Encouraging technical progress in tropical agriculture*

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Abstract: Agricultural needs in poor, tropical countries differ significantly from those in temperate, rich countries. Yet little agricultural research is performed on products for the tropics. Private sector research is particularly concentrated in rich countries. This is a result of significant failures in the market for R&D, in particular, the difficulty of preventing the resale of seed in developing countries. To encourage private R&D in tropical agriculture, traditional funding of basic research may be usefully supplemented by a commitment to reward developers of new agricultural technologies needed in developing countries. Rewards that are tied to adoption may be especially useful in increasing technology up-take. To illustrate how a commitment to reward developers of new agricultural technologies might work, we examine a possible structure for payments for finger millet seed modified to be resistant to blast.

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1 Introduction

Developing countries urgently need increases in agricultural productivity. As of 1990, 66 percent of the labor force in low-income countries (classified by the World Bank as those countries with income per capita below $785 in 1997) was engaged in agriculture (World Bank 1999), and 792 million people in the developing world remained undernourished in 1996-98 (FAO 2000).

The context of efforts to encourage agricultural research and development (R&D) for developing countries has changed significantly in recent years. First, new innovations and possibilities for technological change in agriculture, especially in biotechnology, hold out the promise of major productivity advances. The development of pest-resistant seeds, fungus resistance, or drought- or saline-resistant varieties may increase agricultural yields. Biotechnology also holds out the possibility of developing nutritionally enhanced plant varieties, such as the so-called golden rice that is rich in vitamin A.

Second, the private sector is playing an increasing role in agricultural R&D. Alston, Pardey, and Rosebloom (1998) estimate that the annual growth rate of private agriculture R&D expenditures in the United States, United Kingdom, and Japan was approximately 5 percent over the period 1981 – 1993. Appropriate incentives are needed to ensure that the most socially valuable technologies attract private research effort.

New approaches are also needed because of the failure of many research innovations for developing countries, particularly those in Africa, to translate into adoption and productivity increases. In a review of the United States Agency for International Development’s (USAID) experience with funding agricultural research in Africa, Christensen (1994) concludes that researchers have traditionally done a poor job in producing innovations that effectively address the binding constraints on productivity among smallholders. Widespread research adoption is generally confined to cash crops alone. Despite calls to make research more responsive to farmers' needs by soliciting their input when research programs are designed (see, for example, World Bank 1998), the results of research intended to increase the productivity of subsistence crops often fail to be adopted.

This paper investigates funding mechanisms for spurring private research in tropical agriculture. It first argues that distortions in the research market lead the private sector to underinvest in research on products grown in tropical countries, such as cassava and millet. The potential for the reuse and resale of seed makes it difficult for developers to appropriate the costs of R&D in this sector. In addition, fragmentation of intellectual property rights can reduce access to the final product and incentives to invest in developing new technologies.

The paper then examines whether increased traditional funding of agricultural research may be supplemented by a commitment to pay for specific products upon development and, crucially, adoption. Such a commitment would not require that reuse be prohibited to increase incentives for R&D. As an example, we provide a means of calculating and structuring the payment that might be provided to a firm that develops finger millet seed resistant to blast (pyricularia blight).

Section 2 presents evidence that poor countries have distinct R&D requirements, and that little effort is directed towards these research needs, particularly by the private sector. In Section 3, we argue that support for additional research should be publicly and internationally funded because the R&D market is subject to significant distortions, and that this R&D is a global public good with social benefits that greatly outweigh private returns.

Section 4 examines the appropriate role of "push" and "pull" programs to encourage research. We argue that "push" programs, which fund research inputs, are most appropriate for basic research or in a context in which it is not possible to specify the desired final product. By contrast, "pull" programs, which pay for research output, are appropriate for encouraging the development of specific needed products.

Section 5 examines whether pull programs are appropriate for encouraging research in tropical agriculture. We consider the potential means by which eligible technical advances might be identified, and how the appropriate payment to developers might be calculated. We discuss several issues that might arise when designing pull funding mechanisms for agriculture. Section 6 summarizes and concludes.

2 The current state of research in tropical agriculture

Poor countries have distinct agricultural R&D needs, and these needs are not being met. Agricultural research expenditures as a share of agricultural GDP in developing countries are dwarfed by expenditures in rich countries, and while this gap is significant for public R&D, it is even larger for private R&D.

2.1 Distinct R&D Needs

The R&D needed for tropical agriculture is distinct from that for temperate countries for several reasons. Some staple crops grown in tropical countries, such as cassava and millet, are neither grown in nor imported by rich countries on a significant scale (Scott, Rosegrant, and Ringler 2000, ICRISAT and FAO 1996). Tropical countries have distinct agroecological systems, including higher average temperatures, relatively fragile soils, and a lack of a seasonal frost (Masters and Wiebe 2000). Climatic differences imply that these countries face eco-zone specific weeds and pests. Some crops, such as maize, are grown in both temperate and tropical zones, but different strains are used depending on climatic zone. Climatic zone-specific productivity constraints (National Academy of Sciences 2000) mean that advances in maize productivity in temperate countries cannot be immediately transferred to tropical regions. This example is indicative of a broader phenomenon – agricultural technologies "spill-over" more easily within ecological zones than between them (Diamond 1997). Temperate countries benefit more from the research done by other temperate countries than tropical countries do. Of course, even within temperate regions R&D needs are distinct because of ecological conditions and factor endowments. Ruttan and Hyami (1990) show that the historical agricultural research needs of the US and Japan have differed significantly, despite their common temperate climates, due to the far greater availability of land in the US and labor in Japan.

Different farming technologies also create distinct R&D needs in developing countries. Farming in poor countries is less likely to be irrigated, more likely to take place on hillsides or degraded land, and likely to use few inputs (Pinstrup-Andersen and Cohen 2000). The main source of fertilizer is often livestock. Second, farming often takes place on a small scale and is not mechanized. Weeding, for instance, is done by hand, and draft animals may be the only available source of non-human power. Third, livestock are generally grazed on unmanaged pasture that is often a local common-property resource (Delgado *et al*. 1999).

These differences imply that the research oriented towards temperate, rich countries would not be sufficient for the needs of tropical countries, even if all technological advances were made freely available.

2.2 Public agricultural R&D expenditure

The share of agricultural GDP invested in public sector agricultural research is four times greater in rich countries than in developing countries (Table 1).[1] Although research on tropical agriculture is also performed at International Agricultural Research Centers under the umbrella of the Consultative Group for International Agricultural Research (CGIAR), accounting for these resources does not change the conclusion that public spending on tropical agriculture research is dwarfed by public research expenditure by temperate countries. Only in Asia is research intensity catching up with developed countries; research intensity is declining in Sub-Saharan Africa (Alston, Pardey, and Roseboom 1998).

[1] Expressing investment as a fraction of agricultural GDP is an indicator of research intensity and suggests whether the level of research is commensurate with income generated in agriculture.

Table 1: Annual public agricultural R&D spending as a percentage of agricultural GDP (%) in most recent year

Region	No. of countries	
Developed countries	18	2.39[b]
USA		2.22[c]
Sub-Saharan Africa[1]	17	0.58[b]
Asia & Pacific[2]	15	0.55[b]
China		0.42[d]
Latin America & Caribbean	26	0.54[b]
West Asia & North Africa	13	0.52[a]
CGIAR	42	0.19[e]

Source: James (1996), Alston, Pardey, and Roseboom (1998). [a]1981-1985, [b]1991, [c]1992, [d]1993, [e]1997. Authors' calculation of CGIAR research intensity based on CGIAR Annual Report (1999) and data from World Bank (1999). The denominator of this calculation is the sum of agricultural value added in all non-transition economies classified by the World Bank as low income. The numerator is total annual member contributions to CGIAR.
Notes: (1) Excludes South Africa. (2) Excludes China and Japan.

2.3 Private agricultural R&D expenditures

Private agricultural R&D is even more concentrated in rich countries than is public research expenditure. Table 2 compares private agricultural R&D in developed countries and in a few relatively dynamic developing economies for which data are available. In the US private research intensity is tens or hundreds of times greater than that in developing countries. Virtually no private agricultural R&D investment is targeted towards smaller or economically stagnant developing countries. In those developing countries in which private research intensity is relatively high, such as Colombia and Malaysia, this research is generally directed towards plantation crops, such as palm oil in Malaysia, that are primarily intended for sale in export markets (Pray and Umali-Deininger 1998). R&D in these sectors will arguably drive down world prices, making developing countries as a whole worse off.

To the extent that private companies are more effective in biotechnology research, the concentration of private research in rich countries suggests that, in comparison to developed countries, developing countries are relatively unprepared to generate technological advances in biotechnology.

Table 2: Private agricultural R&D expenditure in selected countries as a percentage of agricultural GDP (%) in 1995

Country	Private R&D expenditure as a fraction of agricultural GDP (%)
United Kingdom	3.71
United States	2.67
Australia	0.49
Colombia	0.41
Malaysia	0.15
Thailand	0.10
Philippines	0.06
India	0.03
Indonesia	0.01
Chile	0.01

Source: Pray and Umali-Deininger (1998); authors' calculation of expenditure per unit of agricultural GDP based on data from World Bank (1999).

The theory of induced innovation, and the historical experience of Japan and the United States, would suggest that appropriate policies and price signals can induce developers to create products that are tailored to particular regions and their ecological and factor endowments (Ruttan and Hayami 1990). However, the data presented above suggest that developing countries have not induced investment in innovation to meet their distinct needs. The next section examines the reasons for the low levels of private sector research relative to agricultural GDP in tropical countries.

3 Failures in the market for tropical agriculture research

Due to a variety of market failures, private returns to R&D are far smaller than social returns; private developers cannot appropriate many of the benefits associated with their research. Even with a well-functioning patent system, social returns to R&D are approximately twice the returns to private investors on average (Nadiri 1993; Mansfield *et al*. 1977). In agriculture in particular, however, firms often have difficulty capturing much of the economic benefit of their investment (Huffman and Evenson 1993). In the US, seed companies retained only 30 - 50 percent of the economic benefits from enhanced hybrid seed yields and only 10 percent of benefits from non-hybrid seed during 1975-90 (Fugie *et al*. 1996).

The gap between social and private returns may be more acute in tropical agriculture; in these regions market failures are particularly severe and poor countries provide little intellectual property rights (IPR) protection (Pray and Umali-Deininger 1998), lowering private returns to R&D.

The gap between private and social returns to investment in agricultural R&D is partly a result of the technological difficulty of preventing the resale of seeds. It is further exacerbated by governments' reluctance to protect developers' IPR because of time consistency problems, and because tropical agricultural research is an international public good benefiting many small countries. Fragmentation of intellectual property rights among several different firms can also reduce returns to R&D investment. Taken together, these market failures suggest a rationale for increased support for tropical agriculture R&D.

A key market failure that inhibits developers from recovering the cost of R&D in agriculture is the potential for the resale of seeds. Plants and animals self-multiply, and under traditional technologies farmers may use and sell their own seed or livestock in future periods after purchasing seed or animals once.[2] This is particularly problematic in developing countries.

If saved seeds were used by the farmer who originally purchased the seeds, seed developers would take reuse into account and could set the price of seeds equal to the present discounted value of the stream of benefits arising from the original seeds and the generations of saved seed created.[3] In contrast, if farmers can sell seed, competition among sellers will quickly drive seed prices close to marginal cost, eliminating the possibility for the seed developer to recoup R&D costs and thus eliminating incentives for investment in R&D.

[2] This is not true of other agricultural products, such as vaccines, medicines, and artificial reproduction technologies that can also improve productivity.
[3] However, to the extent that seeds are reusable, it is difficult for seed companies to price-discriminate among farmers with different size farms. If seeds were not reusable, seed companies could charge the same price per seed to all farmers and would wind up collecting more from farmers with more land. If seeds were reusable, they would sell a small amount of seed to each farmer. In this sense, farmers with small amounts

In practice, farmers reuse open-pollination seeds in both rich and poor countries, though there are efforts to prevent this in rich countries.[4] Resale, however, can generally be effectively prohibited in developed countries. If resale could also be policed in developing countries, these countries would not suffer disproportionately from a lack of R&D. However, prohibiting resale of agricultural products would be difficult in developing countries because farmers are dispersed across many small and often remote plots and seeds are frequently sold in rural markets on a small scale (Byerlee 1996). As a result, monitoring to determine whether farmers are selling seed is likely to be costly and infeasible in developing countries.

To the extent that the yield of seeds declines over time, as is the case with many hybrids of cross-pollinated crops, seed developers have more opportunity to recoup their R&D costs. Declining yields can make it profitable for farmers to purchase new seeds every season. However, this leads researchers to distort their effort towards areas where private, rather than social, returns are highest. Monopoly pricing may lead to inefficient reuse of seed with low germination. Firms also direct research toward non-seed products that are more appropriable, such as pesticides and herbicides, food processing techniques, and to agricultural products that will be used on plantations (Alston, Pardey, and Smith 1997).

Popular opposition is likely to block technological approaches to IPR protection through reuse prohibitions such as a gene use restriction technology (GURT), popularly known as a "terminator gene." When added to seeds, GURT would make the seeds sterile, requiring farmers to purchase new seeds each season, or after a specified number of seasons, in order to continue to use seeds developed with or embodying a particular technology (Jefferson *et al*. 1999). The intention of this product was to protect the property rights of biotechnology firms on seeds containing genetically modified material. Seeds containing this gene have not been commercialized, and GURT has been denounced as unethical by

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of land would be helped by a genetic use restriction technology, which prevents reuse of seed.

[4] For example, on September 13, 2000 a US jury ordered a Louisiana cotton producer to pay $2 million in damages to Monsanto and Delta and Pineland, two agriculture biotechnology firms, as damages for planting 4,000 acres with saved pest-resistant seed (Robinson, 2000). This was the first such case of its

international policy makers and in the popular press (Pinstrup-Andersen 2000, Pollan 1998, National Academy of Sciences 2000, UNDP 1999, ISNAR 1998).[5] As a result of public pressures, a major firm involved in this research, Monsanto, has announced that it has abandoned research on this technology. In general, the implications of GURT (particularly GURT seeds which remain fertile for more than one season) differ little from hybrid seeds in terms of the risks that farmers must bear, and there is evidence that developing country farmers are willing to use hybrids, especially for crops sold in markets. In particular, hybrid maize has been widely adopted in Kenya and Zimbabwe (Christensen 1994). However, the political situation implies that whatever the merits of GURT, it is unlikely that it will prove a solution to the appropriability problem.

The experience of countries with strong IPR for plant breeders has supported the notion that these legal incentives do, in fact, lead to more private R&D and greater technology transfer (Pray 1992), as suggested by Diwan and Rodrik (1991). Historical evidence also supports the contention that IPR encourages R&D in agriculture that is appropriate to local environments and endowments. Technical change in the agricultural sector of the US in the nineteenth and twentieth centuries was facilitated by the existence of an intellectual property rights regime (Khan and Sokoloff 2001), and the private sector played a dominant role in the development of hybrid maize in the 1950s in the US precisely because inbred lines could be kept proprietary (Hayami and Ruttan 1985).

Aside from the technical difficulty of limiting the resale of agricultural products, governments in developing countries have limited incentives to enforce IPR. As a result, most agricultural technology has traditionally been in the public domain, with few patents sought or enforced (Herdt 1999).

One reason why countries do not protect IPR is that agricultural research is subject to

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kind to be settled in court.

[5] Another means by which private developers might get around the multiplicative nature of seeds appears to be more popularly acceptable, but this technology has not yet been fully developed. There is a possibility that a gene can be developed that will act as an “on-switch” in genetically modified seeds. If a farmer applies a spray to his seeds, the desired pest-resistant gene will “turn on” the genetically enhanced quality. It is not clear why this differs fundamentally from the current GURT technology.

what economists call a “time consistency” problem. In general, biotech and agricultural research is both risky and costly, but once a product has been developed, it can be produced at a low unit cost. Without IPR protection, competition in production will drive price towards marginal cost, which is optimal for governments *ex post*, though they may want to create incentives for R&D *ex ante*. Governments therefore have little incentive to live up to commitments to protect IPR. This is not a new issue. Eli Whitney, for example, made little money from the patent that he held for the cotton gin. Blacksmiths could easily reproduce the cotton gin, and Southern juries were creative in finding reasons not to find in Whitney’s favor in numerous patent infringement suits that he filed (Green 1956). Modern researchers anticipate analogous problems in protecting IPR in developing countries.

Another reason for the lack of IPR protection in developing countries is that agricultural R&D is an international public good. No single country will capture all the benefits from a product. For example, an improvement in cassava productivity that is useful in Uganda may be useful in Nigeria and many other countries as well, leaving inadequate incentives for the protection of IPR by Uganda alone.

In the case of products that are grown in rich countries, such as wheat, individual developing countries can rely upon the research done in richer countries and be assured that their free riding alone will have only a marginal effect on total research output. In the case of products that are not grown in developed countries, such as cassava or millet, poor countries cannot free ride on rich country incentives. Because many small countries are beneficiaries of such research it is difficult to coordinate how any gains made by offering incentives such as IPR protection will be shared while excluding free riders. [6]

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[6] Theoretically, poor countries could provide property rights protection only to those products that are uniquely suited to their region. While writing such a property-rights regime into law would be difficult, allowing parallel imports would effectively accomplish such a policy if rich countries do not themselves allow the use of GURT.

To see this, suppose that African countries announced that they were allowing both the use of GURT and the parallel import of seeds that did not have genetic use restriction capability. If developed countries did not allow the use of GURT, firms might develop some products for those markets that did not have this technology, relying on legal and contractual protection of IPR in these countries. However, they might develop products for tropical climates that used GURT, since enforcement of IPR would otherwise be difficult in these areas, and a market for GURT products would be present. If seed imports were allowed, A final factor that inhibits R&D in agriculture is fragmentation of IPR. If several different firms hold complementary patents for a single desired final product, as may be the case if a series of sequential innovations or adaptations to local conditions are needed, then the parties acting individually may set higher prices than would be beneficial to the group collectively. Each IPR holder will neglect to take into account the negative externalities on final demand for other patent holders when setting their own price or licensing fee. Total revenues will be below their potential level if a single set of property rights existed for both technologies. As a result, incentives for R&D are reduced (Green and Scotchmer 1995).[7] *Ex ante* negotiations between developers can mitigate this problem, but such negotiations may be difficult to coordinate, or costly, in practice. While fragmentation of IPR can occur in many fields of technology, it is particularly important in agriculture because agricultural technologies must be adapted to local conditions. This implies that, for example, a different developer than the firm that produced the initial innovation may perform the R&D needed to specialize a technology to local conditions (Evans 1993).

All these factors suggest that the social rate of return to R&D may exceed the private return. Available evidence suggests that social rates of return are high. A review by Alston *et al*. (2000) finds that social rates of return to agricultural research are likely to be above most public and private hurdle rates, in the range of 40 to 80 percent on average. Other reviews confirm that the social rate of return to agricultural R&D is high, in both the US, where Fugie *et al*. (1996) report returns in the range of 40 to 60 percent, and in Africa where Masters, Bedingar and Oehmke (1998) report a much wider range of returns, the majority of which exceed 20 percent.[8]

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then in practice African countries would have access to tropical products with GURT and temperate products without them. Of course, each cassava-growing country would still have incentives to free ride off incentives provided by other cassava-growing countries, and this would make it difficult to secure agreement on such an approach.

This scenario is similar to the proposal made by Lanjouw (2001) for reforms to the patent system for pharmaceuticals.

[7] For a discussion of the implications of sequential innovation for GURT see Swanson and Goschl (2000).

[8] Because of the possibility that the rates of return to successful projects are over-reported relative to those from unsuccessful projects, and because the characteristics of the research being evaluated and rate of return measures vary across studies, these results from surveys of impact studies must be interpreted with

The market failures in agricultural R&D, combined with evidence of high social rates of return to R&D, suggest that programs that encourage the global public good of development of agricultural products used in developing countries could be a cost-effective use of development-assistance budgets. The next two sections of this paper consider what forms of encouragement this effort might take.

4 Ways to encourage R&D in tropical agriculture

Programs to encourage agricultural R&D can be broadly classified as "push" and "pull" interventions. Push programs subsidize research inputs, while pull programs pay for research outputs. Examples of push programs include the grant-funded CGIAR system, work performed in government laboratories, R&D tax credits, and grants to academics such as those provided by the United States National Science Foundation (NSF). Another example is the system of grants provided by USAID to American land-grant universities to perform research in tropical agriculture called the Collaborative Research Support Programs (CRSPs).

Pull programs, on the other hand, increase rewards for the development of a particular technology, for example, by promising to purchase an approved product once it is developed.

Section 4.1 describes the strengths and weaknesses of push programs. Section 4.2 describes the potential benefits and problems of pull programs. We argue that pull programs are best suited to situations in which the desired innovation can be clearly defined.

4.1 Push programs

Direct public funding is typically the best way to stimulate basic research. Simply rewarding development of applied products is not an appropriate means of stimulating

care, however.

basic research since the main objective of these efforts is to provide information to other researchers rather than to develop specific products. In the case of agriculture, for example, basic research in genetics and plant physiology complements more applied research in plant breeding. A program that ties incentives to the development of a particular product would encourage researchers to keep their basic research results private as long as possible in order to have an advantage in the next stage of research. In contrast, grant-funded academics and scientists in government laboratories have career incentives to publish their results quickly. Pull funding of basic research is typically difficult, since it is often hard to describe the desired results of basic research in advance.

While critical for basic research, push programs are subject to information asymmetries, imperfectly aligned incentives between funders and scientists, and politicization. These difficulties can mean that funds spent on push programs may be wasted, and that unpromising avenues of research can continue to be funded.

Information problems arise because scientists know their prospects for developing new products better than policy makers and donors. Scientists may overstate the usefulness of their work or the probability of success in order to appeal for funding. Information asymmetries are also important because scientists are likely to be relatively more interested than funders in pursuing lines of research that will achieve scientific, as opposed to commercial, goals.[9] The later stages of research, which take an innovation through the regulatory and testing process needed for commercialization, tend to be less intellectually interesting than the initial basic research. Scientists may also divert funds for uses not intended by donors.

Many technologies developed by push program scientists have been adopted at low rates in developing countries because scientists have failed to develop products that address constraints faced by farmers (Christensen 1994). Advances worthy of scientific acclaim,

[9] Hiring scientists on a long-term basis at CGIAR institutions, for example, can mitigate this problem. Because scientists employed at these institutions are charged with performing applied research that will result in usable products, it is less tempting to engage in research that will not result in practical agricultural innovations.

such as improved cowpeas that defoliate, that have seemed promising in a controlled environment have not translated well to mixed cropping environment in which farmers actually work (Carr 1989). In an effort to improve adoption rates, recent research programs, such as the Cassava Biotechnology Network, have attempted to identify attractive technological advances by interviewing farmers about their perceived needs (Arends-Kuenning and Makundi 2000). While this may be an improvement over research programs that have no input from farmers' responses to survey questions may depend on how questions are asked; farmers may not know the scientific opportunities and challenges, and there may be opportunities for scientists to manipulate or ignore farmers' responses.

Another problem with push programs is that policy makers and donors running grant programs may be tempted to allocate funds on the basis of political, rather than scientific, considerations.[10] For example, the funds given by USAID to the CRSP program every year are restricted to US land-grant colleges and universities. In fact, a goal of the program is to strengthen these institutions (US Congress 1975). This political goal may compromise the usefulness of this push program if more effective institutions could perform the desired research.

Political considerations may also lead to inappropriate siting of facilities and may make firing staff or terminating particular research programs difficult. Political constraints on salary may preclude hiring staff of the quality found in the private sector. Public sector institutions and programs have historically been difficult to shut down, even if ineffective. Likewise, programs may be initiated for political rather than scientific reasons. For example, CGIAR created the International Center for Agricultural Research in Dry Areas (ICARDA) in 1977 in part to attract funds from the Middle Eastern oil exporters to CGIAR (Eicher 1994). ICARDA is located in Syria, a relatively difficult

[10] The World Bank and other donors have made recent efforts to increase the role of competitive bidding in funding decisions for research performed by African national agriculture research systems (SPAAR Annual Report 1997), in part to alleviate this phenomenon. This constitutes a small portion of total funding. For a review, see Gill and Carney (1999).

country in which to attract and retain high-quality professionals.[11]

R&D tax credits are another type of push program. These credits are subject to problems similar to direct public funding and may be difficult to target. Firms doing research with only indirect implications for the development of the desired technological advance may try to claim the tax credit. Another problem is that only income-earning companies benefit from this policy, so biotech start-ups may not be able to access these funds. As discussed in sub-section 4.2, a tax credit for actual sales avoids this problem, since the credit is only available after the development of the technology.

There is an existing infrastructure for push research in tropical agriculture at the CGIAR research centers, which perform research without seeking property rights protection for their innovations (Alston, Pardey, and Roseboom 1998). CGIAR receives contributions of about $300 million per year (CGIAR 2000). The research performed at the CGIAR centers might be effectively supplemented with an expansion of competitive grant programs. A new international institution could give research grants to any institution from any country. This would be analogous to the extramural funding provided by the US National Institute of Health (NIH), in which NIH experts choose a research priority and a budget and then solicit bids via a request for proposals.

4.2 Pull programs

If policy makers can identify a specific desired technology, it may be more cost-effective to reward research outputs using a pull program rather than more traditional push funding mechanisms. Rewarding research outputs in such appropriate instances may complement existing research efforts at the CGIAR centers and elsewhere. Under pull programs, policy makers or donors pay nothing unless the desired technology is developed, and they pay only for concrete research outputs that meet pre-specified criteria. This creates strong incentives for researchers to (1) carefully select research projects, and (2) focus on developing viable products that genuinely respond to the needs of farmers, rather than

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[11] Despite the relative wealth of the countries served by ICARDA's research, only about 7.5 percent of ICARDA's budget currently comes from Arab countries (CGIAR 2000).

other goals. Policy makers and funders need not themselves select the research approach that should be pursued, but only the necessary characteristics of the final product. Project selection is in the hands of those with the most information.

In the case of agriculture, a pull program would be most effective if the total reward were tied to adoption levels. The power of farmers in determining the characteristics of products brought to market is increased if payment is structured on a per unit basis, rather than as a lump sum, thus rewarding diffusion as well as innovation and creating incentives for researchers to make their products widely applicable and desirable.[12] This is attractive precisely because diffusion of new technologies has been difficult in developing country agriculture in the past (Christensen 1994, Carr 1989).

Under such a pull program, researchers would have strong incentives to maximize commodity uptake and thus to make technological advances that are useful and appropriate for smallholders, taking into account local ecologies and real world farming practices. They would also have incentives to take into account the fact that a key determinant of adoption of new food crops is taste and appearance. Tying rewards to adoption may be a more effective means of inducing the development of technologies that are responsive to small farmers' needs and tastes than recommending that scientists make a show of soliciting farmers' opinions about needed technologies. For such a commitment to increase research effort, governments must credibly state what products will be eligible for the guaranteed payment offered by the pull program and what technical and regulatory hurdles products must overcome to access the commitment.

This proposed pull program is similar to a purchase commitment that has been advocated for vaccines (see for example Kremer 2000a, 2000b, and Sachs and Kremer 1999). [13] A purchase commitment acts to guarantee a unit price, like this proposal, but also guarantees a minimum quantity to be purchased for a particular desired technological

[12] Other pull program designs issues, such as ensuring that the award is credible and fairly rewarded to competing inventors, are discussed in detail in Kremer (2000b).
[13] Other pull mechanisms are less attractive. Patent extensions on the desired technology reduce access and in any case, an extended exclusive right to produce an unprofitable product is not very enticing. Patent

development. In the case of vaccines it is fairly easy to determine the quantity that will be needed as a function of vaccine characteristics. This is more difficult for seeds, and hence pull programs in agriculture should be linked to take-up of the technology.

Sales tax credits, which rebate some of the tax bill of the developer of a product for every unit of that product sold, provide another pull program linking the size of the reward to adoption rates.

For applied research, the incentive mechanisms created by pull programs can relieve the pressure on funders to "pick winners" and can also align the incentives of scientists and policy makers more effectively than grant-funded research. Because rewards depend on use, developers have strong incentives to ensure that their technology will actually be adopted. However, the case for push funding mechanisms remains strong for research at the early stages, and in cases in which it is impossible to specify the desired product.

In the next section we examine how policy makers might use pull mechanisms for specific advances in tropical agriculture. As an illustrative example, we consider the possibility of a pull program for finger millet modified to be resistant to blast.

5 Using pull programs to encourage innovation in tropical agriculture

For pull programs to work, policy makers must be able to identify particular desired technologies, define the necessary health and safety characteristics of the product, and establish procedures for approving products. To determine the appropriate payment to offer for new products, policy makers will also need an estimate of the social value of inventions. In this section, we take up each of these considerations in the case of tropical agriculture.

5.1 Identifying desired advances and their social values

Serageldin and Persley (2000) have identified several constraints that limit the

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extensions on other products distort the markets for these products.

productivity of tropical agriculture. They contend that, because of the nature of these constraints, advances are most likely to come from biotechnology, the portion of agricultural research that is dominated by the private sector. These constraints are summarized in Table 3. Some constraints are global, while some are region-specific. Certain other constraints, such as the low protein content of maize, are global, but have negative effects on only developing countries. Research to alleviate one of these specific constraints may be appropriate for pull funding.

Table 3: Agricultural Constraints in Developing Countries

Commodity	Problem	Affected Regions
Banana/plantain	Black Sigatoka disease	Global
Cassava	Cassava mosaic virus	Sub-Saharan Africa
Maize	Apomixis	Global
	Low protein content	
	Drought	
Millet	Blast resistance	South Asia/ Africa
	Photoperiod response	Global
Sorghum	Drought, heat tolerance	South Asia/ Africa
Rice	Blast, submergence	Global
	Low Vitamin A content	
	Low yield potential	
Wheat	Heat tolerance	Africa/ Asia
	Drought/salinity tolerance	
Cattle	Trypanosomosis	Global
	East coast fever	Africa
Sheep	Heat tolerance, helminths	Global
Goats	Helminths	Global
Chicken	Newcastle virus	Global
Pigs	Viral diseases	Global

Source: Serageldin and Persley (2000).

5.1.1 Example: A pull mechanism for finger millet blast

As an illustration of how a pull mechanism might work for tropical agriculture, consider the case of finger millet blast, or pyricularia blight. This is a fungus that affects a staple crop grown throughout the middle elevations of Eastern and Southern Africa and in South Asia, which can reduce yields by more than 50 percent, and sometimes as much as 90 percent (Pande *et al*. 1995, Adipala and Bua 1995). Finger millet is especially important in Kenya, Uganda, and India, for example, but it is neither grown nor used on any significant scale in rich countries. Total global production is around 3 million metric tons annually, primarily for domestic consumption (National Academy of Sciences 1996).[14] Millet is well adapted to dry and infertile soils, but because it is generally grown in harsh conditions, it has lower yields than other cereals, on average around 0.75 tons per hectare (ICRISAT and FAO 1996).

Table 4 shows rough illustrative calculations of the social value of a blast-resistant seed using millet production data reported by ICRISAT and FAO (1996). Pande *et al.* (1995) use survey results from a random sample of finger millet to estimate the relationship between blast severity and yield reduction. The yield reduction caused by the average severity of blast is 21 percent. This figure is sensitive to the line of finger millet planted, but should be a conservative estimate of average losses because Pande *et al.* performed their survey on a line of finger millet that is considered to be agronomically elite, with some lodging resistance (Esele and Odelle 1995).

Table 4: Illustrative calculation of upper bound of payment for development of finger millet resistant to blast (pyricularia blight)

Row	Figures	Definition	Source
1	172.71	Average market price ($ / mt)	(a)
2	0.75	Average actual yield (mt / ha)	ICRISAT & FAO
3	21.00	Average yield reduction from blast (%)	Pande *et al.*
4	0.16	Output lost from blast (mt / ha)	Row 2 * row 3 / 100
5	27.63	Unit value of seed resistant to blast ($ / ha)	Row 4 * row 1
6	3.33	Finger millet area in developing countries (million ha)	ICRISAT & FAO
7	92.02	Total value of seed resistant to blast (million $)	Row 5 * row 6

Source: Authors' calculations.
Notes:(a) Ackello-Ogutu and Echessah (1998) report average prices of finger millet (per kilogram) in informal cross-border trade between Tanzania and neighboring states (Kenya, Malawi, Zambia, Democratic Republic of Congo, and Uganda) in 1995 and 1996. These reported prices are converted to dollars using exchange rate information from CIA Factbook. Similar, though slightly lower, prices are reported for Bangalore, India by the Indian Society of Agribusiness Professionals (2000).

Using 1994 production figures, we estimate the dollar value of the lost finger millet crop to blast to be approximately $92 million, and therefore the social value of millet that is

[14] Production of finger millet represents about 10 percent of total annual millet production; it is far less common than pearl millet (ICRISAT and FAO 1996).

resistant to blast to be around $28 for a hectare's worth of seed inputs.[15] This measurement of the social value of this technology is an underestimate because blast also reduces 1000-grain mass, a measure of grain quality, a cost not accounted for in these calculations (Pande *et al*. 1995). The measurement of the social value is dependent on the yield potential of the new line of millet; this payment would be inappropriate for a blast-resistant line with a lower yield.

In order to operationalize a pull program for finger millet resistant to blast, the calculation made in table 4 would need to be extended to calculate the appropriate payment for a range of blast-resistant finger millet lines. As well as depending on adoption rates, payment should be dependent on the mean and variance of the yield of the new technology. To avoid the potential result of providing a large reward for a new technology that is only slightly better than existing technologies, funders would need to establish a series of baseline technical criteria that the new technology must meet.

Given the importance of paying for the new product on the basis of total demand, it is likely to be most feasible to pay the firm on the basis of total hectares planted with seeds using the particular technology each year, rather than on the basis of total seeds sold. In the millet example, surveys could be conducted to estimate the prevalence of the new technology, and the firm could be compensated accordingly. This would allow the practice of saving seed to continue, while still providing a return to product developers that covers their research costs and compensates them for bearing risk. This would also mitigate the potential for firms to distort the seed market, for example by offering gifts to those that purchase the product. For the developer to receive payments from the pull program farmers would have to actually plant seeds that they purchase.

One possibility might be to structure the payment to the firm as a percentage of the market price of millet grown using seeds that contain the new technology. In theory this could make many of the specification problems less onerous. The price of the product,

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[15] This is significantly higher than the estimate of the economic value of blast-resistant finger millet made by ICRISAT (1992), which is $8.3 million. However, it is unclear how this estimate was made, and

relative to the price of millet grown using traditional seeds, should summarize information about the aesthetic appeal of the millet. The price should also reflect the fact that farmers will not be enthusiastic about adopting a technology that gives only a small gain (see, for example, the comparison of adoption rates in Africa for new varieties of maize, which can increase yields by 40 percent, and sorghum/millet, for which yield increases are very small without the use of inorganic fertilizers, in Maredia, Byerlee, and Pee 1998).[16]

5.2 Eligibility criteria: Health and environmental safety

If a pull program, such as the one for blast-resistant finger millet described above, were used to encourage research in tropical agriculture, donors and policy makers would need to specify the characteristics that the product should exhibit to be eligible for the program. This would include a requirement that potential advances meet environmental and health regulatory standards before a firm could receive any reward. The regulatory review process could take place in a donor country, or through an international organization.

A pull program for tropical agriculture could require that eligible products pass the same regulatory review process as products in developed countries do. Alternatively, some international organization such as the Food and Agriculture Organization could develop a regulatory regime. If the new product is developed using biotechnology, effective regulation will address both the environmental implications of a new agricultural product (e.g., its weediness), and the health implications of the product (e.g., whether it contains allergens). To determine which regulatory regime is the most preferable, several questions must be addressed. First, can developed-country institutions such as the United States Environmental Protection Agency (EPA) review products that will not be grown in those countries? Second, can international organizations develop review processes that

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whether the full social value of blast-resistance was calculated.

[16] The price of the seed (or other technology) itself will not contain information about the desirability of the product if, as is likely, firms act strategically. Because the total payment will be dependent on adoption, firms could set the price at zero, or close to it, or give away gifts to farmers to encourage purchase of the technology.

have as much credibility as the US EPA and Food and Drug Administration? Third, can a pull program credibly rely on developed-country institutions, whether for actual regulatory review or for guidance as to how a review process should work? These institutions are relatively controversial—and perhaps still evolving—in the area of biotechnology. Public confidence in the developed world about the effectiveness of the regulation of agriculture biotechnology is low relative to, for example, confidence about the regulation of new drugs (see, for example, Pollan 1998).

In developing countries it is likely that guidelines for growing products to postpone the evolution of resistant pests (a resistance management program) will be impossible to enforce. This means that if the pull mechanism rewards development of a pest-resistant plant or a pesticide, the rules of the mechanism must make clear that the subsidy will only be available as long as the product works. If payments depend on adoption donors have some protection against the possibility of paying for products that work for only a short period of time. Firms will have incentives to develop products that are more effective for longer periods, or to invest in teaching farmers management techniques.

6 Summary and conclusions

This paper examines the potential for innovative financing mechanisms to encourage technical change in tropical agriculture. We begin by suggesting that the rates of return to this research are high, but that too little research is undertaken by the private sector due to significant failures in the research market and, in particular, the difficulty of preventing the resale of agricultural products. Adoption rates for new technologies in this sector have also been traditionally low, despite efforts to solicit farmers' preferences. We also show that research expenditures in rich countries vastly outweigh expenditures in poor countries, particularly expenditures by the private sector. This is despite the fact that many more people make their living in agriculture in poor countries and that undernourishment remains a pressing problem in these countries.

These persistent market failures, combined with high rates of return in this sector, suggest a potential role for government intervention. However, traditional push programs have created outputs that are often subject to low adoption rates. Under push programs, researchers have incentives to pursue research avenues that do not result in products farmers will want. "Pull" funding programs seem to be a promising mechanism to complement traditional publicly funded research in this area – particularly in light of the growing importance of private sector research in biotechnology. Pull mechanisms are attractive because no resources are spent until the desired product is developed and approved by regulators, and they can be structured so total expenditure depends on adoption rates. This creates strong incentives for researchers to select appropriate projects and then focus on developing products that farmers will want to use.

For such funding mechanisms to work, policy makers need to define appropriate products, and measure their uptake upon development. Our review suggests that, at a minimum, experimentation with pull programs for tropical agriculture is warranted as a complement to existing push-funded research. To operationalize a pull program, additional research will be needed to determine the appropriate regulatory institutions that would approve new products and to more accurately calculate the social value of desired products.

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