PULLING AGRICULTURAL INNOVATION INTO THE MARKET

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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 agricultural R&D, and they pay only when specified outcomes are delivered.

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Introduction

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

> *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.* Food and Agricultural Organization, 2009.

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 and reduce poverty. Moreover, the growing threats to food security from land and water scarcity, climate change, and declining crop yields suggest that *new* tools are needed to stimulate agricultural innovation and the adoption of new technologies. Given the scope of the challenges, reversing the decline in donor support for agriculture in poor countries is the first step, but it seems likely that the challenges can only be met if donors also find ways to leverage the resources and harness the energy of the private sector. Today, however, because of various market failures that make it difficult for them to recoup their up-front costs in developing new products, agricultural R&D by the private sector is virtually nonexistent in developing countries.

New approaches to addressing market failures in agricultural innovation for developing countries are needed and the aim of this paper is to stimulate a dialogue on what those might look like. In particular, could "pull mechanisms," where donors stimulate *demand* for new technologies, be a useful complement to traditional "push mechanisms," which provide funding to increase the supply of research and development (R&D). With a pull mechanism, donors pay only when specified outcomes are delivered, which helps to solve the information asymmetries between donors and researchers that plague traditional funding for R&D. Engaging the private sector and linking the donor payment to adoption also encourages innovators to pay close attention to what farmers need and want.

The encouraging news is that donor neglect of the agricultural sector in developing countries ended with the spike in food prices in 2008. The 2008 pledge from G-8 leaders meeting in L'Aquila to provide $20 billion for agricultural development and food security, including for research and development (R&D), is a welcome step in reversing the decline in official development assistance (ODA) for this sector. The share of bilateral ODA declined from 17 percent in 1980 to 4 percent in 2003, and 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. But in addition to increasing the level of resources, donors also need to find more effective ways of delivering those resources.

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 for R&D, with pull mechanisms, which engages the demand side, and identifies circumstances 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 social 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 set products 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 there are other potential market failures that undermine the effectiveness of the IPR approach in some situations. For example, where R&D costs are high but market demand for new technologies is uncertain, patents may not be sufficient to attract private investment. This is often the case with basic research, where the information generated is crucial for subsequent innovation and commercial applications are not 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.

Relative to some others, agriculture is also a sector that presents relatively 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, or 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 means that resources can be wasted 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

Innovative approaches are needed because, if patents and other protections for intellectual property are generally 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, for example, 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, while sorghum and millet, along with starchy roots such as cassava, make up another third. This means that private seed companies have little incentive to invest significant sums in developing improved crop varieties because the expected market would be too small to recoup the costs.

It is no surprise, then, 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 (Bientema and Stads 2008). Public sector spending on agricultural R&D in developing countries increased 50 percent from1981 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 when public spending in Africa actually declined (ibid.).

Low and declining investments in agricultural innovation are puzzling given both projections of the need, and estimates of the return on such investments. 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 that is projected to grow from 6 billion 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 agro-ecological conditions—climate, soil, and eco-zone specific weeds, pests—mean that varieties developed elsewhere were not easily adapted for African conditions.
- Land abundance lowered the incentive for farmers to invest in more intensive agriculture.
- Soil depletion, which makes chemical fertilizers less effective.
- Different staple products that are not widely consumed outside Africa, including millet, sorghum, and cassava; among the greatest productivity gains were for wheat and rice, which are relatively less important in Africa as staples.

- 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.

Concentrated efforts to increase agricultural productivity have succeeded in some cases, 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, to determine whether farmers in Tanzania were still using technologies introduced during an earlier project to promote improved food security and household income for smallholders.[1] 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. 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 too expensive
- Increased labor requirements not commensurate with benefit

And the final reason that farmers in this experiment rejected new technologies that the "lack of available markets where the farmers' products achieve attractive prices" (Norwegian University of Life Sciences, 2009, p. 16).

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 investment has a lot to offer in the fight against food insecurity and rural poverty, the remainder of the paper focuses on mechanisms that can pull in the private sector by guaranteeing payments for technologies meeting specified criteria when they are delivered.[2]

This is not to suggest that push mechanisms should disappear. Public funding basic science and early research is essential to provide information to other researchers that can then be developed

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[1] See Johnsen, Mwaseba, and Mombo (2009, p. 16).

[2] 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).

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). Push and pull mechanisms should be considered complementary rather than competing approaches to agricultural innovation.

Pull mechanisms should be preferred in situations where information is asymmetric, 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.

In addition, pull mechanisms help to better align the incentives of donors and researchers. Ex ante funding may lead researchers, especially if they are employed in the public sector and do not anticipate private gains from an innovation, to undervalue features that are important to the final consumer. 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, donors 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 (Levine et al., 2005). 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 (ibid., pp. 23-25). Of those twelve, only five potentially involve donor funding to stimulate innovation: advance market commitments; patent buyouts; prizes; proportional prizes; and best entry tournaments. Patent buyouts, prizes, and best entry tournaments all share the weakness that they are likely to be winner-takes-all, which could undermine broad access to and adoption of the technology if the winner has a monopoly over production. Winner-takes-all approaches also can foster competition of a race to patent type that can result in duplication of research efforts, but not post-award competition to stimulate pressures for continued product improvements. Levine et al. (2005) and Masters (2008) discuss other weaknesses, and strengths, of winner-takes-all approaches.

For similar reasons that led the CGD working group to recommend advance market commitments (AMCs), they seem to offer significant advantages over other pull mechanisms for agricultural innovation as well. 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., op cit). And by creating a market for a product with uncertain demand, it mobilizes additional resources for the latter development and production stages, including for meeting safety, environmental, or other regulatory requirements before release of improved varieties or other technologies.

Both AMCs and proportional prizes, which reward incremental innovation, free donors from having to pick winners in advance and they pay only for results. 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 pull out information about what actually works in an environment as difficult and diverse as African agriculture. This approach, however, 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 as with push and pull mechanisms, these two types of pull mechanisms are also likely to be 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 and we now turn to some of the issues involved in designing a mechanism to address real world problems.

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. Masters argues that the proportional prize is particularly well-adapted for promoting innovation to improve agricultural productivity for two reasons: 1) the technologies that will do the most to improve farm productivity often are not predictable in advance and will

Table 1 Comparing proportional prizes and advance market commitments

Advantages	***Risks***
Proportional Prizes	
• Provides incentive to public and private sectors to generate evidence on successful innovations, measured by both productivity improvement and degree of adoption. • Award process requires revelation of information on innovation that can then be disseminated more broadly. • Innovations will be adapted to local conditions and thus more readily adoptable. Most appropriate for improving productivity where appropriate technologies are unknown.	• If the technology is patentable, access may depend on patent buy-out or compulsory licensing to ensure affordability • Additional mechanisms to scale up production, distribution may be needed. • Uncertainty regarding value of individual prizes may deter investment. • Depending on scale, auditing and verification costs relatively high More likely to "pull" information than innovation.
Advance Market Commitments	
• Creates link between product quality and revenues that accrue to developer. • Creates market for improved products and continual progress. • Ensures access to new products in both the short and long run. • Requires sponsors to pay only if a desired product is developed Most appropriate where characteristics of desired technology are known and can be specified in contract.	• Promises to pay must be credible. • Must be designed to cover appropriate products. • In agriculture, with atomistic, and in Africa undeveloped, markets for inputs, design needs to address distribution and how to ensure sustainability of markets. • Nature of agricultural R&D may require that public institutions play bigger role than under "pure" AMC. May be difficult to apply where markets or public distribution systems are undeveloped.

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.[3]

In Masters' general scheme, donors would set an overall prize amount which would then be divided among applicants who would compile comparable evidence, using the indicators listed above, showing the impact of their innovation. These claims would be verified through an independent audit and the prize divided according to the proportional value of the innovation. The audit method recommended by Masters measures

- the incremental value of the induced productivity improvement, by subtracting from the value of increased output the cost of increased inputs;
- the revealed value to farmers by examining adoption rates; and,
- productivity gains attributable to the innovation by requiring the use of controlled experiments in the field that can be confirmed by the auditor.

In a specific recent proposal for Africa, he proposes a continent-wide fund that would be used to reward productivity-improving innovations wherever they occur, based on the estimated dollar value of the improvement that can be attributed to a particular innovation. 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).

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 purchase commitment from donors, to ensure there will be a market for the resulting product, can be useful. One of the main risks facing innovators is uncertainty regarding potential demand for their product, which lowers the expected return and making innovation less attractive to firms. Commitments to purchase a minimum volume of a new product at a remunerative price reduces this risk and, depending on how far along the process is, can spur either new innovation or adaptation and scaling up of production specifically for developing countries.

A key advantage of the AMC for donors is that, because it is demand-driven, they pay only for innovations that are adopted and only to the degree that they succeed in the marketplace. The Norwegian analysis, discussed above, 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). But there is also a risk for donors if the product turns out not be profitable for farmers after the subsidy is removed and adoption falls.

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[3] Note that 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.

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 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. The advantages of an AMC specifically is that it links payments to product quality and creates incentives, through competition, for ongoing improvements.

A key element of an AMC aimed at developing countries is ensuring long-term, affordable access. Thus, the vaccine model developed by the CGD working group entailed an up-front guarantee to buy a certain number of doses at a price high enough to cover R&D and start-up production costs (depending on the stage of research, it might be mostly the latter). But then the supplier would have to agree to continue supplying the product at a price that just covered production and a "reasonable mark-up," 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 was 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. 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 incorporate heat tolerance to ensure quality in tropical climates, and to build or scale up production to supply new markets. Although it will take years to evaluate the impact of this pilot AMC, early indications are encouraging. Four suppliers have made offers to supply vaccines under the Pneumococcal Advance Market Commitment, supply agreements are on track to be signed by early 2010, and estimates indicate that the pneumococcal vaccine could save approximately 7 million lives by 2030.

A "pure 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, and where public support could help 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. 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 distribution channels, an issue to which we 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 make an AMC relatively more challenging for agriculture. Among these are differences in potential private returns from innovation, the nature of product markets, and the potential for unintended consequences if markets are not adequately developed.

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. Because African markets tend to be small and fragmented, and farm inputs and practices highly locally specialized, investments in R&D where there are economies of scale are unlikely to be profitable. This means that there is a smaller private sector to engage with pull mechanisms, at least in Africa. In Africa, and perhaps other developing countries, AMC for agriculture may need to be adapted to encompass R&D by public research institutions. But that leads to the next challenge, how the results will be disseminated to final consumers without well-developed distribution networks

How to implement an agricultural AMC is also complicated by market structure. Pharmaceutical markets tend to be dominated by one or relatively small number of larger purchasers—in developing countries, often a public health system or hospitals, whereas agriculture, especially in developing countries, has many small, dispersed consumers. This makes the design and distribution problem for donors behind an AMC for agricultural inputs or processing technologies far more difficult, especially in developing countries that have either dismantled or never had an extension service.

The sustainability of agricultural innovations is also crucially dependent on market *development*, beyond the initial market commitment. This is both to solve the distribution problem in the longer run, after the initial role of donors has ended, and to ensure that demand is maintained because the innovation is profitable for farmers. One concern that arises when the goal is improved productivity, as opposed to treating or curing a disease, is that it will lead to development of gluts that trigger lower prices, then lower incomes for farmers (albeit higher for urban consumers) and, ultimately, reduced investment in technology. There may be technologies that primarily allow consumption smoothing by subsistence farmers, but the food security challenge requires broader innovations than that.

Overall, to be most effective, donors need to ensure that farmers will have adequate access to markets for their goods or that support for agricultural innovation is linked to policy reforms and infrastructure development to strengthen markets. While the paper focuses on pull mechanisms for 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 the AMC, including that payments are ex post, for outputs rather than inputs, and that donors are hands-off, allowing the recipient to determine the best way to achieve the specified goal. Cases where COD aid might be particularly useful in enhancing the effectiveness of donor-supported agricultural innovation are development of or improvements in extension services, access to credit, and the building of roads, communications technologies, and other market-supporting infrastructure.

Framework for Identifying Potential Pilots for Pull Mechanisms

The questions to be asked in developing a proportional prize mechanism are different from the questions relevant for a pilot AMC. Since the core idea of proportional prizes is not to focus on particular technologies, but on revealing information about what works, the initial issues to be determined in developing a pilot are the scope and scale of the prize design:

- Whether to target a particular crop, or staples versus export crops, the livestock sector, or all agriculture?
- Whether to focus on a particular area, country, region, or continent?

Masters argues that there are economies of scale in managing proportional prizes and that a continent-wide prize for Africa, covering all agriculture, 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 the latter is that it would not reveal whether innovations for that particular crop or sector were delivering higher social benefits than alternative choices might. Without specifying the desired technology in advance, a proportional prize could reveal information about locally improved varieties that provide incremental benefits in resistance to biotic or abiotic stresses, as well as productivity-enhancing technologies to improve inputs or farming techniques.

Table 2 focuses on potential pilot AMCs. It divides the broad goals of innovation into three categories: more nutritious food, higher yields, 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. Annex table 2 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. From the analysis in these tables, three general questions emerge:

- For a "pure" AMC, would the benefits of the new technology be large enough, or can costs be brought down enough, to make adoption sustainable once subsidies are removed? If not, are ongoing subsidies or other public policies to supplement the AMC 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 AMC 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 services to ensure safe and effective use of new technologies be built into the contract?

Table 2 Areas of Agricultural Innovation Where AMCs Might Be Useful

	Potential AMCs	
Goals of innovation	***Genetic improvements***	***Improved inputs or farming practices***
Improved nutrition	Nutrient-fortified varieties: • Vitamin A-enhanced sweet potato, rice • Protein-enhanced maize or other grain	Fertilizers that also provide nutrients that humans can use Integrated cropping practices
Higher yields	Seed varieties that are more resistant to drought, water stress, diseases, pests: • Drought-resistant maize • Wheat stem rust • Cassava mosaic virus	More efficient (lower cost) fertilizers: • Lower energy-intensive nitrogen • More efficient production processes for phosphate; replacement in face of declining reserves? • Continuous release versions that reduce labor as well as other input costs Practices to improve productivity: • Soil improvements through agroforestry, mixed and inter-cropping (eg, with legumes to fix nitrogen), fallowing, no tillage, application of organic matter • Other practices to improve productivity, e.g., System of Rice Intensification • Irrigation technologies appropriate for smallholders with no access to electricity
Higher post-harvest yields	Post-harvest pest resistance?	Appropriate storage, processing technologies (given energy, geographic constraints), eg: • Post-harvest drier • Micro pasteurizer

If improved seed varieties are a target, determining priorities among the possibilities would depend on a number of other criteria, including:

- Importance of particular crops or sectors to poor countries, measured by indicators such as acreage planted or share of total calories consumed.
- Crop yield gaps in developing countries (relative to more developed countries).

- Magnitude of identified problem (i.e. potential economic and welfare gains).

Annex table 1 gives an indication of the crops that are important in terms of consumption. 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, as noted previously, is an outlier in its reliance on minor crops not widely consumed outside the region. Other data from the UN Food and Agricultural Organization also shows Africa to be outlier in terms of the yield gap in maize, in part because improved varieties are far less common there than in other developing regions.

In addition, donors will need to decide how much risk they are willing to bear and where their dollars could have the greatest bang for the buck. Factors affecting those decisions include where things stand in the development process for potential solutions, with those close to commercial stage being relatively less risky for donors. "Investment gaps" in crop R&D might indicate areas where public funding is most needed, but also where it may be more difficult to pull in the private sector.

Going Forward

In moving "ideas to action," as the CGD working group on advance market commitments sought to do, we need the help of the agricultural, development, and aid reform communities. Please help us by providing comments on the paper and, in particular, thoughts on this question:

- Where would demand-based, market mechanisms be most effective in boosting agricultural productivity?

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: 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 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: a "pure" AMC for seeds may not be feasible because of extensive use of minor crops, 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. Elsewhere: maize is a major staples 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. A form of AMC might be appropriate: • For nutrient-fortification in developing countries with widespread malnutrition or micronutrient deficiencies • Where varieties being improved for developed-country markets need to be adapted for local conditions or pests
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 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, especially given the problem of soil depletion, and,
Fertilizer	In SSA, in particular, often uneconomic because of high	

Pest, disease controls *Irrigation* *Improved farm practices*	transportation costs; also works less in already depleted soils, as in much of SSA Affordability; also need to be adapted to low literacy levels to protect health and safety Appropriate technology depends on local conditions; provisions for maintenance critical Lower cash costs, but may be labor-intensive; can be used to improve soil quality, a priority for SSA	for that, COD aid to improve extensions services might be a better approach than an AMC 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. For both: irrigation technologies adapted to developing-country conditions could be important given the expected increased volatility in weather with climate change.
Post-harvest technologies *Storage* *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. Similar benefits, plus allowing farmer to earn additional income from value-added processing. Constraints on both, especially in SSA, 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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