post* the committee may prefer to reward the individuals who have made the most substantial scientific advances rather than those who made more applied "tweaks" even if these tweaks were critical to producing a useable product, or prefer to reward those individuals who might make the best use of the prize money going forward.

Committees may also use *ex post* discretion to "raise the bar," such as arguably occurred in the longitude example. One way to address this issue is to require that the committee award a certain amount of money within a given time frame—as is the case with architectural contests, for example, where a committee must choose a winner to award a given contract to by a specified deadline.

A combination of the design features described above will often be desirable, but that the way they should be balanced is likely to depend on the technological setting. On the first point, using combinations of the design features avoids putting too much weight on any one feature. For example, if sponsors gave a committee full discretion they may be tempted to award the reward payments to projects that do not fulfill the originally intended goals of the program sponsors. On the other hand, attempting to write down completely exhaustive technical specifications *ex ante* might result in projects specifications that are either too tight or too loose and are not sufficiently flexible. On the second point, the balance of appropriate design features is likely to differ across fields because some fields—say, mathematics—are such than sponsors will be able to very precisely specify in advance what they wish to reward (such as the proof of a specific mathematical conjecture). On the other hand, in other fields it may be necessary to use more vague specifications and leave a committee with some discretion to interpret whether a given project has satisfied the goals of the program. In some fields it is relatively easy to obtain a measure of *ex post* use and impact—as in the case of vaccines, as we discuss below in Section 4; in other areas such measures are often not available.

To clarify some of these issues, below we discuss three examples of cases in which such pull mechanisms may be fruitfully applied: vaccines for so-called "neglected" diseases concentrated in low-income countries (Section 4), agricultural innovations appropriate for low-income tropical country climates (Section 5), and technologies to address climate change and global warming (Section 6).

4 Health innovations

One form of a pull mechanism is the Advance Market Commitment (AMC), which has been proposed primarily in the context of vaccines for so-called "neglected" diseases—such as malaria—that are concentrated in poor countries.

Relative to the social need, there is a dearth of R&D on vaccines and other health technologies for diseases concentrated in poor countries. Private biotechnology and pharmaceutical firms that seek to maximize profits are reluctant to invest in R&D for such diseases if they fear they may be unable to sell the resulting vaccines at prices that would cover their risk-adjusted costs. Low anticipated prices reflect not only the poverty of the relevant populations but also at least two distortions that exist in markets for these vaccines. First, governments and other institutions that buy vaccines for these diseases face time-inconsistency problems—in the sense that although *ex ante* governments want to encourage firms to invest in R&D on these technologies, once the technologies are developed governments and other international organizations have an incentive to bargain for very low prices so as to use limited budgets to expand access to these technologies to as broad of populations as possible. To the extent that firms anticipate such low prices, firms will be deterred from making the necessary R&D investments in the first place. Second, as with R&D on other technologies, the knowledge generated by R&D on these diseases is an international public good—and because the benefits of this R&D will spill over to many nations, none of the many small countries that would benefit from R&D on vaccines for diseases like malaria has an incentive to encourage research by unilaterally offering to pay higher prices.

AMCs are one type of pull mechanism which attempts to address these market failures. Under AMCs, one or more sponsors (such as governments in rich countries, or private foundations) legally commit themselves in advance to underwrite a guaranteed price for a maximum number of pre-defined purchases of a needed product (such as a malaria vaccine)—conditional on its development, a market test mechanism to assure the product is desired by its target consumers, and the product meeting a set of technical specifications set *ex ante* (the meeting of these specifications is determined by an independent committee). This higher guaranteed price provides an economic return for developers of the product, and in exchange these developers agree to a cap in the long-run price that they charge for the product. If no suitable product is developed, no AMC payments would be made.

This type of pull mechanism attempts to decouple the goals of incentives for innovation and access to technologies conditional on their development, and aims to promote both. The AMC structure outlined above addresses access in the short-run (through the topped-up payments) as well as in the long-run (through the capped price).

Like other pull mechanisms, AMCs do not require sponsors to make decisions about which technological approaches are most promising or whether it is technically feasible to produce the product at all. The sponsor simply says how much society is willing to pay for a vaccine and lets the private sector compete to produce it. If no product is developed there would be no cost to the public sector. On the other hand, if a desired vaccine is developed, an AMC would be an extremely cost-effective expenditure from a public health perspective, saving more lives than virtually any comparable direct health expenditure (see Berndt et al. 2007).

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AMCs include a market test mechanism in that the reward to the company is not paid simply for developing a product that meets a set of technical specifications, but rather is tied to actual adoption and use of that product. This provides incentives

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for companies to focus their R&D efforts on products that would actually be used, rather than focusing on producing a product that somehow fits a set of pre-determined technical specifications but is not a good fit with what developing countries need or want. To take a concrete example, there are different technological approaches to developing malaria vaccines. Some of them might provide only short-run protection whereas others are more likely to provide long-run protection. The first type of malaria vaccine would be useful to the military and travelers who would make up a large share of the commercial market for a vaccine. The second type would be more suited to protect the one million people who die of malaria each year in developing countries. Requiring that the product is something developing countries want to use is a way to incentivize firms to develop appropriate products.

A number of governments—Italy, the United Kingdom, Canada, Norway, and Russia—together with the Bill & Melinda Gates Foundation recently announced a $1.5 billion pilot AMC for a pneumococcal vaccine suitable for children in the developing world. U.K. Prime Minister Gordon Brown has suggested that this be the first in a series of AMCs to encourage the development of vaccines against diseases affecting the developing world. While there has been some interest in the United States in the AMC concept (it is, for example, part of the U.S. Senate version of the reauthorization of the President's Emergency Plan for AIDS Relief, or PEPFAR), it has not joined the effort to date.

Annually, pneumococcal diseases kill more than 1.6 million people including up to one million children under the age of five. In developed countries, child deaths from pneumococcal diseases are rare, but in developing countries they are a leading cause of child mortality. Pneumococcal vaccines for adults have existed for some time but it is important to protect children as well, both because of the high death toll among children and because children are important in spreading the disease. A pneumococcal vaccine that protects children against some strains of bacteria has been available in the United States for several years, but a version of the vaccine is needed which covers strains of the disease that are more common in the developing world. The technological challenge involved in developing a new version of the pneumococcal vaccine which covers these strains is modest relative to that involved in developing a malaria vaccine or an HIV vaccine, and several firms are already working on developing such pneumococcal vaccines.

There are some important differences between how an AMC should work for technologically distant targets and for technologically closer targets, like a pneumococcal vaccine. For a product like a pneumococcal vaccine, much of the R&D is done, and the challenge is primarily one of figuring out what price it will take to get one of a small number of specific firms that have expertise in the area to construct large-scale capacity to serve the world's poorest countries as well as the rich- and middle-income world. This price is likely to be well above cost, because firms are very averse to having excess capacity that not only wastes resources, but also could put downward pressure on prices in middle- and high-income markets that represent a different order of magnitude of potential revenue.

For technologically distant targets, policymakers are not trying to guess about the cost structure and willingness to build capacity of a few specific firms, but rather to set a price that would correspond to the value society would put on a vaccine, so as to attract a socially efficient amount of research effort to the search for a vaccine. Setting the price is not so much a matter of trying to peer into the minds of individual pharmaceutical executives as it is one of determining the price at which a new vaccine would be cost effective relative to other health expenditures. Since the R&D effort on many technologically distant targets is likely to be far below the optimal amount, the danger of paying "too much" for such a product seems less acute.

Another difference relates to whether donors should guarantee some portion of demand. A general principal of contracting or mechanism design is that whoever is best placed to affect a risk should, all else equal, bear that particular risk. Once a product has already reached the stage where pneumococcal vaccines currently are, the donor community has more opportunity to influence demand—implying demand guarantees may be beneficial. For earlier stage products, firms still have opportunities to affect product characteristics and thus should bear more risk—implying demand guarantees would be less appropriate.

For a technologically close product, like a pneumococcal vaccine, it is fairly clear what a product will look like, and the main problem is to incentivize capacity construction. Firms will be more inclined to build capacity if they know they will be able to sell an amount which will utilize that capacity, and donors may thus be able to get away with a slightly lower price if they guarantee demand. On the other hand, it would not make sense to guarantee demand for a vaccine that is still very technologically distant, since otherwise a firm might wind up creating a vaccine that complies with a list of technical specifications, but that no countries would want, and donors might wind up having to buy the vaccine. For technologically distant products, donors to AMCs arguably should condition payments on countries being willing to use the product and some buyer being willing to make a modest co-payment (as proposed above), so as to create incentives for firms to develop vaccines countries will want. Once a particular product is developed, and the problem shifts to one of capacity construction, donors could then move into a phase in which they would guarantee a portion of demand. AMCs could also specifically be linked to capacity installation by firms.

If an AMC for a pneumococcal vaccine can significantly cut the historically typical 10–15 year lag between the introduction of vaccines in the developed world and their widespread use in poor countries, it will save millions of lives and constitute an extremely cost-effective health expenditure. This pilot AMC for a vaccine for pneumococcal diseases may also help to lay the groundwork for future AMCs for other vaccines.

5 Tropical agriculture innovations

The private sector has been playing an increasingly important role in agricultural R&D over time, but incentives are lacking for private firms to focus their efforts on innovations needed specifically in tropical areas.

The recently observed rapid increases in food prices have heavily burdened the poor in low-income countries, who spend a large portion of their household income on food. Organizations such as the World Bank have responded with policy proposals that include supplying poor countries with seeds and fertilizers. However, just as private sector R&D on medical technologies is largely directed towards technologies with viable markets in rich countries, private sector R&D on agricultural technologies also tends to focus on products with markets in rich countries. The private sector has been playing an increasingly important role in agricultural R&D over time, but incentives are lacking for private firms to focus their efforts on innovations needed specifically in tropical areas.

As discussed more thoroughly in Kremer and Zwane (2004), poor countries have distinct agricultural needs that are not currently being met. The R&D needed for tropical agriculture is distinct from that for temperate countries for several reasons. Some staple crops grown in tropical countries, such as cassava and millet, are neither grown nor imported by rich countries on a significant scale (Binenbaum *et al.* 2003). Tropical countries have distinct agro-ecological systems, including higher average temperatures, relatively fragile soils, a lack of a seasonal frost, and ecozone specific weeds and pests (Masters and Wiebe 2000). Climatic zone-specific productivity constraints mean that advances in maize productivity in temperate countries cannot be immediately transferred to tropical regions—a phenomenon indicative of the fact that agricultural technologies tend to "spill over" more easily within ecological zones than between them (Diamond 1997, Johnson and Evenson 2000). The types of technologies most useful in poor countries are also often different from the technologies useful in rich countries, because farming in poor countries often takes place on a small scale, is not mechanized, and is less likely to be fertilized.

Increases in agricultural productivity hold great promise for low-income countries, both because agriculture tends to comprise a large share of their national economies and because of the widespread undernourishment that persists in many of these countries. Several new types of agricultural innovations hold promise to address these issues—such as pest-resistant seeds, drought- or saline-resistant seed varieties, or nutritionally enhanced plant varieties (such as the so-called "golden rice" that is rich in Vitamin A). Yet, as discussed in Kremer and Zwane (2004), many important agricultural R&D advances have failed to translate into adoption and productivity increases in low-income countries, particularly in Africa.

Most private agricultural R&D is concentrated on pursuing technologies appropriate for use in rich counties. A key market failure inhibiting developers from recovering the cost of R&D in agriculture is the potential for resale of seeds: specifically, if farmers can sell seed (as well as reuse it) competition among sellers will drive seed prices close to marginal cost, eliminating the possibility for the seed developer to recoup R&D costs and thus eliminating most of the incentive for R&D investment. In rich countries, resale for some products is at least imperfectly prohibited; but in poor countries prohibiting resale is more difficult because farmers are dispersed across small, often remote plots and seeds are frequently sold in small amounts in rural markets.

Experimentation with pull mechanisms for a number of agricultural technologies with high potential returns for use in poor countries is very promising. Kremer and Zwane (2004) highlight several technologies which may be fruitful targets. One potential target technology is finger millet blast-resistant seed. Finger millet blast, or pyricularia blight, is a fungus that affects a staple crop grown throughout the middle elevations of Eastern and Southern Africa as well as South

Asia, and can reduce yields by more than 50 percent—sometimes as much as 90 percent. Kalil (2006) proposes some other potential technological targets, including disease-resistant bananas, cassavas, and millets; heat-tolerant wheat; maize with increased protein content; drought-resistant sorghum; and sheep and goats resistant to intestinal parasites.

Since a major stumbling block in translating technological advances into increases in agricultural productivity is the adoption of new technologies among farmers, pull programs that tie rewards to adoption may be especially useful. One strategy would be to pay-out pull program rewards on the basis of total hectares planted with seeds using the particular technology each year. Payments could be based on a percentage of the market price of millet grown using seeds that contain the new technology, which may be appealing since prices should embody at least some information about how farmers and consumers value the technology.

6 Climate change innovations

Pull mechanisms could also be applied in the context of technologies to address global warming and climate change.

Pull mechanisms could also be applied in the context of technologies to address global warming and climate change. The U.S. government has recently begun to support energy prizes, such as the so-called "H-prizes" to accelerate the emergence of a hydrogen economy. Similarly, the Automotive X Prize, offered by the X Prize Foundation, is intended to increase innovation of efficient vehicles. This prize is awarded to teams that win a stage race for clean vehicles (primarily defined as meeting or exceeding 100 miles per gallon or equivalent fuel economy) that are designed to reach the market, as judged based on safety, cost, features, and business plan. Other such prizes have also been proposed—for example, U.S. Republican presidential candidate John McCain proposed a $300 million prize to spur the development of a more efficient battery to power future hybrids and electric cars.

Kalil (2006) proposes the use of AMC-like prizes in several areas related to energy and climate change, including power storage, storage for off-peak wind-generated energy, advances in solar cells, and net zero energy consumption appliances.

Another potential target for a climate change-related pull mechanism would be technologies to reduce industrial greenhouse gas emissions, such as coal plant smokestacks—so that industrial plants are "carbon neutral" (that is, having zero net emissions of greenhouse gases) or even "carbon negative" (that is, removing more greenhouse gases than they produce). Wald (2008) discusses the example of a coal plant that could capture and store carbon dioxide. Such a plant could have zero emissions, producing pollution-free hydrogen as fuel and pumping carbon dioxide underground for permanent storage. Such a plant could become carbon negative by deriving carbon dioxide from biomass—since plants or trees pull carbon dioxide from the atmosphere as they grow, and the gasification and storage of such biomass would take that carbon out of circulation.

A related set of technologies pull programs could target is carbon sequestration technologies, which capture and securely store carbon that would otherwise be emitted to or remain in the atmosphere. Such carbon sequestration technologies can either capture carbon dioxide at its source (such as from power plants), or remove carbon from the atmosphere directly.

It is worth noting that the appropriate pull program design characteristics would like vary across specific technologies, even within the broad category of energy/climate change technologies. For example, demand for energy efficient cars would likely depend on a number of features—appearance, price, distance that can be traveled without refueling, etc.—and so it would likely be important to base pull program reward payments at least in part on a market test mechanism as with the vaccine AMC as discussed above. On the other hand, rewards for technologies such as carbon sequestration could potentially be based on an output that could be more easily specified in advance—such as a price per ton of carbon captured and sequestered.

The potential usefulness of some of these proposed energy and climate change-related technologies has been debated, but arguably such situations are especially good fits for pull programs. A key benefit of pull programs is that money changes hands only if a successful product is developed, so sponsors need not worry that they will invest millions in a project that may ultimately fail. Individual scientists and firms working on the specific scientific problems involved are best placed to judge the scientific prospects: if they judge the scientific prospects to be worthwhile they can invest time and resources pursing projects, and if not they can invest their time and effort elsewhere.

It is worth noting that climate change-related pull programs also offer important potential benefits to low-income countries, many of which arguably have more limited capacities to address climate change and yet may be more vulnerable to its impacts.

7 Conclusions

Pull mechanisms such as AMCs could join other tools for stimulating research like the patent system and the peer review system. Experimentation with various pull mechanism structures would likely be of very high value in attempting to refine and develop these new types of incentive structures. It is worth noting that it took time for institutions such as the patent system or the peer review process to evolve into their current forms. These institutions, which today we think of as integral to supporting our systems of innovation, required time as well as trial-and-error to develop.

As an example for the patent system, since the first U.S. Patent Act was put in place in 1790, rules have developed on what is allowed to be patented, who is allowed to file patents, for how long patents should be held, etc. Likewise, the peer review progress has made tremendous progress over time. Weller (2001) discusses how prior to World War II, editors frequently made all decisions themselves with only informal advice from colleagues, and that only recently has the paradigmatic "editor plus two referees" system become widespread (Rowland 2002). Work by individuals such as Vannevar Bush, who lobbied for the evaluation of scientific research by scientists, not government officials, led to the establishment of the modern system of federally-supported peer-review institutions for decision-making on federal funding for scientific research in the United States.

While the immediate outcomes of such pull mechanisms would be the potential development of new vaccines for neglected diseases, new agricultural technologies for tropical climates, or new technologies to address climate change, an additional outcome would be the development of a new tool for stimulating R&D. Such pull mechanisms would provide a valuable complement to the set of more traditional foreign aid mechanisms, and many such pull programs could be implemented by multi-donor collaborative efforts. Greater transatlantic and global cooperation in designing and implementing such mechanisms could accelerate learning and help inform public policy decisions to address global challenges.

Greater transatlantic and global cooperation in designing and implementing such mechanisms could accelerate learning and help inform public policy decisions to address global challenges.

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