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Encouraging Private Sector Research for Tropical Agriculture

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Summary. — 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 research is particularly concentrated in rich countries. This is a result of significant failures in the market for research and development (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 research may be usefully supplemented by a commitment to reward developers of specific new agricultural technologies. Rewards tied to adoption may be especially useful in increasing up-take. An illustration of how a commitment to reward developers of new agricultural technologies might work is provided.

Key words — agriculture, R&D, technical change, tropical countries

1. INTRODUCTION

Developing countries urgently need increases in agricultural productivity. As of 1995, 57% of the labor force in low-income countries (classified by the World Bank as those countries with income per capita below $745 in 2001) was engaged in agriculture (World Bank, 2002), and 797 million people in the developing world remained undernourished in 1999 (FAO, 2002).

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 (see, for example, Huang, Pary, & Rozelle, 2002). 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

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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 Roseboom (1998) estimate that the annual growth rate of private agriculture R&D expenditures in the United States, United Kingdom, and Japan was approximately 5% during 1981–93. Other authors have suggested that increased private sector biotechnology research effort for the tropics is important and desirable (Arends-Kuenning & Makundi, 2000; Byerlee & Fischer, 2002; Pardey, Roseboom, & Beintema, 1997; Spillane, 2002; World Bank, 2001). 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. In Africa, widespread research adoption is generally confined to cash crops alone. More recently, the International Institute for Tropical Agriculture has again identified the "limited adoption of new and improved technologies that have been developed by the research community" as an important problem limiting the growth of food production in sub-Saharan Africa (IITA, 2002, see also Santaniello, 2002), in addition to the lack of technologies themselves. 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. Masters (2003) also considers a similar set of issues and has proposed a funding mechanism for tropical agriculture that is related to the proposal made by Kremer (1998) for public buy-out of socially valuable patents. More broadly, this paper is related to the academic literature on research incentives, including Scotchmer (1999), Shavall and Van Ypserle (2001), Wright (1983), and to the extensive literature on agricultural research in particular, including Alston and Pardey (1996), Evenson and Kislev (1976), Evenson and Westphal (1995), Huffman and Just (1994, 2000), Huffman and Evenson (1993) and Sunding and Zilberman (2001) and the references therein.

This paper 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.

The paper then examines whether increased traditional funding of agricultural research may be supplemented by a commitment to pay for specific products upon development. We suggest that this funding mechanism, which rewards private firms for successfully developing technologies chosen by policy makers, may be promising if payments can be structured so that a developer's reward depends on adoption. Crucially, such a commitment would not require that seed reuse be prohibited to increase incentives for R&D. It can also provide incentives for developers to design products that can work even in the context of the faulty supply chains for agricultural products that are often encountered in developing countries, or to improve these supply chains directly. As examples, we provide an approach to calculating and structuring the payment that might be provided to a firm that develops finger millet seed resistant to blast (pyricularia blight) or banana that is resistant to black Sigatoka disease.

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

Section 4 examines the 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 outputs, can be useful 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 that are not being met. Agricultural research expenditure as a share of agricultural GDP in developing countries is dwarfed by expenditure in rich countries, and while this gap is significant for public R&D, it is even larger for private R&D (Pardey & Beintema, 2001).

(a) *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 (Binenbaum, Pardey, & Wright, 2003). Tropical countries have distinct agroecological systems, including higher average temperatures, relatively fragile soils, a lack of a seasonal frost, and eco-zone specific weeds and pests (Masters & Wiebe, 2000). Climatic zone-specific productivity constraints 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; Johnson & Evenson, 2000). Temperate countries benefit more from the research done by other temperate countries than tropical countries do. [1]

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 & 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 nonhuman power. Third, livestock are generally grazed on unmanaged pasture that is often a local common-property resource (Delgado, Rosegrant, Steinfeld, Ehui, & Coubois, 1999).

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

(b) *Insufficient agricultural R&D expenditure*

The share of agricultural GDP invested in public sector agricultural research is nearly four times greater in rich countries than in developing countries where 0.62% of agricultural GDP is spent on public research (Pardey & Beintema, 2001). Although research on tropical agriculture is also performed at International Agricultural Research Centers (IARCs) 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. [2] In Latin America and Asia research intensity is catching up with developed countries; research intensity is declining in sub-Saharan Africa where the most recent figures show public expenditures to be about 0.85% of agricultural GDP as compared to 2.64% in developed countries (Pardey & Beintema, 2001).

Private agricultural R&D is even more concentrated in rich countries than is public research expenditure (Pardey & Beintema, 2001; Pray & Umali-Deininger, 1998). In the United States private research intensity is tens or hundreds of times greater than that in developing countries. The private sector performs much of the biotechnology research, with proprietary claims to key tools and products for this type of R&D (Byerlee & Fischer, 2002). Most important, virtually no private agricultural R&D investment is targeted toward smaller or economically stagnant developing countries. In those tropical countries in which private research intensity is relatively high, such as Colombia and Malaysia, this research is generally directed toward plantation crops, such as palm oil in Malaysia, that are primarily intended for sale in export markets (Pray & Umali-Deininger, 1998). R&D in these sectors will arguably drive down world prices making developing countries as a whole worse off.

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 (Hayami & Ruttan, 1985; Ruttan & Hayami, 1990). The figures reported above suggest, however, that many tropical 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

Available evidence suggests that social rates of return to agricultural R&D are high. A review by Alston, Chan-Kang, Marra, Pardey, and Wyatt (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 40–80% on average (see also Evenson, 2001). Other reviews confirm that the social rate of return to agricultural R&D is high, in both the United States, where Fuglie *et al.* (1996) report returns in the range of 40–60%, and in Africa where Masters, Bedingar, and Oehmke (1998) report a much wider range of returns, most of which exceed 20%. [3]

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 (Scotchmer, 1999; Shavall & Van Ypserle, 2001; Wright, 1983, and especially Evenson & Westphal, 1995 in the case of agriculture). 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 & Umali-Deininger, 1998), lowering private returns to R&D. Even with a well-functioning patent system, social returns to R&D are approximately twice the returns to private investors on average (Mansfield *et al.*, 1977; Nadiri, 1993). In agriculture in particular, however, firms often have difficulty capturing much of the economic benefit of their investment (Huffman & Evenson, 1993). In the United States, seed companies retained only 30–50% of the economic benefits from enhanced hybrid seed yields and only 10% of benefits from nonhybrid seed during 1975–90 (Fuglie *et al.*, 1996).

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. [4] If farmers can sell seed, as well as reuse it, competition among sellers will drive seed prices close to marginal cost, eliminating the possibility for the seed developer to recoup R&D costs and thus quickly eliminating most of the incentives for investment in R&D.

In practice, farmers reuse nonhybrid seeds in both rich and poor countries, though resale for some products is at least imperfectly prohibited in developed countries. If resale could be policed as effectively in developing countries, these countries would not suffer disproportionately from a lack of R&D. But prohibiting resale of agricultural products would be difficult in poor countries because farmers are dispersed across many small and often remote plots and seeds are frequently sold in small amounts in rural markets (Byerlee, 1996).

Other means of capturing the economic benefits of saved seed are also possible in developed countries that are infeasible in poor countries. In the United Kingdom, for example, a flat-rate royalty on proprietary cultivars is collected as a surcharge on seed-cleaning services (Evenson & Wright, 2001). Even in developed countries, however, private investment in improved self-pollinated or open-pollinated varieties continues to be limited despite attempts to protect IPR and limit resale; for example, the Plant Variety Protection (PVP) Act of 1970 appears to have done little to stimulate research on wheat productivity in the United States despite the fact that it nominally makes the resale, though not reuse, of seed from a PVP variety illegal (Alston & Venner, 2002).

To the extent that the yield of saved seed declines over time, as is the case with many hybrids and improved open-pollinated varieties, 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. This may, however, lead researchers to distort their effort toward areas where private, rather than social, returns are highest. Similarly, firms also direct research toward nonseed products that are more appropriable such as chemical and mechanical technologies (Alston, Pardey, & Smith, 1997).

Popular opposition is likely to block technological approaches to IPR protection such as gene use restriction technologies (GURTs), one version of which is popularly known as a "terminator technology." When added to seeds, this "terminator" technology could 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, Blyth, Correa, Otero, & Qualset, 1999). GURTs, which may take several forms, are intended to protect the property rights of firms for products containing genetically modified material. Seeds containing this technology have not been commercialized, and GURTs in general have been denounced as unethical by policy makers and in the popular press (ISNAR, 1998; National Academy of Sciences, 2000; Pollan, 1998; UNDP, 1999). Whatever the merits of GURTs, it is unlikely that they will prove a solution to the appropriability problem in the short run. [5]

The experience of countries with strong IPR for plant breeders supports the notion that these legal incentives do lead to more private R&D and greater technology transfer (Diwan & Rodrik, 1991; Pray, 1992; Swanson & Göeschl, 2000). Historical evidence also supports the contention that IPR protection encourages R&D in agriculture that is appropriate for local environments and endowments. Technical change in the agricultural sector of the United States in the 19th and 20th centuries was facilitated by the existence of an IPR regime (Khan & Sokoloff, 2001), and the private sector played an important role in the development of hybrid maize varieties in the 1950s in the United States precisely because inbred lines could be kept proprietary (Hayami & Ruttan, 1985).

Aside from the technical difficulty of limiting the resale of agricultural products, and despite the evidence that effective IPR protection can lead to increased R&D, governments in developing countries have limited incentives to protect 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 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 toward 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. [6] 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 protection of IPR by Uganda alone.

In the case of products that are grown in rich countries, such as wheat, most small developing countries can rely upon the research done in rich countries and be assured that their free riding will have only a marginal effect on total research output. In the case of products 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. [7]

Another 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 & Scotchmer, 1995). *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 locally adapted. 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).

Even if IPR were protected in developing countries, missing links in the formal product supply chain in these countries create barriers to technology diffusion that reduce incentives for R&D (Tripp & Rohrbach, 2001). Traditionally, a formal sector seed-supply chain begins with improved germplasm that is used by breeders to develop locally adapted varieties. Variety release is typically allowed with either mandatory or voluntary registration and associated testing. Seed multiplication is done by either the private or public sector and is also subject to voluntary or mandatory certification and quality control. This commercial seed reaches farmers through processors, cooperatives, retailers and other vendors. Extension agents and NGOs may also participate in distribution efforts. Each element of this chain often fails to function effectively in poor countries.

New varieties often fail to reach farmers in poor countries or reach them after a long delay because distribution occurs mainly through informal channels including seed saving and barter (Marieda, Howard, & Boughton, 1999; Nottenburg, Pardey, & Wright, 2002). Inefficiencies or shortcomings in the multiplication and distribution of planting material in poor countries increase the cost of distributing new cultivars and thus act as a disincentive to private research. Developers anticipate that desirable products may not reach farmers in a timely fashion because of problems with the supply chain. This uncertainty reduces expected profits and, accordingly, research effort.

The market failures in agricultural R&D for the tropics combined with evidence of high social rates of return to R&D suggest that international support for tropical agricultural R&D is a potentially 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 (see Anderson, 1997), work performed in National Agricultural Research Systems (NARS) and other government laboratories, R&D tax credits, and the system of grants provided by USAID to US 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. Such programs have been seriously considered as a means of encouraging R&D for tropical diseases (Kremer, 2001a, 2001b; Kremer & Glennerster, 2004; Sachs & Kremer, 1999), and suggested as potentially useful in tropical agriculture (Arends-Kuenning & Makundi, 2000; Sachs, 1999; Spillane, 2002; World Bank, 2001).

In Sections 4(a) and 4(b) we discuss the merits of these approaches to funding research. We argue that pull programs are best suited to situations in which the desired innovation can be clearly defined by donors or governments.

(a) *Push programs*

Direct public funding is typically the best way to stimulate basic research. [8] Simply rewarding development of applied products is not an appropriate means of stimulating 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.

There is an existing infrastructure for push research in tropical agriculture at the international CGIAR research centers, which usually perform research without seeking property rights protection for their innovations (Alston *et al.*, 1998). CGIAR receives contributions of about $360 million per year (CGIAR, 2002), or about 12% of public spending on tropical agriculture R&D (Pardey & Beintema, 2001).

CGIAR played a key role in developing the suite of technologies responsible for the Green Revolution, providing huge gains in agricultural productivity and welfare throughout the world.

While critical for basic research, and often more important for more applied work, push programs are subject to information asymmetries, imperfectly aligned incentives between funders and scientists, and are vulnerable to politicization (Huffman & Just, 2000). Funds spent on push programs may be wasted, and unpromising avenues of research can continue to be funded. These inefficiencies can make it difficult to realize fully the potentially extremely high returns to the investment of public funds to compensate for limited private interest in agricultural R&D.

Information asymmetries arise because scientists know their prospects for developing new products better than policy makers and donors. These asymmetries can hamper push programs. Scientists may overstate the usefulness of their work or the probability of success in order to appeal for funding. Scientists may be interested in projects that are academically interesting but have little real-world applicability. [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.

Some technologies developed by push program scientists have historically been adopted at low rates in developing countries (IITA, 2002) because scientists have failed to develop products that address constraints faced by farmers (Christensen, 1994; Santaniello, 2002). Some advances worthy of scientific acclaim, such as improved cowpeas that defoliate for example, which have seemed promising in a controlled environment have not translated well to the mixed cropping environment in which farmers actually work (Carr, 1989). Constraints that scientists may think are important can be of secondary concern to farmers. For example, Theile, van de Fliert, and Campilan (2001) discuss a case in which technology to reduce pest-induced losses from sweet potato weevil in Uganda was met with little enthusiasm because farmers, in this case, were more interested in improved root quality. Adoption has also been slowed by technological advances that alter the taste or appearance of food crops. Theile, van de Fliert, and Campilan describe an improved variety of sweet potato that farmers in Uganda declined to adopt because the color of the plant was redder than the traditional variety, and Nowakunda, Rubaihayo, Ameny, and Tushemereirwe (2002) describe the inferior use quality (high tannin, hard texture, and poor taste) of hybrid bananas available in East Africa.

Creating incentives for scientists to develop products that farmers will want to adopt through push programs is challenging. Even if donors require that scientists work with farmers to identify their perceived needs and decide what research to undertake, such as the Cassava Biotechnology Network does for example (Arends-Kuenning & Makundi, 2000), scientists may sometimes make only *pro forma* efforts to identify farmers' needs. Even if scientists genuinely seek participation from farmers, it may be difficult to know how to assess farmers' input. Responses to survey questions may depend on how questions are asked and farmers may not know the scientific opportunities and challenges.

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. For example, the funds given by USAID to the CRSP program every year are restricted to United States land-grant universities. In fact, a goal of the program is to strengthen these institutions (United States 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. Greenland (1997) discusses these issues in the context of CGIAR.

Public sector institutions and programs may be difficult to shut down. Bertram (1993) summarizes the experience of CIMMYT's (International Maize and Wheat Improvement Center) work on triticale. Beginning in the 1960s, CIMMYT began working on triticale, believing that it had good potential for adoption in poor countries. CIMMYT succeeded in improving the weight and grain quality of the crop and it has been adopted widely, but overwhelmingly in developed countries. Determining when or if CIMMYT, which is mandated to focus on the needs of developing countries, should cease working on triticale is a difficult decision to take.

Likewise, programs may be initiated for political rather than scientific reasons. Some have suggested that political considerations, in part explain the establishment of the International Center for Agricultural Research in Dry Areas (ICARDA) in 1977 (Eicher, 1994). ICARDA is located in Syria, a country in which it may be relatively difficult to attract and retain high-quality professionals, and its mandate overlaps with that of another CG center (Greenland, 1997). Outside observers continue to suggest that the CGIAR might consider requiring ICARDA to generate "strong" funding from the Middle East or cease as a CG center (Anderson, 1998).

(b) *Pull programs*

In cases in which policy makers can identify a specific desired technology and its social value, it may be effective to complement existing or expanded research efforts at the CGIAR centers and elsewhere by rewarding research outputs using pull programs. Under pull programs, policy makers or donors pay only for concrete research outputs that meet pre-specified criteria. This creates strong incentives for researchers to (i) carefully select research projects, and (ii) focus efforts on developing viable products rather than on other ancillary 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. Pull programs in agriculture could potentially be used both in rich and in poor countries, particularly for non-hybrid crops where appropriating returns is difficult, but we focus here on their potential in tropical agriculture.

In agriculture, a pull program may be most effective if donors pre-specify a desired technology and commit to paying a reward that is tied to adoption levels in the event that this technology is developed. 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 products widely applicable and desirable. This is attractive precisely because diffusion of new technologies has sometimes been difficult in tropical agriculture (Carr, 1989; Christensen, 1994; IITA, 2002; Santaniello, 2002).

If payments are tied to adoption, rewards to developers depend on new products being things that farmers in poor countries actually want to use. This "market test" acts as a form of discipline on the process; if donors announce an award for something that will not interest farmers, then developers, anticipating low uptake and thus low profits, will not undertake the research. 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 solicit farmers' opinions about needed technologies. The practice of saving seed could be continued as IPR protection in the form of patents is not necessary when the government can identify a technology that is needed and its social value (Wright, 1983).

Private firms have been rewarded before by international organizations for research in tropical agriculture. These programs differ from pull programs in that payment was not contingent upon successful development, and the funding agency determined the firm that would receive payment prior to development. Rausser, Amden, and Simon (2000) describe a payment made by the Plant Sciences Research Programme of the Overseas Development Administration (ODA) to a private company, which holds the relevant patents, to produce transgenic germplasm expressing insect-resistant genes for potatoes and sweet potatoes. In return, ODA receives a nonexclusive, royalty-free license to this technology and distributes the germplasm to breeders in developing countries. Brenner and Komen (1994) describe a similar arrangement in which funding was provided by USAID to a firm for the development of virus-resistant sweet potato in return for a nonexclusive license to the product in poor countries.

For applied research of this sort, if desired outputs can be identified, the incentive mechanisms created by pull programs can relieve the pressure on funders to "pick winners" among competing technological approaches and can also align the incentives of scientists and policy makers more effectively than grant-funded research. Under a pull mechanism, no payment is made until research is successful. Because the recipient of the reward is not pre-specified, more productive firms may undertake the desired research even if it means licensing needed technologies. If rewards depend on use, developers have strong incentives to ensure that their technology will actually be adopted. But the case for push funding mechanisms remains strong for research at the early stages and in other cases in which it is impossible to specify the desired product.

Even in a context of traditional funding mechanisms, private sector research effort has been identified as an important element of an R&D strategy for the tropics (Anderson, 1998; Byerlee & Fischer, 2002; James & Krattiger, 1999; Rausser *et al.*, 2000). It is generally suggested that this would be accomplished through public-private partnerships, though private firms currently have little interest in the success of diffusion efforts (Swanson & Göeschl, 2002).[10] Thus, the possible relationships or licensing agreements between private firms and local organizations that may be required by a reward that is tied to adoption are not unique to the proposed pull funding mechanism. A pull program, however, would create new incentives for private firms to diffuse their innovations to poor countries.

A pull program that makes rewards contingent on adoption could potentially create incentives along the supply chain. Tying awards to adoption rates means that private-sector firms, with their access to venture capital, genes, and biotechnology tools and know-how, but perhaps little capacity for seed multiplication in poor countries and little advantage in agricultural extension, must take the existing and potential seed supply chain into account when making research effort decisions. Firms will not have incentives to pursue products that might be extremely productive in laboratory conditions but inappropriate for real-world contexts unless they think they can overcome this problem. For example, in a context in which formal seed distribution is costly, firms may work to ensure that varieties they develop can withstand biotic stresses during storage, thus increasing the number of times seed can be saved for reuse and reducing the need for contract growers or seed farms.

If the difficulties presented by the supply chain can be surmounted, a pull program provides strong incentives to figure out how to do so. Developers might decide to purchase or create seed firms in poor countries. Alternatively, they may find a partnership with a tropical-country firm or organization attractive for adaptive stages of development or issue nonexclusive licenses. A pull program provides strong incentives for public and private complementary assets to be combined to bring products to farmers that they actually want.

Of course, in some cases firms may decide that supply chain problems make product development and dissemination untenable. In this case, under pull programs no donor resources will be spent. This may be optimal. It may be a socially inappropriate use of resources to fund some types of R&D if the supply chain is extremely weak and cannot be either designed around or improved at reasonable cost.

5. THE POTENTIAL ROLE OF PULL PROGRAMS IN TROPICAL AGRICULTURE R&D

For programs of this type to work, policy makers must be able to identify particular desired technologies, define the necessary health and safety characteristics of products, and establish procedures for approving and paying for products. To determine the appropriate payment to offer for a product, donors need an estimate of the social value of the innovation. This section discusses these requirements.

(a) *Identifying desired advances and their social values*

Serageldin and Persley (2000) of the World Bank have identified several constraints, summarized in Table 1, which limit the 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. The Rockefeller Foundation (2002) has identified a similar set of target problem areas. Prioritization exercises such as these suggest that specific desired advances that may be appropriate for pull funding can be identified.

(i) *Example: A pull mechanism for blast-resistant finger millet*

As an illustration of how a pull mechanism might work for tropical agriculture, consider the case of finger millet blast, or pyricularia

Table 1. *Agricultural constraints in developing countries*

Commodity	Problem	Affected regions
Banana/plantain	Black Sigatoka disease	Global
Cassava	Cassava mosaic virus	Sub-Saharan Africa
Maize	Low protein content	Global
	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).

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%, and sometimes as much as 90% (Adipala & Bua, 1995; Pande, Mukuru, King, & Karunakar, 1995). Finger millet is especially important in Kenya, Uganda, and India, but it is neither grown nor used on any significant scale in rich countries. [11] 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, around 0.75 tons per hectare (ICRISAT & FAO, 1996).

Table 2 shows rough illustrative calculations of the social value of a blast-resistance trait using millet production data reported by ICRISAT and FAO (1996). [12] 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%. 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 (Esele & Odelle, 1995).

Using 1994 production figures, we estimate the dollar value of the lost finger millet crop to blast to be approximately $91 million annually, and therefore the social value of the de-

Table 2. *Illustrative calculation of upper bound of annual payment for development of finger millet resistant to blast (pyricularia blight)*

Row	Figures	Definition	Source
1	172.71	Average market price ($/m)	(a)
2	0.75	Average actual yield (m/ha)	ICRISAT and FAO (1996)
3	21.00	Average yield reduction from blast (%)	Pande *et al.* (1995)
4	0.16	Output lost from blast (m/ha)	Row 2 * row 3/100
5	27.20	Unit value of blast-resistant trait ($/ha)	Row 4 * row 1
6	3.33	Finger millet area in developing countries (million ha)	ICRISAT and FAO (1996)
7	90.57	Total value of blast-resistant trait (million $)	Row 5 * row 6

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.

sired trait to be around $28 for a hectare's worth of seed inputs. [13] 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.

(ii) *Example: A pull mechanism for disease-resistant banana*

A second example of a pull mechanism for tropical agriculture comes from black Sigatoka disease. This is a fungus that affects banana and plantain production throughout most of the world. While it can be largely controlled through a combination of chemical fertilizer use, herbicide application, and deleafing in commercial or large-scale production, it is a major constraint for plantain and banana production in Africa (Craenen & Ortiz, 1998) where bananas and plantains are widely grown for subsistence uses (FAO, 2002). Banana is clonally propagated, which makes the development of new breeds through conventional means relatively difficult (Pearce, 2003).

Table 3 shows rough illustrative calculations of the social value of the black Sigatoka-resistant trait using production and yield data from FAOSTAT. Because banana production in Latin America is often for commercial export, this calculation is restricted to African production (about 35% of global production) which is overwhelmingly for domestic consumption. Average yield reduction from black Sigatoka is about 30% (Mobambo, Gauhl, Pasberg-Gauhl, & Zuofa, 1996). Similar estimates of the yield increase that results from fertilizer and herbicide treatment are reported by Gomez Balbin and Castano Zapata (2001). We estimate the annual social value of black Sigatoka resistance in Africa to be around $156 for a hectare's worth of inputs or $155 million in total. As in the millet example, the measurement of the social value of the trait is dependent on the yield of the new line of banana.

To use a pull program for finger millet resistant to blast or banana resistant to black Sigatoka, the calculations in Tables 2 and 3 would need to be extended to calculate the appropriate payment for a range of finger millet and banana lines. In addition to depending on adoption rates, payment should be dependent on the mean and variance of the yield of the new technology relative to traditional varieties. To avoid the potential for 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, such as drought tolerance in the case of millet, for example, that the new technology must meet. Designing eligibility standards would be far from trivial.

(b) *Pull programs and the technology supply chain*

Products specified by donors as desirable and appropriate for pull-program funding, such as blast-resistant millet, may begin with genes or other genetic material manipulated by the private sector with patented techniques and tools. This process occurs, however, at the beginning of a potentially long supply chain that connects farmers with the research process. For a pull program to be used in agriculture, donors must take this supply chain into consideration when designing the program's rules.

Table 3. *Illustrative calculation of upper bound of annual payment for bananas suitable for Africa resistant to black Sigatoka disease*

Row	Figures	Definition	Source
1	85.47	Average market price ($/m)	(a)
2	6.09	Average actual yield (m/ha)	FAOSTAT (2002)
3	30.00	Average yield reduction from disease (%)	Mobambo *et al.* (1996)
4	1.83	Output lost from disease (m/ha)	Row 2 * row 3/100
5	156.43	Unit value of resistant trait ($/ha)	Row 4 * row 1
6	0.99	Area planted in banana in Africa (million ha)	FAOSTAT (2002)
7	154.47	Total value of resistant trait (million $)	Row 5 * row 6

Notes: (a) Famine Early Warning System (2001) reports monthly banana prices in markets in Uganda September 2000–April 2001. The price used here is an average of these that is converted to dollars using 2001 exchange rate information from CIA Factbook.

Donors could potentially make payments to parties at any of several steps in the formal supply chain, as long as rewards are conditional on actual use. Providing incentives to the party eligible for the reward in turn gives this party incentives to provide rewards to other elements of the supply chain. One could imagine payments made to parastatal seed companies releasing varieties with the desired trait, variety registrants, or the firm that is the source of the improved germplasm used to create the foundation seed that is the basis for varietal registration.

One idea of a possible way that a pull program could operate would be to write the rules of the program so that payments are made to the entity that registers the first variety meeting the desired specification (e.g., blast-resistance as well as other baseline technical criteria) in an eligible country (or region in the event that seed regulations become regionalized in parts of Africa). The variety might be registered by a foreign company or by a domestic company or national research institute that performed adaptive research by contract or agreement with a private developer. The division of the reward between the registrant and other firms that participated in the development process would be a matter for the parties to resolve privately. It may be relatively transparent to identify who registers a variety as compared to determining the actions of various labs.

When designing a pull program in agriculture, it would be important to consider that once the first variety expressing the desired trait has been introduced new varieties that are incrementally superior in some or all agroecological conditions might be developed. In addition, a stream of new varieties will be needed, to address the breakdown of pest-resistance over time in some cases, or to make other varietal improvements. The rules of the pull program must make clear that the subsidy would be available only as long as varieties remain technically effective as compared to some baseline standard. If payments depend on adoption, donors have some protection against the possibility of paying for products that work for only a short time.

The potential for a stream of varietal improvements meeting the desired specifications, possibly created by reverse engineering the initial variety registered, raises the question of how to reward the development of these follow-on technologies. Ideally, payments for a follow-on technology should reflect the incremental social value of the new variety, which is likely to be much lower than the social value of the first variety meeting the desired specifications. But attribution of credit, and thus payment for incremental improvements, are likely to be difficult. Separately measuring adoption of various varieties of a particular product would likely be infeasible.

Paying the initial registrant based on the hectares planted would give them incentives to fund research aimed at improving the variety and adapting it to local conditions. As Green and Scotchmer (1995) discuss, it would be possible in theory to reach the first-best level of R&D if firms could negotiate how rewards would be shared before work is undertaken, but otherwise it might be difficult to reach this outcome. Kremer and Glennerster (2004) discuss the tradeoffs between rewarding initial and subsequent developers in the context of pull programs for vaccines. Certainly, the rules of the program would need to be written to ensure that breeders that illegally release varieties cannot receive rewards.

One possibility might be to structure the payment to the firm as a percentage of the market price of millet or bananas grown using material that contains the new technology, or the relative price of these products as compared to products grown from unimproved varieties. In theory this could make many of the specification problems less onerous. The price of the product, relative to the price of products grown using traditional means, should summarize information about the aesthetic appeal of the new product. [14]

Donors might take into account whether the desired product is closely related to products that private developers currently study (e.g., plantains that are related to dessert bananas produced for export) or unrelated to most major private R&D efforts (e.g., finger millet or cowpeas). The greater the extent to which a pull program would require redirection of research efforts and unfamiliar joint ventures, the greater the risk for firms and the larger the reward that might be required to induce research effort.

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 that has developed the desired trait on the basis of total hectares planted with material using the particular technology each year, rather than on the basis of total seeds or propagation material sold. This would allow the practice of saving seed to continue, while still providing a return to developers. The potential for firms to distort the seed market is also mitigated; for the developer to receive payments farmers would have to actually plant seeds that they purchase.

Practically, one possibility is that adoption could be measured using a combination of aerial photography, ground truthing, and field surveys, perhaps in conjunction with agricultural census efforts or monitoring efforts currently used to predict food insecurity. For example, data collected and synthesized by the USAID-funded Famine Early Warning System Network includes ground-based meteorological, crop, and rangeland conditions for many of the poorest African countries. It might be possible to build upon this data collection effort to measure adoption of pull program crops.

(c) *Eligibility criteria: Health and environmental safety*

The lack of local expertise in using and regulating modern biotechnology is a major constraint on the use and diffusion of this technology in developing countries (Nottenburg *et al.*, 2002). Many of the poorest countries have inadequate biosafety regulation and lack the infrastructure to independently ensure that new agricultural technologies developed using biotechnology meet health and environmental standards. This constraint on the diffusion of technologies exists whether a pull funding mechanism is used or not. Likewise, uncertainty about local regulatory policies will continue to act as a disincentive for investment, even if a pull program were introduced. Capacity-building efforts that are supported by donors for NARS would continue to be important if pull funding were introduced in tropical agriculture.

(d) *Other "pull" funding approaches*

Masters (2003) has proposed a pull mechanism for tropical agriculture that is related to the proposal we make here and that made by made by Kremer (1998) for public buy-out of socially valuable patents. [15] Masters proposes that donors make a one-time payment to buy tropical agriculture innovations into the public domain; rather than the auction method proposed by Kremer, he proposes that the buy-out payment be determined through *ex post* impact assessment calculations developed using standardized techniques. Developers would submit a proposed reward payment, a fixed fraction of the estimated social benefit of the innovation, and a proposed split of revenue among participants in the R&D effort to an expert panel. This panel would be tasked with approving the size of the reward to give and the division of the reward among developers involved in a project. Unlike the proposal in this paper, patent rights would be relinquished by the private sector in Masters' proposal through a nonexclusive licensing agreement and the adjudication authority would take part in deciding how to share a reward among parties.

Masters' approach avoids the task of specifying the desired technology beforehand that is central to a pull program of the kind proposed here. Instead, it relies on *ex post* assessments of the value of unspecified innovations. This raises several potential issues for program design.

A central rationale for the use of pull programs is the time consistency problem, as discussed earlier. Once R&D costs are sunk, an adjudication panel acting in the public interest would have incentives to obtain a product as cheaply as possible after it has been developed, even if society highly values a product. A key question is therefore whether potential developers will have sufficient confidence in the way in which impact is assessed to invest. One way to provide assurances to developers that they will be adequately rewarded for their research effort is to limit the discretion of donors to determine reward payments that will be made after products have been developed. The pull program proposed here essentially adopts this approach; Masters' proposal would leave more discretion in the hands of the adjudication panel.

As Masters notes, there is an existing academic methodology for agricultural impact assessment (e.g., Alston *et al.*, 1995). In many situations, however, subjective judgements would still need to be made by the panel granting rewards. For example, suppose that a firm applies for the reward on the basis of a new variety that exhibits both higher average yield and higher yield variance. To correctly account for this trade-off when valuing the product would be difficult and there would likely be no consensus as to appropriate means by which to do so in all cases. Additional complications would be introduced in the event that the new variety tasted differently than traditional varieties, or required additional labor or water in a given season. With large amounts of money potentially at stake, the necessary subjective judgments may result in controversy and legal disputes could arise. Anticipating this, firms may find this funding proposal less attractive.

Required licensing agreements may also act as a disincentive for research. This requirement may raise the possibility that proprietary technology could be shared with competitors in rich-country markets as a result of participation. Not all proprietary technology is patented, and developers may be concerned that trade secrets, for example, or simply other intangible knowledge that provides a particular developer an advantage over other firms, would be leaked as a result of nonexclusive licensing.

A second concern related to the adjudication panel's discretion is that the *ex post* impact assessment process may also be vulnerable to politicization. A panel of experts with discretion to determine which products are socially valuable and the division of a reward among parties may be influenced by considerations other than the usefulness of the technology. The panel may be inclined to reward small or developing country-based firms rather than major multinationals.

Another issue is that, under Masters' proposal, firms might claim rewards for activities they would have done even in the absence of the program since the rewards would not be tied to specific products for which donors felt research was inadequate.

Nonetheless, all these potential problems must be set against the benefit of not having to set specific *ex ante* eligibility requirements tied to particular technologies. In our view, it is worth trying a number of different approaches to improving incentives for agricultural R&D.

(e) *Funding pull programs for tropical agriculture*

Commitments to pay firms that disseminate advances in tropical agriculture could be undertaken by governments of industrial countries, the World Bank, or private foundations like the Rockefeller or Danforth Foundations. One institution could establish the basic infrastructure for a program and make an initial pledge. Other organizations could later make pledges of their own. The initial pledge could cover particular products or countries, and later pledges could broaden the program. Developing countries could be required to make a co-payment to encourage their cooperation and commitment.

An explicit commitment to help finance purchases of new agricultural products need not interfere with other initiatives to improve agricultural productivity because the commitment need not be financed until a desired product was developed. The historical and legal record provides strong evidence that a suitably designed commitment will be interpreted by the courts as a legally binding contract without funds being set aside in an escrow account at the outset (Morantz & Sloane, 2001).

If research funding were balanced between push and pull mechanisms, donors could continue to use current-year budgets to support CGIAR or agricultural extension while committing to future rewards to firms under a pull program. The strong incentives created by pull programs may make donors more enthusiastic about funding research for tropical agriculture as they can be confident that resources will not be wasted. NARS or IARCs also might compete directly for pull program rewards if those institutions and their funders decided this was an appropriate use of their resources.

6. SUMMARY AND CONCLUSIONS

This paper examines the potential for innovative financing mechanisms to encourage private R&D in tropical agriculture. Government-funded 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. Experimentation with "pull" funding programs for a targeted number of advances seems to have tremendous potential to complement traditional publicly-funded research in tropical agriculture—particularly in light of the growing importance of the private sector in biotechnology. The practical considerations surrounding a pull program that rewards development of specific desired products would certainly require considerable study before a pull program in tropical agriculture could go forward. A next step might be the creation of a working group to study these questions similar to that created to examine advance contracting for vaccines by the Center for Global Development and the Bill and Melinda Gates Foundation.

Pull programs 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. Experimentation with pull funding programs for a targeted number of advances would provide another tool for donors to use to complement traditional publicly-funded research in tropical agriculture, adding balance to the research funding portfolio that is currently lacking.

NOTES

1. Even within temperate regions R&D needs are distinct because of ecological conditions and factor endowments (Huffman & Just, 1999; Ruttan & Hayami, 1990).

2. The denominator of the calculation of CGIAR research intensity is the sum of agricultural value added in all nontransition economies classified by the World Bank as low income (World Bank, 2002). The numerator is total annual member contributions to CGIAR (CGIAR, 1999).

3. Because rates of return to successful projects may be overreported relative to those from unsuccessful projects, and because the research being evaluated and rate of return measures vary across studies, these results from surveys of impact studies must be interpreted with care.

4. This is not true of other products, such as animal vaccines, that can also improve agricultural productivity.

5. In general, the implications of GURTs (particularly GURTs in which seeds remain fertile for more than one season) differ little from hybrid seeds in terms of the risks that farmers must bear. There is evidence that African farmers are willing to use hybrids (Byerlee & Heisey, 1996; Christensen, 1994).

6. 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 poor countries.

7. Theoretically, poor countries could provide property rights protection only to those products that are uniquely suited to their region (Lanjouw, 2001). 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 GURTs.

8. 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 technology may try to claim the 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.

9. Hiring scientists on a long-term basis at CGIAR centers, for example, can mitigate this problem. Because CGIAR scientists 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. Merit increases can also function as an incentive component of scientists' contracts (Huffman & Just, 1999).

10. Examples include the Papaya Biotechnology Network, collaboration between the Agricultural Genetic Engineering Institute in Egypt and Pioneer Hi-Bred, and the agreement between CIAT and Papalotla (Binenbaum, Nottenbburg, Pardey, Wright, & Zambrano, 2003; Rausser *et al.*, 2000).

11. Total global production is around three million metric tons annually, primarily for domestic consumption (National Academy of Sciences, 1996). Production of finger millet represents about 10% of total annual millet production (ICRISAT & FAO, 1996).

12. More complete methods for impact assessment calculations that could be an appropriate starting point for careful social value calculations have been developed by Alston, Norton, and Pardey (1995) and are reviewed by Evenson (2001).

13. 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.

14. The price of the technology itself will not contain information about the desirability of the product if, as is likely, firms act strategically. Since total payment will be dependent on adoption, firms could set the price near zero or give away gifts to farmers to encourage purchase of the technology.

15. 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. Other pull mechanisms are less attractive. Patent extensions on the desired technology are not very enticing and patent extensions on other products distort the markets for these products.

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