# Pulling Agricultural Innovation and the Market Together

**Kimberly Ann Elliott**

## Abstract

Feeding an additional three billion people over the next four decades, along with providing food security for another one billion people that are *currently* hungry or malnourished, is a huge challenge. Meeting those goals in a context of land and water scarcity, climate change, and declining crop yields will require another giant leap in agricultural innovation. The aim of this paper is to stimulate a dialogue on what new approaches might be needed to meet these needs and how innovative funding mechanisms could play a role. In particular, could "pull mechanisms," where donors stimulate demand for new technologies, be a useful complement to traditional "push mechanisms," where donors provide funding to increase the supply of research and development (R&D). With a pull mechanism, donors seek to engage the private sector, which is almost entirely absent today in developing country R&D for agriculture, and they pay only when specified outcomes are delivered and adopted.

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*Three of every four poor people in developing countries live in rural areas…and most depend on agriculture for their livelihoods*.
World Bank, 2008 World Development Report

*Agriculture in the 21st century faces multiple challenges: it has to produce more food, feed and fibre for a growing population with a smaller rural labour force, more feedstocks for a potentially huge bioenergy market, contribute to overall development in agriculture-dependent developing countries, adopt more efficient and sustainable production methods and adapt to climate change.* UN Food and Agricultural Organization, 2009.

**Introduction**

Feeding an additional three billion people over the next four decades, along with providing food security for another one billion people that are *currently* hungry or malnourished, depends on using every available tool to raise agricultural productivity, reduce poverty, and strengthen safety nets to cushion the impact of future shocks. Ensuring food security requires a range of policy responses, but, in the face of growing threats from land and water scarcity, climate change, and declining crop yields, new and improved tools to stimulate agricultural innovation and the adoption of new technologies are clearly needed.

Given the scope of the challenges, reversing the decline in donor support for agriculture in poor countries is the first step, but donors also need to find ways to leverage the resources and harness the energy of the private sector. Doing the latter, however, requires the reversing the current situation, where agricultural R&D by the private sector is virtually nonexistent in developing countries because of market failures that make it difficult for them to recoup up-front costs in developing new products.

This paper explores how "pull mechanisms," where funders stimulate demand for new technologies, could be a useful complement to traditional "push mechanisms," which provide funding to increase the supply of research and development (R&D). Pull mechanisms help to solve the information asymmetries between donors and researchers that complicate traditional push funding for R&D. Engaging the private sector and linking donor payments to adoption also encourages innovators to pay close attention to what farmers need and want. There are many mechanisms for engaging the private sector in innovation for developing countries, but the focus here is on those where donors pay only when specified outcomes are delivered *and* adopted.

The encouraging news is that donor neglect of the agricultural sector in developing countries ended with the spike in food prices in 2008. In L'Aquila, Italy, in 2009, G-8 leaders pledged to provide $20 billion for agricultural development and food security in coming years. That is a welcome step in reversing the fall in the share of bilateral official development assistance (ODA) for agriculture from 17 percent in 1980 to just 4 percent in 2003. Multilateral assistance dropped even more (WDR 2008, Pardey et al., 2006). Within aid to agriculture, support for public research and development (R&D) also slowed in the 1990s and in Africa, which never really experienced a green revolution, public spending declined.

The decline in public investment in agriculture was, in part, due to the fact that commodity prices, on average, declined for decades and many thought the food problem had been solved. Cyclical factors played an important role in the spike in food price in 2007-08, but the crisis also underscored the longer-term demand and supply factors, exacerbated by climate change, that could cause a reversal in the downward trend—population growth, rising incomes, biofuel production, growing land and water scarcity, and declining yield growth. Even in the face of growing needs, however, increased funding to meet these needs will only be sustained if donors can show that it is being used effectively.

The plan of the paper is as follows. The first section looks at why public support for agricultural R&D is needed, where the gaps are, and what we can learn from where the green revolution did and did not succeed. The second section contrasts push mechanisms, which focus on the supply side of R&D, with pull mechanisms, which engage the demand side, and identifies conditions where pull mechanisms can be helpful in overcoming market failures. The third section presents a framework for assessing the potential of pull mechanisms to contribute to agricultural innovation needs.

**Market Failures in Innovation *and* in Developing Countries**

Innovation is a classic public good and market forces alone typically fail to induce a socially optimal level of innovative activity. This is both because innovation produces spillover benefits that innovators cannot fully appropriate, and because production costs are often well below the up-front costs of research and development. If the inventor must compete with copycats that sell at a price just covering production costs, and she cannot recoup those up-front investment costs and make a profit, then innovation will be under-supplied and society will be worse off.

A common solution to these market failures is to grant innovating firms patents, or other forms of intellectual property rights (IPR), that give them a period of market exclusivity during which they can sell products at prices above competitive levels. Governments adopt this approach in many situations because, relative to direct government funding of R&D, patents allow the private sector to make decisions on investments guided by information from markets about what consumers want and are willing to pay for. The reliance on market mechanisms also opens the potential rewards of innovation to all and avoids the danger that incentives will be limited to those individuals, institutions, or ideas that may be in political favor at a given time.

But other market failures can undermine the effectiveness of the IPR approach in some situations. For example, where R&D costs are high and market demand for new technologies is uncertain, patents may be insufficient to attract private investment. This is often the case with basic research, where the information generated is crucial for subsequent innovation but commercial applications are not immediately obvious. This is also a situation that often arises in developing countries that are small and poor, meaning that innovations adapted to their special needs may not generate sufficient profit to attract private-sector investment. The problem of small size is often compounded by governments that make their technology licensing decisions nationally rather than supranationally.

Relative to most other sectors, agriculture presents greater challenges for inventors trying to appropriate the benefits of their efforts. For crops that are self-pollinating, for example, farmers can re-use seed from year to year, making it difficult for inventors to enforce patents and recoup their costs. Thus, in the United States in 2000, the private sector accounted for 72 percent of all R&D spending, but only 55 percent in the agriculture sector. Within agriculture, private sector R&D tends to focus on areas where the benefits are more easily appropriable, such as hybrid seeds that have to be replaced every year or two, chemical inputs, and machinery (Pardey and Alston 2010, pp. 6, 9).

In areas of research where intellectual property rights are not sufficient to allow innovators to capture the fruits of their labor, governments often rely on direct funding of R&D to subsidize the development of technologies they expect to have large social returns. While this traditional approach is and will remain an important part of the R&D landscape, it raises other dilemmas related to what economists call principal-agent problems. Kremer and Zwane (2004, pp. 92-93), for example, note that asymmetric information is a problem between donors and researchers and that the incentives of donors and researchers may not be aligned. Making research grants ex ante, when donors have incomplete information, can lead to wasted resources if donors pick the wrong "winner" among various proposed approaches to a problem. Kremer and Zwane also point to the risk that R&D allocations can become politicized, again wasting resources.

Common alternatives to public subsidies to encourage socially beneficial innovation include regulatory mandates and taxes or other price-based mechanisms, such as feed-in tariffs for renewable energy use by utilities. The focus of this paper, however, is on how public and private donors could complement traditional "push mechanisms" with innovative, demand-based, pull mechanisms that pay ex post for agricultural innovations aimed at developing countries.

### *Under-investment in agricultural R&D for developing countries*

If patents and other protections for intellectual property traditionally used in rich countries are less powerful for agriculture than for other sectors, they are even less helpful in stimulating innovation in developing countries. Low-income countries, even when they are added together (excluding China and India), constitute a market that is often too small and poor to make large R&D investments profitable. In African agriculture, the obstacles are even larger because there are many staple crops that are not demanded in significant quantities elsewhere.

Annex table 1 shows the main sources of calories in developing country regions. Wheat, rice, and maize, which are also widely grown and consumed in rich countries, account for most of the staple grains consumed in South and East Asia. But in sub-Saharan Africa, those grains account for just under a third of calories consumed, on average, while sorghum and millet, along with starchy roots such as cassava, make up another third. Private seed companies have little incentive to invest significant sums in developing improved varieties for these minor crops because the expected market would be too small to recoup the costs. Annex table 2 tells a somewhat more complicated story, with maize and rice being relatively important in many parts of Africa, but also showing large yield gaps relative to the rest of the world, including key countries in Asia. The latter suggests that inattention to Africa-specific crops is not the only reason that the green revolution failed there, an issue to which I return in a moment.

Given these challenges, it is no surprise that the share of private investment in total agricultural R&D spending in developing countries was only 2 percent in 2000 and just 5 percent of private R&D spending was in developing countries. Public sector spending on agricultural R&D in developing countries increased 50 percent from 1981 to 2000, and the developing-country share of the total also increased, from 38 percent of the total to 43 percent. But, these investments are slowing, with average annual growth rates down from 3 percent in the 1980s to just 1.9 percent in the 1990s, a decade when public spending in Africa declined (Bientema and Stads 2008).

According to the UN Food and Agricultural Organization, food production will have to increase 70 percent by 2050 to keep up with a global population expanding by 50 percent to 9 billion (United Nations 2009). Given the physical and environmental constraints on increasing land and water use, productivity will have to increase substantially to meet the demand. Moreover, research suggests that investments to improve agricultural productivity make economic sense. A meta-survey of published rates of return on investments in agricultural R&D and extension services found an overall average return of over 40 percent, though the individual estimates varied widely. The average for investments in sub-Saharan Africa was just below the overall average, in the mid-30s (reported in WDR 2008, pp. 165-66).

***Lessons from the Green Revolution and the non-revolution in Africa***

Perhaps public investment in agricultural R&D declined because people thought the problem had been solved. The R&D-based green revolution of the 1960s and 1970s sharply raised agricultural productivity in Asia, but it largely bypassed Africa. Moreover, yield growth is slowing in Asia as well and there are growing concerns about the environmental consequences four decades into the green revolution. Thus the revolution needs to be renewed and adapted to reflect concerns about climate change, water scarcity, pollution and health threats, and lagging progress in Africa.

In general, among the priorities for research in the face of these constraints are:

- New farming techniques that reduce (or do not increase) carbon emissions and that conserve water.

- Replacements for or improved efficiency of energy and resource-intensive fertilizers.
- Safer pest control methods, whether chemical, biotech, or through management practices.
- Storage and processing technologies to reduce post-harvest losses.

In Africa, despite some progress in recent years, the adoption of improved crop varieties remains well below the levels in most other developing regions. Among the key reasons for this are (adapted from Minot 2008):

- Different staple products that are not widely consumed outside Africa, including millet, sorghum, and cassava; the Green Revolution focused mostly on maize, wheat, and rice, which are relatively less important in Africa as staples.
- Different agro-ecological conditions—climate, soil, and eco-zone specific weeds, pests—mean that varieties developed elsewhere are not easily adapted for African conditions.
- Different farming technologies that do not work as well with improved seed varieties
    - Mostly rain-fed—only a small percentage of the land in Africa is irrigated.
    - Low fertilizer use because of costs due to small scale, transportation.
- Soil depletion, which makes chemical fertilizers less effective.
- Land abundance in some areas, and weak property rights in others, lowers the incentive for farmers to invest in more intensive agriculture.
- Lack of access to markets also undermines the incentive for intensification in some areas.

Concentrated efforts to increase agricultural productivity have succeeded at some times in some countries in Africa, but often only with government subsidies. When those subsidies proved unsustainable and were withdrawn, farmers often abandoned the new technologies or methods and the gains were reversed. In 2009, a Norwegian university released an impact assessment, commissioned by the Norwegian Agency for Development Cooperation, examining whether farmers in Tanzania were still using technologies introduced earlier to promote food security and higher household incomes for smallholders. The study found that some technologies were still in use and some had even spread to neighboring villages, but many others had been wholly or partially rejected (Johnsen et al. 2009). The reasons listed in the study for rejecting new technologies included:

- Did not yield benefits under unfavorable weather conditions, especially drought
- Unavailability of an introduced technology.
- Did not match farmers' priorities or meet their preferences (e.g., for taste).
- Inputs associated with technology were too expensive.
- Increased labor requirements were not commensurate with benefit.

And the final reason that farmers in this experiment rejected new technologies was the "lack of available markets where the farmers' products achieved attractive prices."

Overall, the technologies rejected in this analysis did not meet the market test of producing benefits large enough to offset additional costs. That is exactly the test that demand-based, pull mechanisms are designed to force innovators to pass.

## Inducing Agricultural Innovation

The section above discussed the reasons that traditional, IPR-based approaches have not worked well in stimulating agricultural innovation for developing countries. It also discussed some of the reasons that traditional push mechanisms, which involve donors paying *ex ante* to increase the supply of R&D, are not always as effective as they might be. For those reasons, and because the private sector has a lot to offer in the fight against food insecurity and rural poverty, the remainder of the paper focuses on pull mechanisms. A key feature of these mechanisms is that they aim to engage the private sector in research in developing countries where traditional IPRs are either weak or not valuable enough to generate interest. A second feature is that they seek to alleviate information asymmetries, both between donors and researchers and between researchers and consumers by making payments for technologies *ex post*, when they are adopted.[1]

The key difference between push and pull approaches is summarized in Spielman et al. (2006):

> Incentive mechanisms can be categorized as those that either reduce the costs of R&D and promote basic research to encourage spillovers (push mechanisms) or those that increase the expected returns to R&D by improving or creating favorable market conditions (pull mechanisms).

Both types of mechanisms are needed and this paper does not suggest that push mechanisms should disappear. Public funding of basic science and early research is essential to provide information to other researchers that can then be developed into specific applications. There are also situations where "R&D performance is observable with clear milestones and quality assurance" where push mechanisms work well (Masters 2008, p. 8). Thus, push and pull mechanisms should be considered complementary rather than competing approaches to agricultural innovation.

Pull mechanisms are particularly useful in situations where funders and researchers do not have access to the same information, where it is difficult to identify the best path to an innovation and therefore to set benchmarks or observe the quality of the research while it is ongoing. Pull mechanisms generate information about what works and free donors from having to pick "winners" for research grants based on imperfect information about the best scientific approach.

[1] Pull mechanisms aimed at engaging the private sector in innovation for developing countries are a subset of performance-based mechanisms for delivering foreign aid more effectively. See Savedoff (forthcoming).

Asymmetric information between funders and researchers also makes it difficult to align incentives between those two groups. For example, ex ante funding may lead researchers to undervalue features that are important to the final consumer, especially if the researchers are employed in the public sector and do not anticipate private gains from an innovation. Thus, a number of agricultural innovations that worked well in experiments were not embraced by farmers in the field. In addition to the examples in the Norwegian study cited above, Kremer and Zwane (2004, p. 93) describe several others, including an improved variety of sweet potato that Ugandan farmers rejected because it was redder than the local variety. By putting the onus on innovators to ensure that the final product meets the needs of consumers—by linking payments to the level of demand—donors can partially address the asymmetric information between researchers and consumers and increase the prospects for broad adoption.

Pull mechanisms can also generate competition and harness the energies and leverage the resources of the private sector, particularly in the development phase and in taking research to the market. For example, if there is sufficient competition in the market, a tax credit for electric vehicles incorporates market feedback into its incentive and pushes the inventor to continually improve the product in order to capture a larger share of the market.

So which specific pull mechanisms might be appropriate to stimulate agricultural innovations for developing countries? In 2003, the Center for Global Development convened a working group made up of economists, public health professionals, lawyers, and pharmaceutical and biotech experts to analyze potential mechanisms for inducing commercial investment in vaccine development. A summary of the pros and cons of twelve different options analyzed by that group is contained in table 2.1 of their final report (Levine et al. 2005). Of those twelve, many involve various tweaks to existing patent systems that do not resolve the IPR challenges in developing countries.

Only five of the twelve alternatives examined by the CGD working group involved donor funding to pull private sector investment in innovation for developing countries: advance market commitments; patent buyouts; prizes; proportional prizes; and best entry tournaments. Prizes and best entry tournaments share the weakness that they are likely to be winner-take-all, which could undermine broad access to and adoption of the technology if the winner has a monopoly over production. Winner-take-all approaches also can foster competition of a “race to patent” type, which can result in duplication of research efforts but not post-award competition to stimulate pressures for continued product improvements. Patent buyouts could be helpful in situations where there are potential spillovers from rich country R&D, but they will not stimulate innovation to meet specific developing country needs. Levine et al. (2005) and Masters (2008) discuss the weaknesses and strengths of other approaches.

As the CGD working group concluded with respect to vaccines, advance market commitments (AMC) also seem to offer significant advantages over other pull mechanisms for agricultural innovation, at least in some areas. By engaging the private sector, it puts “decisions about which avenues to pursue and which to abandon… in the hands of those with the biggest stake and with the most knowledge about the prospects for success" (Levine et al. 2005). And by creating a market for a product with uncertain demand, it mobilizes additional resources for late-stage development and production costs, including for meeting safety, environmental, or other regulatory requirements that must be met before release of improved technologies.

As pointed out in Masters (2008, p. 11), however, designing an AMC requires being very specific about the characteristics of the desired technology and that is not always possible when the goal is improving agricultural productivity in the real world, where there are many unknowns. He, therefore, recommends proportional prizes to generate information about what actually works in an environment as difficult and diverse as African agriculture. This approach, however, rewards incremental innovation, and still leaves the question of how socially beneficial innovations will be scaled up and brought to market more broadly. If the process reveals potentially profitable opportunities that the private sector had previously just missed, then firms may choose to invest with no further public action needed. But if there are other market failures, then additional public interventions may be needed.

Both AMCs and proportional prizes free donors from having to pick winners in advance and they pay only for demonstrated results. As with push and pull mechanisms, these two types of pull mechanisms are complementary rather than competing and it is possible to imagine the two mechanisms being used in conjunction with one another. For example, a proportional prize might be used to identify innovations that produce the largest productivity gains in a particular area, and then, if demand is still too uncertain for the private sector to invest, an advance market commitment could be designed to provide incentives to scale up production and more broadly disseminate the results. Table 1 summarizes the advantages and risks of these two pull mechanisms while the following sections turn to some of the issues involved in designing a pull mechanism to address real world problems.

<table>
<tr><th colspan="2">Table 1 Broad comparison of proportional prizes and advance market commitments</th></tr>
<tr><th>Advantages</th><th>Risks</th></tr>
<tr><td colspan="2">Proportional Prizes</td></tr>
<tr><td>• Provide an incentive to the public and private sector to generate evidence on successful innovations, measured by both productivity improvement and degree of adoption.<br>• Award process requires revelation of information on innovation that can then be disseminated more broadly.<br>• Innovations will be adapted to local conditions and thus more readily adoptable.<br><br>Useful for identifying sources of productivity improvement where key mechanisms unknown.</td><td>• If the technology is patentable, access may depend on patent buy-out or compulsory licensing to ensure broad affordability.<br>• Interventions to scale up production and distribution may also be needed.<br>• Uncertainty regarding value of prizes may deter investment.<br>• May reward innovations that would occur anyway.<br>• Depending on scale, auditing and verification costs can be high.<br><br>In the beginning, more likely to “pull” information than new innovation.</td></tr>
<tr><td colspan="2">Advance Market Commitments</td></tr>
<tr><td>• Create a link between product quality and revenues that accrue to developer.<br>• Create a market for improved products and continual progress.<br>• Ensure access to new products in both the short and long run.<br>• Require sponsors to pay only if a desired product is developed<br><br>Most appropriate where characteristics of desired technology are known and can be specified in contract.</td><td>• Promises to pay must be credible.<br>• Must be designed to cover appropriate products.<br>• In agriculture, with atomistic, and in Africa undeveloped, markets for inputs, design needs to address distribution.<br><br>Difficult to apply where markets and distribution systems are undeveloped.</td></tr>
</table>

***Proportional prizes***

A proportional prize, as developed by William Masters (2008), avoids the problems associated with winner-takes-all prizes by making rewards proportional to the measured impact of any successful innovation. The specific proposal by Masters was developed for sub-Saharan Africa and he argues that the proportional prize is particularly well-adapted for promoting innovation to improve agricultural productivity there for two reasons: 1) the technologies that will do the most to improve farm productivity often are not predictable in advance and will also often have to be adapted to local conditions, and 2) productivity impacts can be measured using relatively accessible data on outputs, inputs, prices, adoption rates, and production.[2]

In Masters' general scheme, donors would set an overall prize amount which would then be divided among applicants who could compile evidence showing the impact of their innovation. These claims would be verified through an independent audit and the total prize amount divided among successful applicants according to the proportional value of the innovation. An audit by prize managers is required to verify the data submitted by applicants, focusing on three elements:

- the incremental value of the productivity improvement, measured as the value of increased output minus the cost of increased inputs;
- the revealed value to farmers, measured by adoption rates; and,
- evidence that the productivity gains are attributable to the innovation through verification of controlled experiments in the field.

In a specific recent proposal for Africa, he proposes a continent-wide fund of $12 million that would be used to reward productivity-improving innovations using any technology, wherever they occur, with individual rewards based on the estimated dollar value of the improvement that can be attributed to a particular innovation. The total prize fund would be $5 million per year over two years, with $2 million used to administer the prizes. The awards would be widely publicized with the expectation that successful innovations that could be scaled-up and adopted more widely—whether locally, nationally, or regionally—would attract additional investment and thus spread the benefits (communication with author).

If appropriable, the scaling up investment might come from the private sector, but that could raise questions about access for poorer producers. Alternatively, some additional public intervention might be needed to ensure broad access.

[2] Note that, in the scheme proposed by Masters, this would not be official data collected by government agencies that are often weak and underfunded, especially in developing countries. Rather, the data would typically be local, not national, and it would be generated or collected by those competing for prizes and then would be audited by prize administrators.

***Advance market commitments***

In situations where desirable characteristics of a new technology are known, for example a nutrient-fortified staple food crop or a new or improved storage technology, then an advance market commitment from donors, to ensure there will be a sufficiently remunerative market for the resulting product, can be useful. A problem in many developing countries is that potential purchasers are too poor, and markets too small, to provide a reasonable assurance that R&D costs will be recouped. A commitment by donors to pay an above-market price up to a certain number of units of a new product demanded by consumers reduces this risk. As discussed in detail in Levine et al. (2005), an AMC could be used either for an early stage product, such as a malaria vaccine, to spur new innovation, or at a later stage, such as with the existing pneumococcal vaccine initiative, to stimulate adaptation and the construction of new production facilities. Another key element of the AMC idea is to ensure long-term access by requiring suppliers to continue to supply the product at an affordable price for some period after the donor commitment ends.

A key advantage of an AMC for donors is that, because it is demand-driven, donors pay only for innovations that are adopted and only to the degree that they succeed in the marketplace. The aforementioned Norwegian analysis of the factors behind adoption or rejection of agricultural innovations in Africa found that farmers would reject improved crops that did not have the taste or cooking properties of varieties with which they were familiar (Johnsen et al. 2009). Under an AMC, the private sector has an incentive, and the expertise, to develop a product that meets consumer preferences.

How an AMC for agriculture might work in practice can be explored by examining efforts to use the mechanism to stimulate production of vaccines adapted to developing-country conditions and diseases. As with agricultural technologies, the private sector ignores those markets because they are too small and poor, and thus too risky, to be worth investing the large sums typically involved in developing new drugs. But engaging the private sector and using markets to stimulate innovation and product development offers important advantages over push mechanisms. If an AMC succeeds in stimulating competition to supply a targeted innovation, it can be designed so that it links payments to product quality and creates incentives for ongoing product improvements.

To ensure long-term, affordable access, the vaccine model developed by the CGD working group entailed an up-front guarantee to pay an above-market price up to a ceiling number of doses, contingent on developing country demand. In return, the supplier would have to agree to continue supplying the product at an affordable price after AMC payments ended or be subject to financial penalties. The CGD working group report provides details on how contracts for a vaccine AMC might be structured, depending on whether the targeted innovation is in the early or later stages of development.

In June 2009, a pilot AMC for pneumococcal vaccines was launched, with six donors committing $1.5 billion to cover the top-up price on a certain number of doses, and the Global Alliance for Vaccines and Immunisation (GAVI Alliance) committing another $1.3 billion to help poorer developing country governments pay their share of the vaccine cost. In this case, pneumococcal vaccines had already been developed for and were in wide use in developed countries. But they were not being offered in most developing countries because demand was too uncertain to justify the investments in adaptation, for example to treat different strains in developing countries and to incorporate heat tolerance to ensure quality in tropical climates. Firms were also reluctant to take on the risks of building or scaling up production to supply these markets. In March 2010, the first long-term supply agreements were signed with two firms, and estimates indicate that the pneumococcal vaccine could save as many as 7 million lives by 2030.[3]

An AMC for agriculture would involve identifying a technology that donors were confident would have significant social value, by improving nutrition, agricultural productivity, or other elements of food security. Additionally, public support would need to be able to bring the technology down the cost curve far enough to create a sustainable market over the long run. Given the paucity of private-sector involvement in agricultural R&D in many developing countries, it may be necessary to consider a modified AMC that would rely relatively more heavily than in the vaccine case on public-sector institutions or public-private partnerships at some points in the product development and dissemination chain. Because of the underdevelopment of rural markets in many poor countries, donors will also have to pay very careful attention to supply chain issues and the level of market development, an issue to which I turn now.

***Developing markets as a prerequisite for committing to markets***

There are some key differences between health and agricultural systems and markets in developing countries that could make an AMC relatively more challenging for agriculture. Among these are differences in the appropriability of returns from innovation, especially for many seed or agricultural techniques, and the potential for unintended consequences if markets are not adequately developed. These concerns seem particularly relevant in Africa.

First, since the benefits of many agricultural innovations are particularly difficult for inventors to appropriate, the private sector is less involved in general than in most other sectors, as described above in the section describing the landscape of agricultural R&D. This is particularly true in Africa where 90 percent of seeds are either saved from year to year or purchased in local markets from other farmers (Minot et al. n.d, 54–56). Because African markets tend to be small and fragmented, and farm inputs and practices vary locally, investments in R&D with economies of scale are unlikely to be profitable. This means that there is a smaller private sector to engage with pull mechanisms in Africa.

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[3] See http://www.vaccineamc.org/files/AMC_ProcessSheet2009.pdf, last accessed April 28, 2010.

In addition, the heterogeneity and informality of markets may make it difficult to judge potential market demand, increasing risks for investors. But that is also often a problem in pharmaceutical markets, particularly vaccines, where shifting priorities and government budget constraints can lead to large year-to-year fluctuations that can be exacerbated in markets dominated by a relatively small number of larger purchasers. Ensuring that products are developed that will be demanded in the market is one of the key benefits of the AMC mechanism, but that is undermined by offering a quantity, rather than just a price, guarantee to suppliers. In situations of very uncertain demand, donors may want to consider a minimum quantity guarantee, but that risks creating a product that no one wants.

Another concern arises where the goal is improved productivity, as opposed to treating or curing a disease. If final markets do not function well, improved yields could result in gluts that trigger lower prices, often meaning lower incomes for farmers, and, ultimately, abandonment of the technology. In general, if innovations do not lead to increased profitability for farmers, they will not be sustained, if they are adopted at all. This, in turn, means that farmers must have adequate access to reasonably well-functioning markets for their goods.

That, then, raises the role of governments in providing public goods, such as infrastructure, information, and a stable policy environment so that farmers have an incentive to invest in improvements to intensify production. While the paper focuses on pull mechanisms for market-based agricultural innovation, donors may also want to look at a similar mechanism for delivering aid to governments that encourages them to improve public services or provide public goods to support the adoption of new technologies. The proposal, called cash on delivery aid, "enables funders and recipients to pursue mutually desired outcomes through a contract that specifies the results that recipients will achieve and the fixed payments that funders will provide" (Birdsall and Savedoff 2010, p. 18). COD aid shares many features with an AMC, including that payments are ex post and that donors are hands-off, allowing the recipient to determine the best way to achieve the specified goal. Some potential applications of COD aid for agriculture are discussed in box 1.

**Box 1 COD Aid for Agriculture**

The key to creating an effective cash on delivery (COD) aid program is in the selection of the indicator used to trigger payments. The indictor chosen should be an *outcome,* not an input or output, and it must be carefully designed to avoid creation of perverse incentives. For example, in the education case developed by Birdsall and Savedoff (2010), using the number of additional children enrolled in school was rejected because there is no assurance that either they or the teachers show up or that anyone learns anything. In agriculture, selecting appropriate indicators would take at least as many months of research and consultation as COD aid for education took, but a few areas where this approach might be useful can be suggested. Improvements in extension services to help farmers adapt and adopt new technologies is one obvious area, but the number of employed agents or the number of dollars expended are inputs and would not be appropriate indicators. More appropriate indicators might be a measure of improved soil quality or fewer pesticide poisonings among farmers and their families. Another area where this tool might be considered is the construction of roads, with an indicator being numbers of farmers delivering food to markets. The adoption of communications technologies, or other indicators of the delivery of market-supporting infrastructure, is an additional possibility. But for any pilot, appropriate indicators would have to be thought through very carefully to ensure that the incentives between donor and recipient are properly aligned.

**Framework for Identifying Potential Pilots for Pull Mechanisms**

Table 2 shows areas where pull mechanisms might be used to stimulate innovation in agriculture for developing countries. It divides the broad goals of innovation into three categories: more nutritious food, higher productivity, and higher post-harvest yields. The general areas in agriculture where innovations might be targeted are genetic improvements, whether through conventional breeding or biotech practices, and improved non-seed inputs or farming techniques. Though the table ignores the broader context of effective social and political institutions and public goods provision that is needed to provide an effective enabling environment for innovation and technology adoption, policymakers cannot. Education in effective use of new technologies, whether provided by private supplier networks or by public extension services, is also crucial to ensure sustainable adoption and safe use.

<table>
<tr><th colspan="3">Table 2 Selected Options for Using Pull Mechanisms to Stimulate Agricultural Innovation</th></tr>
<tr><th></th><th colspan="2">Areas for Innovation to Achieve Goals</th></tr>
<tr><th>Goals of innovation</th><th>Genetic improvements</th><th>Improved inputs or farming practices</th></tr>
<tr><td>Improved nutrition</td><td>Nutrient-fortified varieties:<br>• Vitamin A-enhanced sweet potato, rice<br>• Protein-enhanced maize or other grain</td><td>Fertilizers that also provide nutrients that humans can use<br><br>Integrated cropping practices</td></tr>
<tr><td>Higher productivity (through higher, or at least more consistent, yields or lower costs)</td><td>Varieties that are more resistant to drought, water stress, diseases, pests:<br>• Drought-resistant maize<br>• Wheat stem rust<br>• Cassava mosaic virus</td><td>More efficient (lower cost) fertilizers:<br>• Lower energy-intensive nitrogen<br>• More efficient production processes for phosphate; replacement in face of declining reserves?<br>• Continuous release versions that reduce labor as well as other input costs<br><br>Irrigation technologies appropriate for smallholders with no access to electricity<br><br>Biocontrols for pests, disease<br><br>Practices to improve productivity:<br>• Soil improvements through agroforestry, mixed and inter-cropping (e.g., with legumes to fix nitrogen), fallowing, no tillage, application of organic matter<br>• Other practices to improve productivity, e.g., System of Rice Intensification<br>• Integrated pest management</td></tr>
<tr><td>Higher(and more consistent) post-harvest yields</td><td>Post-harvest pest resistance</td><td>Appropriate storage, processing technologies, adapted to energy, geographic constraints:<br>• Hermetic storage containers, silos<br>• Post-harvest drier<br>• Micro pasteurizer</td></tr>
<tr><td colspan="3">NB: proportional prizes could be used to reward innovations in any of these areas, with relatively more difficulty in some areas than others; AMCs would be difficult to apply in the development and dissemination of improved farming practices, or other disembodied technologies. Traditional push support for R&D and COD or other forms of aid may be more effective in the latter case, while also contributing to an overall environment that promotes innovation.</td></tr>
</table>

The proportional prize mechanism as developed by Masters is technology-neutral and could be used for any of the technologies in the table. Moreover, Masters argues that there are economies of scale in managing proportional prizes and that a continent-wide prize for Africa, open to any innovation that improves agricultural productivity by whatever means, would be appropriate to lower administrative costs. But it would also be possible to experiment with a smaller trial that might target a particular country or area, or a particular crop or sector. The problem with selecting narrower targets is that the process will not reveal whether those innovations will deliver higher social benefits than alternative choices might. It also seems probable that proportional prizes could reveal information about locally improved varieties that provide incremental benefits in nutrition or resistance to biotic or abiotic stresses, but breakthrough technologies seem less likely to be developed under this approach.

In considering candidates for an AMC in agriculture, some of the categories in Table 2 are more appropriate than others. Disembodied technologies that come from learning or information, for example with regard to agroforestry or other farming techniques for improving nutrition or productivity, make it particularly difficult for innovators to make a profit using a market-based mechanism, even with a donor subsidy in the early phases. Annex table 3 discusses some of the issues involved in piloting an AMC for agriculture in the other areas. It combines the six cells of the matrix in table 2 below into three categories—seeds, other inputs, and post-harvest technologies—and discusses general pros and cons of public support for innovation, as well as particular issues related to using an AMC approach. A few key of the issues are fleshed out here.

Improved seed varieties are frequently mentioned in the literature as an area where innovation is needed and an AMC might be useful. The first question is, where is the need and potential benefit greatest? Annex tables 1 and 2 show crops that are important in terms of consumption, and also where the largest yield gaps occur, rough indicators of need and potential benefit from innovation. In the poorer regions of the world, grains and starchy roots still account for nearly two-thirds of calories consumed and wheat, rice, and maize are important staples globally. Africa is an outlier in its reliance on minor crops not widely consumed outside the region. Annex table 2 also shows Africa to be an outlier in terms of its yield gap in maize and rice, in part because improved varieties are far less common there than in other developing regions.

Africa may not be best candidate for a vaccine-type AMC for seeds, however, for reasons discussed earlier. Different mechanisms, or adaptations of prizes, AMCs, or other mechanisms may be needed. One adaptation of the AMC idea that might be useful in Africa is discussed in Box 2. Other developing regions, particularly Asia, did widely adopt improved seed varieties during the green revolution and they may offer better targets for an AMC. A key question in these cases is whether ample research is going into raising major yield crops in rich countries, or whether specific problems in developing countries create specific R&D needs where public funds could help. Rice is an obvious candidate because of its continued importance as a staple food for such large numbers of poor people. Achim Dobermann from the International Rice Research Institute posted a comment on the CGD website indicating that the paper inspired a list of perhaps ten potential AMC pilots, including the development of faster cooking rice to save energy. He was also one of several to suggest better options for hermetic storage as an important need in general in the developing world.

**Box 2 Endpoint Royalties: Prize or Advance Market Commitment?**

Among the reactions to the paper posted on the CGD website was an interesting idea from Greg Traxler of the Gates Foundation.[4] Traxler notes that some developed countries, rather than relying on patents, charge farmers a fee when they sell their crop and, after identifying the seed variety, deliver a royalty-like payment to the developer. He suggests this scheme could be adapted for poorer farmers in developing countries with donors creating a fund to pay these "endpoint royalties," based on surveys of adoption of improved varieties. This adaptation is needed because many poor farmers sell little if any of their crop in formal markets, making it difficult and expensive to collect endpoint royalties from them, nor can the fee be collected up front, since few farmers, at least in Africa, buy seeds in formal markets.

Depending on specific design details, the adaptation for poorer countries could be seen as either a modified proportional prize or modified AMC. If the donors' promise to pay is credible and investors respond, then the idea is similar to a proportional prize with payments based on observed market shares for different varieties (but not relative to social benefit, as in the Masters' proposal). If potential seed developers are not convinced of the credibility of the fund, however, they might respond only if there is a legally binding contract, in which case, the idea looks more like a version of an AMC. Unlike the plan for the pneumococcal vaccine, however, ongoing donor subsidies might be necessary, at least until private seed markets develop further in Africa. This is an interesting idea that is worth exploring in more depth in future research.

With respect to improved inputs, more efficient and effective fertilizers and irrigation technologies that can be sustainably produced and used are critical needs. A key question for fertilizers is whether the R&D being done for developed-country markets would be likely to spill over to developing countries, or whether additional effort is needed to create or adapt products for poorer markets. Africa, again, poses particular challenges, including the need to improve soil quality and infrastructure so that fertilizers are cost-effective.

With respect to pest and disease control, safer chemicals are one of several options, but there are others. Several participants in CGD's online consultation mentioned the problem of aflatoxin-producing fungi infecting grains and other crops. In addition to negative health effects from consuming tainted crops, commentators noted that aflatoxin levels in African crops often exceed international regulatory standards and thus block exports. Bandyopadhyay Ranajit from the International Institute of Tropical Agriculture in Nigeria noted that there is an aflatoxin biocontrol product that has been developed and used in the United States and other countries and

[4] Comment submitted on the CGD website, April 20 and subsequent private communications. All comments remain available at http://www.cgdev.org/section/topics/food_and_agriculture/incentivesforaginnovation.

that could be adapted for Africa with donor support, similar to the AMC for the pneumococcal vaccine.

Finally, several public and private comments referred to the need for post-harvest storage and processing technologies to improve post-harvest yields. Many of these technologies are relatively simple to produce and use and the major needs are in dissemination and training in their proper use. In addition, sustainable innovations would need to take into account the lack of electricity in rural areas in most developing countries.

In terms of the pilot design for an agricultural pull mechanism, three general questions emerge:

- Can a sustainable market be created given political, institutional, and other constraints? Would the benefits of the new technology be large enough, or can economies of scale from a market commitment bring down costs enough, to make adoption sustainable once subsidies are removed? If not, are ongoing subsidies or other public policies to supplement the pull mechanism in addressing market failures feasible?
- Is investment needed in early-stage innovation, or for adaption and dissemination of existing technologies? For example, treadle pumps exist and work well in some places so is the need for further innovation or dissemination of that product? Should the pull mechanism focus on research and development, or mainly on how to scale up production and pull the technology down the cost curve?
- Are supply chains and other market institutions in place to facilitate adoption, and to avoid localized gluts? Can incentives for private-sector advisory and training services to ensure safe and effective use of new technologies be built into the contract?

**Going Forward**

The needs in developing agriculture and promoting food security are great and a variety of tools are needed. Pull mechanisms are particularly useful to engage a largely absent private sector in innovative activities in this area. In selecting potential pilots to support, donors need to, first, determine the regional and functional areas of interest and then determine the appropriate tool to fit. A vaccine-style AMC for agriculture may not work as well in Africa as in other regions, but adaptations of the idea using public-private partnerships may be useful, along with the proportional prize idea to incentivize innovations that are well adapted to local conditions. An AMC for improved rice varieties could potentially improve food security for billions in Asia, while more effective storage technologies could do that around the world.

The next steps in creating a proportional prize fund to stimulate agricultural innovation and adoption are relatively simple, if one follows the Masters model, but the process for selecting a potential AMC pilot is more complicated. With a proportional prize fund, the key decisions involve the geographic and sectoral scope of the initiative.

With respect to an AMC pilot, donors must first decide which goal of innovation they want to pursue—improved nutrition, productivity, or post-harvest yields—and then which general area of agricultural innovation will be the focus—improved varieties or inputs (including post-harvest activities). The paper has tried to identify some of the technologies where an AMC approach might be appropriate, but donors will have to choose among those, based on relative need, balanced against budget constraints. Unless there is a consensus choice, picking a pilot candidate would require a more systematic consultation process than was possible for this paper, involving potential donors and other stakeholders including private firms, developing-country governments, farmers' associations, and other civil society groups. Once a category of technologies is chosen, further extensive discussions would be needed to determine the specifics of the desired technology, as well as contract details, such as price and the amount of donor subsidy. GAVI's AMC website has a timeline showing the years of work and engagement needed to bring the pneumococcal vaccine (nearly) to fruition.[5] No less effort would be required for an agricultural AMC, but the potential pay-off is large as well.

[5] http://www.vaccineamc.org/pilot_timeline.html, last accessed June 2, 2010.

| Annex Table 1 Sources of Daily Calories in Developing Countries | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | **Sub-Saharan Africa** | | **Latin America, Caribbean** | | **South Asia** | | **East, SE Asia** | |
| | Percent of daily calories provided by: | Imports as share of domestic supply | Percent of daily calories provided by: | Imports as share of domestic supply | Percent of daily calories provided by: | Imports as share of domestic supply | Percent of daily calories provided by: | Imports as share of domestic supply |
| | | | | | | | | |
| Cereals, starchy roots | 66 | 21 | 40 | 31 | 63 | 2 | 64 | 25 |
| Wheat | 7 | 77 | 13 | 62 | 21 | 3 | 6 | 105 |
| Rice | 8 | 42 | 9 | 16 | 35 | -- | 49 | 5 |
| Maize | 15 | 9 | 14 | 18 | 2 | 2 | 5 | 38 |
| Sorghum, millet | 14 | 1 | -- | 33 | 3 | -- | -- | -- |
| Starchy roots | 20 | -- | 4 | 2 | 2 | -- | 4 | 6 |
| | | | | | | | | |
| Other vegetable products | 28 | | 40 | | 29 | | 27 | |
| Animal products | 6 | | 20 | | 8 | | 9 | |
| | | | | | | | | |

-- =negligible

Source: UN Food and Agriculture Organization, FAOSTAT database.

**Annex Table 2 Indicators of Innovations Needs in Selected Regions and Countries**

| | | Area Harvested (hectares) | Share of total calories consumed(percent) | Yield Gap (relative to ROW, %)* |
|---|---|---|---|---|
| **Eastern Africa** | Maize | 13,550,985 | 24.2 | 320 |
| | Sorghum | 4,293,998 | 4.6 | 40 |
| | Cassava | 2,907,865 | 9.0 | 46 |
| | Rice | 2,381,748 | 6.6 | 107 |
| | Wheat | 1,743,522 | 9.0 | 77 |
| **Central Africa** | Cassava | 3,354,691 | 32.1 | 60 |
| | Maize | 3,475,522 | 12.5 | 495 |
| | Wheat | 14,102 | 6.6 | 97 |
| | Rice | 610,999 | 4.5 | 340 |
| | Sorghum | 1,482,675 | 3.6 | 78 |
| | Millet | 1,422,174 | 2.4 | 75 |
| **Southern Africa**** | Maize | 3,080,409 | 31.4 | 34 |
| | Wheat | 782,320 | 17.1 | 4 |
| | Rice | 1,450 | 5.3 | 85 |
| **Western Africa** | Rice | 5,773,673 | 12.4 | 148 |
| | Sorghum | 14,861,350 | 10.5 | 77 |
| | Millet | 16,818,968 | 10.3 | -9 |
| | Cassava | 5,720,437 | 9.8 | 17 |
| | Maize | 7,973,242 | 8.9 | 200 |
| | Wheat | 43,514 | 5.3 | 78 |
| **China** | Rice | 29,493,292 | 27.0 | -42 |
| | Wheat | 23,617,075 | 20.5 | -39 |
| **India** | Rice | 44,000,000 | 30.0 | 39 |
| | Wheat | 28,038,600 | 20.1 | 12 |
| | Millet | 11,997,600 | 3.0 | 1 |
| | Sorghum | 7,764,000 | 2.1 | 52 |
| **Indonesia** | Rice | 12,309,155 | 50.5 | -13 |
| | Maize | 4,003,313 | 7.5 | 26 |
| | Wheat | 0 | 6.1 | N/A |
| | Cassava | 1,193,319 | 4.6 | -33 |
| **Vietnam** | Rice | 7,414,300 | 60.2 | -18 |
| | Wheat | 0 | 3.7 | N/A |
| | Maize | 1,125,900 | 2.6 | 27 |

* Minus sign indicates local yields higher than the rest of world (ROW) average.

** Excluding South Africa.

**Source:** UN FAOStat, online.

| Annex Table 3: Issues Involved in Choosing a Pilot AMC | | |
|---|---|---|
| **Innovation area** | **General pros and cons** | **Issues related to AMC** |
| ***Seeds*** | Improved varieties typically work best in conjunction with adequate water, other inputs<br><br>In Africa, seed, input markets not well-developed, and most acreage rain-fed; ~90 percent of seeds obtained through farmer saved seeds or local markets | Africa: an AMC aimed at engaging the private sector in development and dissemination of improved varieties may not be feasible because of extensive use of minor crops, and under-development of markets on both the supply and demand sides. A modified AMC might be used to create or adapt production and distribution channels to market products developed in public institutions or through public-private partnerships, which are active in many areas.<br><br>Elsewhere: maize is a major staple but it is also a major crop in developed countries improved varieties are mostly hybrids where the benefits are more easily appropriated by the innovator. Wheat and rice are also important developing-country staples that are also major crops in developed countries. Drought, and many (though not all) disease threats are common, so substantial private and public research is already going into improvements in these crops.<br><br>A form of AMC might be appropriate:<br>• For nutrient-fortification in countries with widespread malnutrition deficiencies<br>• Where varieties being improved for developed-country markets need to be adapted for local conditions or pests<br>• For improved varieties of rice, since such a large number of the world's poor depend on it |
| *Hybrids* | Yields drop sharply in short time and must be replaced; constraints above limit adoption of improved hybrid varieties in SSA | |
| *GM* | GM subject to similar constraints, unless a OPV; also constrained in SSA by regulatory environment and fear of export losses in EU due to opposition to GM | |
| *Open-pollinated varieties* | Seeds can be saved, making them more affordable for farmers but less lucrative for seed companies | |
| ***Other inputs*** | Markets often not well-developed and knowledge needed for effective application often lacking | Africa: until infrastructure and markets are developed, the focus might be better placed on improved farming practices than on chemical inputs, |

| | | |
|---|---|---|
| *Fertilizer*<br><br><br><br>*Pest, disease controls*<br><br><br>*Irrigation* | In SSA, in particular, often uneconomic because of high transportation costs; also less effective in already depleted soils, as in much of SSA<br><br>Affordability; also need to be adapted to low literacy levels to protect health and safety<br><br>Appropriate technology depends on local conditions; provisions for maintenance critical | especially given the problem of soil depletion, and, for that, traditional push or COD aid to improve extensions services might be a better approach than an AMC<br><br>Elsewhere: clear needs for more efficient, less energy-intensive fertilizers and safer pesticides, herbicides, or organic techniques. These needs also exist in developed countries, however, so the question in designing an AMC would to be to identify the particular constraints limiting innovation or dissemination in developing countries. Two issues relevant for developing countries are *labor abundance* (in some areas) and *illiteracy*, which could suggest adaptations that are relatively more cost-effective, or safer, in developing countries specifically.<br><br>For both: sustainable irrigation technologies adapted to developing-country conditions to mitigate increased volatility in weather with climate change. |
| ***Post-harvest technologies***<br>*Storage*<br><br><br><br><br><br>*Processing* | Would be helpful both for subsistence smallholders, allowing them to smooth consumption over the seasons, and for more commercially-oriented farmers; would allow both to earn more from crops by not having to sell immediately after harvest.<br><br>Similar benefits, plus allowing farmer to earn additional income from value-added processing.<br><br>Constraints on both, especially in SSA, from limited or no access to reliable energy. | An AMC would be appropriate, either to develop or adapt and disseminate storage or processing technologies. Key features will be scale—adapted to smallholder or village-level use—and lack of access to electricity. |

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