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Abstract

The majority of biotech research and almost all of the commercialization of genetically engineered crops has been done by private firms based in industrialized countries. The dominance of the private sector in biotechnology research and product development has raised concern in developing countries that their farmers – particularly poor farmers – may not benefit from biotechnology either because it is not available or is too expensive. This paper examines the consequences of the emergence of a few large companies as the leaders in the commercialization of biotechnology and analyses a number of concerns about who benefits from biotech research. It reviews the status of crop biotechnology research worldwide and analyses the influence of intellectual property rights and market concentration on the development and diffusion of new technology. The paper explores the potential of public-private partnerships recommends policy measures and investments that could focus more biotechnology research on the problems of the poor and alleviate some of the concerns about the impacts of biotechnology.

This paper was prepared as background material for the 2003 issue of *The State of Food and Agriculture,* which has the theme “Agricultural Biotechnology: Meeting the Needs of the Poor?” Several companion papers are also available in the ESA Working Paper series.

Key Words: Agricultural Research, Technological Change, Economic Development, Biotechnology

JEL: H41, O13, Q16

* Content and errors are exclusively the responsibility of the authors and not the FAO or the authors’ institution.

1 INTRODUCTION

The majority of biotech research and almost all of the commercialization of genetically engineered crops has been done by private firms based in industrialized countries. A companion paper to this one describes the economic incentives that drive agricultural research and the resulting patterns of research investment for biotechnology. The dominance of the private sector in biotechnology research and product development has raised concern in developing countries that their farmers – particularly poor farmers – may not benefit from biotechnology either because it is not available or is too expensive. This paper examines the consequences of the emergence of a few large companies as the leaders in the commercialization of biotechnology and a number of concerns about who really benefits from biotech research. We discuss how some policy measures and government investments could focus more biotechnology research on the problems of the poor in ways that could simultaneously alleviate some of the concerns about the allocation of biotechnology benefits.

Since the major advances in biotechnology that are actually in use by farmers are primarily in the plant area and because of the dominant role of plant agriculture as a source of food and employment for the poor, this paper focuses on plant biotechnology, especially genetic engineering.

2 THE PRIVATE SECTOR IN BIOTECHNOLOGY RESEARCH

The large role of the private sector in biotechnology research, the dominance of private sector research by a few firms, and the extensive patenting of research tools and genes has led to a number of concerns by developing countries and others. These concerns include:

- The neglect of poor peoples' crops and poor regions;
- The impact of intellectual property rights and genetic use restriction technology (GURTs) on accessibility of technology and genetic resources to developing country scientists and farmers; and
- Potential monopoly power of the biotech firms and their ability to extract excess profits from farmers.

This sections looks at the empirical evidence that is available on each of these issues.

2.1 Research for orphan crops, traits and regions

Private firms invest in agricultural research in order to earn a profitable return for their shareholders. Their profits depend, among other things, on the size of the potential market for their inventions. Firms are unlikely to invest very much money on research to improve crops for which the market is small and the potential payoff is low (Pray and Naseem, 2003). The dominance of the private sector in developing new GM varieties suggests that the needs of the poor will be neglected since the markets for these products are likely quite small. The data on field trials supports this argument: the crops and traits that are most important to the poor have been neglected. Furthermore, there is little or no biotech research in the poorest countries.

Research priorities: crops

Since 1987, when the first field trials were approved, there have been more than 11,000 trials of 81 GM crops worldwide (Figure 1).[1] The most widely tested crop worldwide is maize with 34 percent of total field trials, followed by canola (11 percent) and potato (10 percent). Soybean and cotton follow, each with 7 percent of approved field trials worldwide (Figure 2).

Staple food crops have not been the subject of much applied biotech research, although the number of field trials for wheat and rice, the most important food crops in developing countries, has increased in recent years. Wheat and rice are the 9th and 10th most frequently tested crop worldwide, each with about 2 percent of field trials approved. This may mean that these crops are starting to receive some much needed attention. Notably, in 2000, cassava was tested for the first time worldwide in Colombia and was to be approved for testing in the United States in 2001. Yam, another important subsistence crop, has not yet reached the field trial test stage, but other "orphan commodities" such as bananas, sweet potato, lentils and lupins have all been approved for field testing in one or more countries. There are no serious biotech research investments in the five most important food crops in the semi-arid tropics: sorghum, pearl millet, pigeon pea, chickpea and groundnut.

Table 1 shows that developing country research is even more concentrated on maize and other commercial crops than US and Canadian biotech research. Rice and wheat are the subject of only 3 percent and 1 percent, respectively, of all field trials in developing countries.

Research priorities: traits

The characteristics or traits of GM crops being researched around the world primarily focus on herbicide tolerance and insect resistance. As shown in Figure 3a and 3b, 29 percent of all field trials are for herbicide tolerance. In industrialized countries the second most important trait tested is insect resistance (21 percent of all field trials). In developing countries insect resistance is the most widely tested (37 percent) trait. Another major difference between industrialized and developing countries is that industrialized countries put much more emphasis on product quality traits (more than 16 percent) than developing countries (6 percent). Field trials on agronomic traits, which includes increased yield per ha, is a low research priority in developing countries (1 percent) and in industrialized countries (6 percent). Research on production constraints of particular importance to developing countries, tolerance to abiotic stress such as drought and salinity, is rare.

Research priorities: countries

Field trial data shows that developing countries have been slow to take up applied research on GMOs. For the entire period approximately 15 percent of all field trials were in developing or transition countries, although in recent years the percentage has increased to 23 percent (Table 1). The low numbers reflect the lack of private firm interest in these countries and the difficulties their governments are having in establishing a regulatory system for biosafety. In 1999 field trials of GM crops were approved for the first time in Lithuania, Czech Republic, Moldova, Romania, Slovakia, Slovenia, Turkey and the former Yugoslav Republic. In 2000 Kenya and the Philippines were added to the list -- by 2000 at least 58 countries had reported biosafety field trials (Pray et al., 2003). The number of field trials approved in South Africa doubled between 1999 and 2000 (from 55 to 110), but other countries such as Argentina and New Zealand have stopped field trials in certain years while re-evaluating their biosafety system.

[1] This data source counts each individual test plot as a separate trial, so the same GM event may have multiple trials in a given country. Other data sets, such as the FAO BioDeC, count all test plots for an event in given country as one trial. Therefore, the total number of trials will differ across data sets although in percentage terms they are more comparable.

2.2 The spread and role of intellectual property rights

Intellectual property rights and the size and distribution of research gains

Unless private sector plant breeders, biotechnology scientists and biotech firms are able to make a profit from their inventions, they will have little incentive to invest in research. They must be able to control the use of their inventions in order to charge enough in seed prices, licensing fees or royalties to make their investment profitable. Their capacity to control the use of their inventions and capture the social value of their inventions is called 'appropriability'. A higher degree of appropriability means that firms can capture a larger share of the total social benefits of research and will therefore have more incentives to continue investing in research. The optimal degree of 'appropriability' is that which maximizes the total social value of biotechnology research and which yields a socially desirable distribution of the benefits (Pray and Naseem, 2003).

Inventors can control the use of their inventions through legal means of intellectual property rights (IPR) protection, such as patents, plant breeder's rights, trademarks, and trade secrets (Table 2). Inventors can also use biological means to protect against copying. Putting new characteristics into hybrid cultivars can partially protect the invention because farmers must buy new seed every year or risk severe yield losses if they use saved seed. Other biological means, such as GURTS, can prevent farmers and unauthorized companies from reproducing protected seeds in their fields (Pray and Naseem, 2003). Although some companies have pledged not to use GURTS, it is instructive to examine the potential impacts on developing country farmers if similar technologies were to become widespread.

Agricultural research yields social benefits (for farmers, consumers and society as a whole) through the creation of new technologies (Pray and Naseem, 2003). Because appropriability is a key determinant of the overall level of private sector research, effective IPR protection for the products of biotechnology provides benefits not only for the inventors, but also for society. Farmers can benefit from through lower production costs and/or improved yields; consumers benefit through lower commodity prices and improved quality attributes; society benefits from the economy-wide growth effects of agricultural productivity gains.

For farmers, the optimal amount of appropriability for biotechnology research is a function of the discounted total size of payoff to society from biotechnology and the share that farmers capture. The higher the share of technology going to companies, the more they will invest in research, and the greater the total discounted benefits to society will be. The higher the farmers' share, the more farmers benefit from currently available technology, but this could lower the total discounted benefits because there will be less technology in the future and less total future benefits. Thus, farmers and the policy makers who are concerned about farmers' welfare have to assess how much more technology they would get if they strengthened IPRs. For a small or medium sized African country, including micro-organisms in the patent system is unlikely to lead to major research investments by Monsanto or Syngenta. However, stronger plant breeders' rights might encourage local companies or small companies from Zimbabwe or South Africa to invest in plant breeding.

IPR protection in developing countries

Laws to protect new plant varieties and biotech inventions spread rapidly in developing countries in the late 1990s. Their spread was accelerated by the trade related intellectual property (TRIPS) component of the World Trade Organization (WTO) agreement which required signatories to put in place some type of *sui generis* system of plant variety protection and patent protection for biotechnology inventions by 2000 (some developing countries have until 2005 to implement these IPRs). As of December 1, 2001, 49 states were members of the International Union for the Protection of New Varieties of Plants (UPOV), which indicates that they have some plant variety protection**.**

Patent laws in many developing countries have also been strengthened recently in part because of TRIPS agreement. A number of countries still exclude novel plants and animals from patent coverage, but many of them do allow patenting of novel microbes as is required by WTO. Many of the countries that exclude plants from patent coverage – especially in Europe – protect plant varieties through strong plant breeders legislation and enforcement. Table 3 indicates the type of intellectual property rights that are available in Latin America. It shows considerable variability of protection.

Impacts of IPR protection on research

A recent study (Fuglie et al., 2003) summarized the findings of a number of studies on the impact of implementing plant breeders' rights:

> For the USA experience, Stallman (1986) found that the 1930 Plant Patent Act had no noticeable effect on fruit breeding, due to high development costs and difficulty of enforcing IPR for these commodities. Several studies examined the impact of the 1970 Plant Patent Act on private research on field crops. Perrin, Hunnings and Ihnen (1983) concluded that the establishment of plant breeder's rights for field crops did spur private investment in soybean breeding, but for other crops the incentive effects were small. Butler and Marion (1985) also concluded the effects of the plant breeders' rights on private research investments were modest at best. In a more recent study, Alston and Venner (2002) found that the US PVPA of 1970 did not stimulate any increase in private wheat breeding research or wheat yield.
>
> For developing countries, studies have found a generally positive relationship between the establishment of agricultural IPR and private innovative activity so long as other requisites are in place. The establishment of plant breeders' rights in Argentina did not stimulate private research until the plant breeding industry effectively organized itself to provide enforcement [van Wijk and Jaffe (1995)]. In Chile, PBR law did not increase local research but encouraged the introduction of new varieties bred elsewhere, especially from similar ecological conditions in the United States [van Wijk and Jaffe (1995)]. Garcia (1998) found PBR did apparently stimulate private plant breeding research in Brazil, and Aquino (1998) obtained similar results for Mexico. In their survey of private research in seven Asian countries, Pray and Fuglie (2002) concluded that agricultural IPR may increase private incentives to invest in agricultural research so long as countries first allow the private sector to compete in agricultural input markets, establish a productive public research system, and maintain good legal institutions.

The only study that looks specifically at the impact of intellectual property rights and complementary institutions on biotechnology research is an econometric study (Pray et al., 2002). Using time series data from 37 countries, the authors found that plant breeder's rights and the strength of property rights in general were positively associated with the spread of applied agricultural biotechnology research as measured by the number of biosafety field trials of GM plants. Other positive and significant variables were the size of the countries' seed industry and the amount of commercialization of the agricultural sector and the amount of public biotechnology research in the country.

2.3 Access to biotechnology

The large biotech firms in the U.S. and Europe through their own research and through mergers and acquisitions of other firms have amassed major portfolios of proprietary biotechnology tools, genes, and information. Much of this knowledge and these techniques can only be obtained from the company that owns it through a license for research or for commercialization. The main concern is that companies may try to charge large royalties that firms and public research institutes in developing countries could not afford to pay in order to license the technologies. In some cases firms may not be interested in licensing because of the possibility of liability problems or bad public relations if something goes wrong.

Another concern is that many of the major breakthroughs in biotechnology which were developed and patented by public sector biotechnology institutes are not available either. The universities that developed them often license them exclusively to small or large private firms, which then have the rights to sublicense them. For small biotech firms these patents are the main assets of the firm. They may not have time and resources to market these technologies to developing countries. They will be very reluctant to license the technology in countries with weak intellectual property rights where they could lose control of their technology. Finally, if they do market the technologies, they may be too expensive for the public sector.

Although most of the discussions on access to biotechnology have focused on the negative impact of intellectual property rights on biotechnology, IPRs can increase access to biotechnology to developing country scientists. They give the owners of these technologies – multinationals, universities, and individuals – increased incentive to market their technologies in developing countries. Prior to IPRs, the main incentive for sharing the technology was humanitarian; now firms also have a financial incentive. The other way in which IPRs make technology more accessible is through patents because they make the information about how technology works publicly available. Patents of most industrialized countries can be searched on the web anywhere there is an internet connection and computer. Some non-profit organizations, like CAMBIA[2] in Australia, provide guidance on how to search for patents as well as access to some sets of patents.

Many biotech labs in developing countries are currently using proprietary biotechnology. Descriptions of some of these proprietary technologies have been published, some genes are in commercial use and can be obtained through reverse engineering, and some techniques have made their way abroad in unauthorized routes through graduate students, post docs and public research. In most developing countries these techniques either can not be or have not been patented. This means that there is nothing illegal about the use of these technologies for research or the commercialization of plant varieties based on these techniques. The complexity of developing a transgenic plant means that many patented technologies may be required to produce a GM plant with the desired trait. A now famous study of Golden Rice found that it was based on 70 patented technologies held in 30 different institutions (Kryder et al., 2000). These patents applied in both industrialized and developing countries (see Table 4). However, in some major rice consuming countries none of these patents exist and only a few are applicable (Pardey et al., 2003).

No comprehensive survey of patented genes and research tools in use in developing countries has been published, but a recent survey of scientists in Latin America by ISNAR indicates that their use is extensive. They found that government scientists were using patented

[2] See their website at www.cambia.org

techniques extensively without knowing they were patented in some cases or not caring about it in others (Salazar et al., 2000).

If genes and research tools are protected by patents in the developing country or if the developing country scientists or farmers of the country hope to export the agricultural products developed using these techniques, innovators who wish to commercialize the technology need to license them from their owners. A recent study reviewed the need for licensing and found that in most developing countries this was not a major problem because they export little back to markets where they might be blocked (Binenbaum et al., 2000). Soybeans, bananas, and rice are the main crops that developing countries export to Europe and the main problem of exports is consumer acceptance, not that an American or European firm will prevent a developing country from exporting a product produced with patented technology.

The main problem in accessing these technologies in developing countries is not companies that are unwilling or unable to share their technologies due to IPRs, but the lack of research capacity in developing countries to use these techniques (Pardey et al., 2003). Countries with poorly developed National Agricultural Research Services (NARS) do not have the scientific capacity to know which technologies would be most useful or how to use them if they did get access to them. Too many developing countries fall into this category (Table 5) (Pray and Naseem, 2003).

There is still a problem of access to patented technology for many institutes in countries that have intermediate or advanced national agricultural research capacity. Many technologies are difficult to obtain without going to the owners of the technology. The technologies may require biological material, complementary proprietary technology, and information not disclosed in the patents to make them work. Even if the technology could be used without permission from the owners, public or private institutes may decide that they will not use it without obtaining proper permissions. This decision may be motivated by the desire of the local institute to have longer term collaboration with the owner of the technology or it may be out of the desire to export the products produced by this technology. As mentioned above in some developing countries IPRs on plants and biotechnology are growing stronger and the local research institute may have a legal obligation to obtain permission. As Table 2 shows a number of the key patents on Golden Rice are held in developing countries.

Discussions with researchers from national institutes and IARCs indicate that IPRs have slowed access to biotechnology in developing countries. Foundations and aid donors are so concerned about these problems that they are funding a number of institutions such as the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), which is a decade old, and the newly established African Agricultural Technology Foundation (AATF) to address them. Section 5 will discuss options for providing more access.

2.4 Monopoly power of biotech multinationals

The concentration of plant biotech research and patents in the hands of a few multinationals companies (Figures 4a and 4b) has caused fears of market power and monopoly pricing. There are concerns that multinationals will take over the seed industry from local firms and use their market power to increase the price of biotechnology so much that they will capture all of the benefits from research while farmers capture nothing. These concerns have been raised most dramatically by the debate over GURTs, which opponents have labeled “terminator” technology.

It is now possible to use data from farmer surveys to test the hypothesis that companies capture the benefits from biotech and farmers capture little or nothing. A review of these studies shows that the share of benefits going to farmers decreases as the strength of legal, institutional and biological protection of technology increases; but even in the developing countries with the strongest IPRs and monopoly power by one firm, farmers still capture most of the benefits. We then speculate what the impact of successful GURT technology might be.

Farmer benefits from technology under different IPR regimes

The first study that looked at how the benefits of private plant breeding research were divided in a developing country found that the value of increases in farmers' yields, due to adopting private hybrid sorghum and pearl millets, greatly outweighed the increase in cost of seeds (Pray et al., 1991). The authors calculated the increased net income of seed firms from the sale of private hybrids rather than hybrids produced by the government from a survey of seed companies. The farmers' increase in net income due to the adoption of private hybrids was based on a survey of farmers. Firm's profits and farmers' profits were added to calculate the total benefits of private research. For hybrid sorghum, the seed companies captured at most 18.5 percent of the benefits as profits, while 81.5 percent of benefits went to farmers. For hybrid pearl millet, seed firms captured only about 6 percent of benefits. More than 90 percent of the benefits from private pearl millet research went to farmers.

Studies of the benefits from biotechnology research also show that farmers capture most of the benefits (see Table 6). In all of the studies shown in Table 6, except Bt cotton in Argentina, the share of farmers in the total benefits to society (measured as farmers profits plus the profits of the monopoly supplier of technology) was far greater than the benefits to the suppliers of the technology. The seed/biotech company obtains more than the farmers only in the Argentina Bt cotton case. However, if the benefits to farmers who are using black market seed in Argentina could be included, then most of the benefits would go to farmers (Qaim and deJanvry, 2002). Biotech companies capture about a third of the benefits as illustrated in the case of South Africa and India (Pray and Schimmelpfennig, 2001). In the other cases, China and herbicide tolerant soybeans in Argentina show farmers capturing between 80 and 90 percent of the benefits (Qaim and Traxler, 2002).

The difference in the share of benefits clearly reflects the differences in the firms' ability to protect their technology from unauthorized copying. This ability is due to a combination of the law on intellectual property rights, enforcement of regulation, institutional structure of the industry, and characteristics of seed technology. Table 7 describes the combinations of IPR, institutions, and technical characteristics that can lead to strong appropriability for firms. It then presents examples of these characteristics and the share captured by firms from the empirical studies. The weakest appropriability is at the top of the table. The top row describes the situation that existed during the Green Revolution. High yielding wheat and rice varieties were not protected by intellectual property and could be easily duplicated by farmers. A few small firms made limited profits from producing and distributing seed, but all research and much of the foundation seed distribution was financed by the government. Another case in which the innovators can not make money from biotechnology is Brazil where herbicide resistant soybeans are illegal but are very easy for farmers and small seed companies to produce and sell. Moving down Table 7 seed companies start to make money from plant breeding research when they develop hybrids. In India, private firms produced pearl millet and sorghum hybrids based on public inbred lines. This allowed the firms to capture some benefits from the farmers.

In the middle of the table China has patent laws, plant breeders' rights, and trademarks which promise to protect Monsanto and the Chinese government Bt varieties from copying. The biosafety regulations are stringent and it is time consuming to obtain permission for commercialize and new product which should restrict competition. However, due to problems of enforcement of these laws, most of the Bt cottonseed that farmers planted was produced by farmers or small seed companies and government research institutes who did not apply for biosafety committee approvals or pay royalties to the owners of varieties or genes (Pray and Schimmelpfennig, 2001). Thus, GM seed is sold for very low prices and Monsanto and CAAS are able to capture only a small share of the benefits while the farmers, in the short run at least, obtain most of the benefits.

Near the bottom of Table 7 the highest technology fees and seed prices and share of benefits for the companies are for Bt cottonseed in Argentina, South Africa, and India. In Argentina, Bt cotton farmers sign contracts agreeing not to reproduce seed and Monsanto has contracts with the limited number of ginning companies to buy all cotton seed. Nevertheless, experts estimate that more black market Bt seed is planted than legal seed. In South Africa also, farmers agree not to replant their own seed and Monsanto has contracts with the two gins in the country to ensure that none of the seeds go back to farmers. In addition they have patents on the genes and plant variety certificates for the varieties. In India, the Bt gene is in a hybrid, which farmers have to buy each year to get decent yields. In all of these countries it is now very expensive, time consuming and risky for companies or government agencies proposing new Bt strains or new Bt varieties to move through the biosafety regulatory process. This indirectly guarantees Monsanto and its partners a monopoly on Bt cotton varieties for a number of years in all three of these countries.

The important results from tables 6 and 7 are that even in developing countries such as South Africa where companies have very strong intellectual property rights, farmers captured most of the benefits from the GM crops. Another important fact is that strong intellectual property rights can induce the private firms to do some research and technology transfer even in cases like South African cotton where the size of the crop and the market is very small.

Possible impact of GURTs on research and distribution of benefits

The important economic questions concerning GURTs in developing countries are whether they would allow seed and biotech companies to extract a larger share of the benefits of new technology from farmers and whether they would provide private firms with increased incentives to do research. Because GURTs are still an experimental technology and not in commercial use anywhere, it is necessary to look for similar types of technology or countries with very strong IPR protection and assess the impact on farmers.

There are two types of historical experience that may provide some insights into the possible impact of GURTs. Hybrid crops offer one model. GURTS would have a somewhat stronger impact on farmers because no farmers could replant their high yielding seed. Hybrids farmers can replant the seed if they are willing to take 20 percent yield loss which puts a ceiling on seed prices. If low cost open pollinated varieties or other hybrids are available, seed companies will only get a small share of the benefits as is the case with hybrid pearl millet and sorghum in India (see Table 7). Likewise, if varieties or hybrids that are relatively close substitutes to varieties with GURTs are available, GURTs will not provide monopoly power or excessively high seed prices.

Bt cotton in South Africa may offer a better model of what would happen if GURTs were introduced into developing countries. In the South African market, there is a monopoly on the Bt gene and on Bt cotton seed sales, and there are contracts with the cotton gins to prevent them from selling seed back to farmers. As a result nearly 100 percent of cotton seed is purchased each year. Nevertheless, private firms only capture a third of the benefits. Bt cotton in the United States has a similar institutional and IPR system, but farmers still capture more of the benefits than seed companies. In Australia, where institutions and the small number of farmers leads to very strong IPR protection, the companies did capture most of the measurable financial benefits, but in recent years the companies have had to reduce their share of benefits (James 2002). The Australia and Argentina cotton cases would seem to be the extreme cases, while the U.S. and South Africa cases where farmers capture most of the benefits are more likely to be the experience that developing countries would experience if a really effective, inexpensive GURT system is ever developed.

In fact, variety GURTs may never make it to the market. GURTS that will prevent farmers from reproducing their own seed will require at least 5 to 10 years to develop, and then the plant varieties produced will have to go through biosafety regulatory processes in each country (CGRFA, 2002). Thus, it is unlikely that they will be commercially available in developing countries in the next 10 to 15 years. Even then it may not be commercialized. Assuming that the GURT system results in a transgenic variety that would have to go through the biosafety regulatory system, the cost of using this system would be a major impediment to companies and it might also reduce the demand for the variety. This would significantly reduce its attractiveness to most companies. In addition, the negative publicity against GURTs has caused at least one large biotech company – Monsanto – to state publicly that they will never develop or use a system that prevents farmers from saving their own seed.

Despite the popular opposition to GURTs, this technology could actually generate substantial social benefits by stimulating more research for and technology transfer to developing countries, particularly increasing incentives for crops in which the seed is typically a pure line variety such as wheat, rice, soybeans, and cotton. They would be less important for crops in which the seed is typically a hybrid such as maize and sunflower. GURTs would not impact clonally propagated crops like sugarcane and cassava. Some economists have used simulations of the impact of GURTs based on the experience of hybrid maize to conclude that the enhanced level of control of intellectual property that GURTs provide would initially encourage further private research, but will impede subsequent research by allowing firms to extract monopoly profits on existing varieties (Goeschl and Swanson, 2000).

One of the few empirical studies that provides some guidance on the impact of GURTs on plant breeding research examined the determinants of private plant breeding research in India (Pray and Ramaswami, 2001). They found that the development of technology that allowed the production of hybrid rice and hybrid mustard in India led to a substantial amount of new investment in plant breeding research in these crops by both local companies and multinationals. This suggests that the stronger biological protection of varieties of self pollinated crops that is provided by GURTs could stimulate more research.

It is not possible to know exactly what the impact of GURTs would be on farmers. It probably will not be as dramatic as many of the critics imply. Rather it is likely to be an incremental increase in the strength of IPRs in crops that could, in turn, increase the share of biotech and seed companies in the benefits of research. The example of Bt cotton in South Africa and the United States suggests that farmers are still likely to capture most of the benefits from new varieties protected by GURTs. There are also some studies that suggest GURTs could induce more private research particularly in self-pollinated crops like rice. However, GURTs technology may not be ready for commercial use for years in the future.

3 PUBLIC RESEARCH AND RESEARCH POLICY FOR THE POOR

There is a strong consensus among economists about what kind of research is needed for biotechnology to contribute to reducing poverty and which institutions should do it (Byerlee and Fischer, 2002; Pingali and Traxler, 2002; Lipton, 2001; Naylor et al., 2002):

- there should be public biotech and plant breeding research on commodities and traits that meet the needs of the poor;
- policies and regulatory restrictions need to be transparent and efficient without unnecessary restrictions on private firms that wish to develop and sell biotechnology for commercial crops and for hybrids; and
- public-private collaboration is needed so that public research and small local and regional firms can get access to research tools and genes that will assist the poor.

There is not, however, a consensus about how to encourage more public biotech and conventional research on poor peoples' crops in developing countries, particularly in the current climate of skepticism about the benefit of biotech, declining donor interest in funding agricultural research, and low agricultural prices. The tools for encouraging private biotech research are better known, albeit more controversial, particularly policies such as strengthening patents and or public research that encourages private research.

This section of the report discusses research priorities for the poor, incentives for more private research on the poor, incentives for public sector, and public-private partnerships.

3.1 Research priorities for the poor

This section summarizes what appears to a consensus of needed crop research for the poor: that research should develop traits and crops for small farmers rather than for the currently targeted large commercial farmers. The traits needed to improve the condition of the poor farmers include increasing yield potential, increasing stability of yields through resistance to biotic and abiotic stress, and enhancing the ability to grow subsistence crops in difficult environments like drought and salinity (Lipton, 2001). A trait that may not be so important in land-scarce, labor-abundant economies where hand-weeding is a source of employment is herbicide tolerance. The crops which need to be the focus of research are the basic staples of the poor: rice, wheat, white maize, cassava, and millets (Naylor, et al., 2002). Finally, the farmers targeted should be small farmers, who have limited access to land, machinery, and chemical inputs and not the large commercial farmers in the industrialized or developing countries.

Other researchers have shown that one of the most efficient ways to reduce micronutrient malnutrition of the poor is through enhancing the iron, zinc, and vitamin A content of basic food grains (Graham et al., 2001). In some cases this can be done through conventional breeding. In fact the first new varieties for micronutrient malnutrition are likely to be high iron rice produced through conventional breeding. However, for some characteristics such as enhancing rice with Vitamin A, GM crops can be an important part of the answer.

In addition to the development of crops to meet the needs of the poor, consumers and governments in developing countries are starting to demand more research on the environmental and health impacts of GM crops. Without such research, consumer and environmentalist groups may prevent GM crops from being approved for commercial use in developing countries. And, in the absence of scientists conducting such research, developing countries have no local expertise to help policymakers sort out the conflicting claims about GM crops.

3.2 Private research to focus on poor

Despite the evidence from the field trial data that first generation research of private firms did not concentrate on the crops, traits and countries needed to make a difference for the poor, there is a considerable amount of biotech research in the private sector that is producing knowledge, research tools, genes, and GM varieties that can be useful to the poor in developing countries. Such research includes the rice genome research financed by Monsanto and Syngenta and the functional genomics research on rice that will identify what genes and groups of genes do in rice and other grains. Research of this type will probably require public sector plant breeding to produce actual varieties for the poor, but with some changes in appropriability the private sector could play a role. Other examples include the Bt gene developed by Monsanto that has been incorporated into cotton for small farmers in Africa and Asia and recently into white maize in South Africa. In these cases private firms have been willing to commercialize technology that can benefit the poor, and would do it more widely if allowed.

As indicated above and in Pray and Naseem (2003), a private firm's investments in research or commercialization of a new technology will depend on the expected size of the market, their ability to appropriate some of the gains from the crop, and the costs of research and commercialization. Government actions that increase market size and appropriability and reduce the costs of innovation will ultimately create financial incentives that will spread their technologies to more small farmers. Some areas for consideration include:

- Liberalizing input markets and eliminating government corporations and subsidies can increase the potential size of the market for innovations. This was an important factor in increasing private agricultural research in Asia (Pray and Fuglie, 2000) and still may be important in the seed market in some countries since seed markets are often the last markets to be liberalized (Gisselquist et al., 2002).
- Harmonizing biosafety regulatory measures to remove unnecessary barriers to the transfer of new conventional and transgenic plant varieties between developing countries would allow private firms or public sector institutions to have bigger markets for the products of their research. For example, the South African seed company, Pannar, could supply more technology throughout Africa, and China could supply biotechnology widely in Asia.
- In countries with weak national agricultural research capacity and institutions, government intervention may be needed to create the necessary physical infrastructure such as transportation and communication and institutional infrastructure such as law and order and enforceable contract law that are required for markets to work.
- In countries with more advanced NARS and institutions, appropriability for private firms can be strengthened through stronger IPR laws and their enforcement and also through government research programmes. Government research has increased appropriability in the past by producing hybrid seed in crops that had always primarily been pure line varieties. For example, the research by the Indian government and IRRI in developing hybrid rice has induced more private plant breeding research in India (Pray and Ramaswami, 2001).
- Government can reduce the cost of research by using public sector research universities that produce highly skilled scientists. Government research institutes

identify and provide useful new germplasm for plant breeding programmes. Easing restrictions on trade in inputs required for research, such as chemicals, can reduce research costs, and easing restrictions on foreign direct investment can attract more resources for research and technology transfer. Small local firms may also need government assistance to get access to proprietary technology.

- The regulatory system is the most important government policy that restricts the private role in spreading biotechnology, because government decisions about approving or not approving a new technology and whether further research might be required can add substantial costs to the research and development process. Companies will not invest in transgenic research tailored to the needs of a particular country or attempt to commercialize a product there unless a transparent, science-based regulatory system is in place. If companies have to spend millions of dollars on biosafety research that duplicates research done elsewhere, they will be less interested in investing in the country. Furthermore, if the biosafety regulatory process is not science based and transparent, companies will not invest because of concerns that the system is not really protecting human health and the environment. Finally, if the regulatory process is a very time consuming and expensive process, the only institutions that will able to afford to commercialize a GM crop will be large multinationals. American and European firms typically expect to spend $10 million for each new transgenic product to develop the portfolio of health, environment, and agricultural biosafety information required in the regulatory process.
- In addition to providing commercial incentives for private research to assist the poor, governments can show good will by providing positive publicity perhaps in the form of prizes to firms that develop and spread technology to the poor. Tax incentives or better investment opportunities could be provided for private firms that invest in the needs of the poor are also possibilities. In the United States and elsewhere private foundations and charitable organizations such as the Rockefeller Foundation have been established and grown in part because of tax incentives.
- One final possibility for providing incentives to the private sector to do more research is a major prize programme for agricultural technology that reduces poverty or food insecurity (Lipton 2001). This competition would focus on crops of major importance to the poor, both public and private institutes could compete, and the amounts would be large enough to make it worthwhile for firms to compete. The money could come from a combination of government and private foundation. The recent announcements of a $200 million programme by the Bill and Melinda Gates Foundation to fund research on diseases that cause millions of deaths in developing countries offers a possible model for funding such a programme.[3]

3.3 Role of public research

It is clear from the field trial data in Section 2 that private firms will not develop many of the traits or new varieties needed by the poor. Most of the major biotech companies have been reducing the number of crops that they work on as their research budgets shrink. Monsanto, for example, now focuses their research on four crops: maize, soybean, wheat, and cotton. It has stopped most research on major crops like rice and potatoes, which used to be major research crops.

[3] See their website at www.gatesfoundation.org

There is consensus among economists that public research must be part of the answer. The public agricultural research systems of developing countries are an essential ingredient for harnessing the benefits of biotechnology for the poor. The IARCs are also starting to play an important role, just at the time when their budgets are being slashed. It is important to state again the key role of public research and several other points.

The first issue is the difficulty of obtaining funding for biotechnology and conventional research on problems of poor people. Public agricultural research in general and especially the IARCs are facing declining financial support. In the competition for declining funds, the poor face considerable difficulty. Almost by definition the poor do not have well organized lobbying groups that can lobby for their interests when government research resources are being allocated. Yet there are NGOs, charities, foundations and some donors who are specifically focused on the poor. These groups need to be mobilized to support research on poor peoples' problems. Some of these groups, particularly some of the NGOs, are very skeptical or opposed to biotech research. There are some things that can be done to mobilize support for the public research:

- Public institutions at the national and international level should focus on the development of useful technologies for small farmers. At present the only public sector successes in developing transgenic crops for poor farmers are Bt cotton produced by the Chinese Academy of Agricultural Sciences. Several of the IARCs are involved in developing biotechnology applications, including transgenic varieties, aimed at poor farmers, but these efforts need to be strengthened.
- More studies are needed on the economic, environmental and health benefits and concerns that poor farmers face from biotechnology and alternative technologies. Such research can help answer some of the remaining scientific questions about the safety of transgenic crops and can help people compare them with existing alternative production systems.
- Programmes that educate farmers and consumers about the potential benefits and risks of biotechnology can empower people to make informed choices.
- Transparent biosafety regulations can help ensure that appropriate regulatory decisions are made and can reassure people that they are protected from unacceptable risks.
- Programmes like participatory breeding (see box) that involve citizens in decision making on the technology can help direct public research to the issues that are important for poor farmers. Participatory research programmes can help generate more support for public research among the poor and the organizations that support them.

A second issue is that an expensive, unpredictable, and opaque biosafety regulatory regime is even more restrictive on public research than private research, because public institutes have considerably less money to finance environmental, health, and agricultural trials to meet regulatory requirements than the private sector does. Governments must find ways to rationalize their regulatory requirements and fund the necessary trials if they want public biotech research to help the poor or compete with the private sector.

A third issue is that the public research sector can be more efficient in their research efforts if they can get access to some of the proprietary technology available in the small and large biotech firms so they do not have to re-invent the wheel. The following section examines some alternatives for public-private partnerships to leverage public resources for the benefit of the poor.

Box: Can Biotech Research Address Poor Farmers' Needs? The Role of Participatory Agricultural Research

The potential of biotechnology to meet the needs of resource poor farmers is immense. The problem as articulated by Lipton (2001) is that the potential is "locked into a system where it is not used for such purposes, and where a few large firms are competitively bound to protect their investment by means that, at present, threaten public research." Section 3 discusses several approaches that have been suggested to unlock the potential of biotechnology for the welfare of the poor. For public-private partnerships to be successful also requires that the needs of the farmers are properly accounted for through participatory research. In participatory agricultural research farmers are considered to be active participants who may lead the research process and whose ideas and views influence its outcome, rather than passive bystanders or objects of research (Thro and Spillane, 2000). This is important because farmer's perception and preferences for particular technologies will influence ultimate adoption. Participatory agricultural research is considered as integral to the overall research strategy and priority setting rather than as a substitute.

Thro and Spillane (2000) suggest several reasons as to why participatory research related to biotechnology is needed. First, collaborative and farmer-led decisions about whether or not to use biotechnology require that farmers and researchers understand each other's vocabulary and typologies and have at least a rudimentary grasp of each other's expertise. Second, given the biosafety and environmental concerns of biotechnology products, it is important that farmers be aware of these negative outcomes. If they are not aware, scientists are implicitly assuming that farmers exhibit no preference for one technological approach over another and that they are passive adopters of biotechnology solutions. Third, the ability of biotechnology to allow the development of entirely new traits and plant types requires researchers to understand and identify new options some of which may be identified only through participatory research with farmers.

To date, very few priority-setting exercises with resource poor farmers have led to the implementation of biotechnology assisted research projects. One area where biotechnology tools could be particularly be useful is in plant breeding. Tools such as marker-assisted selection, inducible promoters, controllable male sterility, inducible apomixis, and visual markers provide greater flexibility in local breeding and increase the range of varietal options from which farmers can choose. However since it is unlikely that resource poor farmers will be able to finance biotechnology assisted participatory plant breeding, an alternative approach is to use participatory needs assessment techniques. Pingali et al (2001) develop a methodology for eliciting farmers' preferences using a experimental voting method. The methodology allows for quantitative estimates of preferences and the socioeconomic determinants of adoption. They find that farmers have strong preferences for certain technologies, in particular those that conserve scarce factors of production or maximize farm income, but are ambivalent about others.

For participatory biotechnology research to be successful requires that certain conditions be met. Perhaps the most important is that the information on proposed technologies be conveyed clearly, and that there be sustained communication between biotechnologist, plant breeders and farmers. While participatory research is focused on the improvement of local livelihoods, one must not lose sight of the fact that basic and applied research is still useful and needed. Even basic research must carefully address the issues raised by farmers but it may call for greater collaboration between social scientists and biological scientists to translate the needs of farmers into priorities for basic research.

3.4 Public-private partnerships

A recent review of the options for accessing biotechnology has been conducted highlighting the possibilities for partnerships between public NARS, local seed companies, global companies and the CGIAR (Byerlee and Fischer, 2001). This section summarizes some of the key points of that review and then, rather than list some of the partnerships that exist, we concentrate on the few successful cases of transferring biotechnology to farmers and developing new technologies.

Public sector access to patented biotech genes and tools

There are at least four ways public research institutes or local firms can obtain patented biotech genes and tools. First, they can simply use the technology without seeking permission from the owner. For technologies that are easily copied or fully revealed in patent disclosures, it may be efficient and legal for scientists to do this if no patent on the invention has been filed in the country or if these technologies are excluded from patent coverage. Although many important biotech tools are widely patented, especially in countries with well developed NARS, obtaining information in this manner can show whether that technique can be fully utilized since some techniques may require biological material that is difficult to access or other proprietary technology and knowledge that is only available from the inventor. Also, some commercial products can contain or be composed of proprietary tools that may not be exportable to developing country markets.

A second option is to purchase the technology. The public sector may have the most success in purchasing these technologies from Universities or small private companies. For example a consortium of public research institutes in Asia, led by IRRI, purchased the rights to a Bt gene from a small Japanese biotech company (Byerlee and Fischer, 2001). However, few key technologies will be available for purchase.

Material transfer and licensing agreements are a third possibility. Material transfer agreements (MTAs) define the conditions for research use and leave the conditions for commercialization to a future date. Initially this method is cheaper but there is the risk that the company that does the research will not be allowed to commercialize the technology developed later. Licensing agreements, on the other hand, specify the conditions for commercialization of a technology, the payments, and the sharing of benefits. They are probably the most common form of technology and know-how transfer (although in some countries the first option, use without permission, is more frequent).

Alliances and joint ventures (JV) are the fourth possibility. In JVs both parties agree to provide specific assets and to share the benefits; JV contracts typically include MTAs and licensing agreements on technology. There is a growing consensus that partnerships between the public and private sector will be needed to effectively use biotechnology for the poor in developing countries (Pingali and Traxler, 2002; and Byerlee and Fischer, 2001).

Elements of successful partnerships

To negotiate successful partnerships, partners have to identify their goals, value their assets, identifying complementarities, and identifying the potential to segment markets for the different partners (Byerlee and Fischer, 2001). Partners must also recognize their different cultures and values – public research attempting to maximize social benefits while private firms maximizing profits. To reach a partnership agreement requires negotiations.

Table 8 identifies the research assets of the different groups that might be partners in a public-private joint venture. The strongest assets of public research institutions tend to be their germplasm, variety assessment infrastructure, and (in the stronger NARS) the capacity to do upstream research. They generally also have a positive public image which can be an important asset. Private local firms have local knowledge, breeding programmes and seed marketing and delivery systems. Multinationals have the biotechnology, access to capital markets, and economies of market size, and skills dealing with regulatory agencies. The CGIAR institutes have germplasm, breeding programmes, global germplasm exchange, etc. Assets like germplasm and genes clearly are complementary assets. For example, EMBRAPA has used its soybean germplasm assets to development a partnership with Monsanto to obtain Roundup Ready genes and access to plant transformation technology. Together they have produced a series of Roundup Ready varieties that are awaiting the Brazilian Supreme Court decision on whether GM crops can be commercialized or not.

Many technologies could be used to meet the needs of the poor, but the markets are too small to be profitable to large private firms and thus they do not want to sell or bargain away their rights to these technologies because they wish to use them in places where they are or can be profitable. If markets can be segmented so that the public sector has the rights to use any technology that is provided by the firm or is jointly developed to serve the resource-poor farmers, and the private sector is given the rights to sell the technology to the commercial farmers, then the two groups can have the basis for a partnership. A number of agreements of this type, which segment the world by crops, by regions, by country income level, and by trade status, have been negotiated but none have yet been tested to see how they work. The experience with Bt cotton and herbicide tolerant soybeans suggests that it will be very difficult to effectively segment markets by certain traits.

Examples of public-private partnerships

There are a large number of institutional experiments going on with different types of public private research and technology transfer. Only a few of them have been successful in developing useful technologies and have been less successful in getting the technology out to the poor. A few have been successful in developing commercial varieties but they are being delayed by regulations or other legal challenges from commercializing the technology. We summarize some of the "successful" joint ventures and then identify some of the characteristics that they have in common.

The most successful examples of a joint venture that has been able to spread biotechnology to poor farmers are in China: Ji Dai and An Dai seed companies. Ji Dai is a joint venture between two U.S. based companies (Monsanto and Delta & Pineland) and the Hebei Provincial Seed company in China. An Dai is a joint venture between the same U.S. companies and the Anhui Provincial Seed Company in China. These JV contracts provide that Monsanto supplies the Bt gene, Delta & Pineland provides the cotton varieties while Ji Dai and An Dai provide the variety testing, seed multiplication, and seed distribution networks in their respective provinces and beyond. Ji Dai started selling seed in 1998. Ji Dai and An Dai sales of Bt cotton seed are now about 2,000 metric tons and the total planting of their Bt varieties (including farmer saved and unauthorized sales by other seed companies) is over a million ha. All of their seed sales go to small farmers (under 2 ha) although not always poor farmers. Approximately two-thirds of the households that adopted Bt cotton had per capita incomes less than US $360 (converted at official exchange rate) and those with per capita incomes of less than $180 actually got higher gains in income per ha than farmers with per capita income greater than $360 (Pray et al., 2001).

The incentives for participating in these joint ventures were money and perhaps some publicity. The U.S. companies hoped that the provincial government-owned seed companies would provide them with the political clout that they needed to get GM cotton varieties approved by the biosafety committee and into commercial production. They also hoped that the provincial seed companies would provide them with some market power so that they could charge high enough prices to actually make profits. Their first hope seems to have been fulfilled as they were able to get approval for their varieties in some (but not all) provinces. However, their second goal of market power appears to be quite limited. The provincial seed companies were looking for new money making opportunities also. Previously, cotton seed had not been a commercially interesting enterprise but introducing the Bt gene greatly increased the value of cotton seed that contained it. Now, they could make money from the seed. In addition, the provincial authorities were successful at reviving an important cash crop that had been declining due to severe pest attacks.

Another project that successfully targets poor farmers is Bt cotton adoption by small farmers in Makhatini Flats in South Africa. This land is located in a government irrigation project where all of the growers are small African farmers and many do not have access to irrigation. Monsanto, Delta & Pineland and Clark, the major cotton purchasing and ginning company (which is owned by the farmer co-op OTK in South Africa) made special investments of technical personnel and other resources to teach small farmers how to use Bt cotton profitably. They also worked with the local government research station and government extension service. Farmers can obtain up to 1290 Rand/ha credit for inputs and labor costs of cotton production from Vunisa, another cotton buying co-op which is owned by Clark. Vunisa uses most of its money to buy inputs that are provided directly to the farmers. The cotton produced by these farmers is sold to Vunisa that deducts the amount of the loan and then pays the farmer the remaining value of his crop (Vunisa, 2001). Cash payments are made to farmers for hiring people or paying themselves and their family to do hand weeding of their crops. The money for this credit in the early years came from the government Land Bank and the interest rate is fixed by the government. The 1290 Rand is supposed to pay all of their costs of production except harvesting. Virtually all cotton farmers in Makhatini have adopted Bt cotton and most appear to have made substantial gains in income as a result of it (Ismael et al., 2001; see also Traxler, 2003).

The incentive for private South African firms to participate in this programme seems to come from a combination of political and social goals. The South African government is putting pressure on all private firms to do more social welfare projects. The success of Bt cotton in Makhatini Flats has been excellent public relations for the companies involved. It seems highly unlikely that the project actually makes enough increased income from the sales of Bt seed to make up for all of the research and extension resources that they have invested, particularly in recent years when they have had to provide all the credit and farmer payback was about 70 percent of it. But what they are getting is valuable experience in developing strategies to work with poor small farmers in Africa.

Examples of successful technology development

Brazil provides a number of examples of collaboration in research and technology development that may be replicable in other countries with large public and private research capacity. The JV between EMBRAPA, the Brazilian government's Agricultural Research Corporation, and Monsanto on transgenic soybeans is an example of collaborative applied research. EMBRAPA provides the varieties and some plant transformation technology and Monsanto provides the genes and most of the transformation technology. Monsanto sells the GM soybeans through its dealer system and EMBRAPA will get royalties from the sales. A portion of the sales will go back to a research fund for sustainable soybean production.

A second type of collaborative research is when private firms or co-ops in developing countries hire individual scientists or rent labs at universities or government institutions in a collaborative effort. For example, the Cooperative of Cane, Sugar and Ethanol Producers of the State of Sao Paolo (COPERSUCAR) developed transgenic, virus-resistant sugarcane varieties by hiring faculty at the University of Sao Paolo at Campinas, the University of Minnesota, and Texas A&M to do specific parts of the research that they could not do in-house. As a result of this collaboration, COPERSUCAR has developed virus-resistant sugarcane that has been tested by its biosafety regulators and is ready for production when it becomes legally possible to grow GM varieties (Pray, 2001).

Several of the smaller but more advanced NARS have had successful partnerships with large firms to develop new technology. Egypt provides one useful example of a public-private JV in research (Byerlee and Fischer, 2001). In this case the Applied Genetic Engineering Research Institute (AGERI), an Egyptian public research institute, and Pioneer Hi-Bred, jointly developed a new Bt gene. In the collaboration, the Egyptian public system gains access to expertise to develop the local strain of Bt (the innovation) and to educate its staff. The private sector partner pays the legal costs of patenting the invention and has access to the new Bt strain for use in markets outside of Egypt.

Another example is the Monsanto and the Kenya Agricultural Research Institute collaboration on virus resistant sweet potatoes, which started more than a decade ago. Monsanto provided the gene and trained a Kenyan scientist in biotechnology. Virus-resistant varieties are now in field trials and the commercial release of this technology is possible in the next few years.

Promising collaborations

For smaller countries with less well established NARS, international research centers or regional intellectual property holding companies may be the only source of biotechnology. The international centers have entered into a limited number of joint ventures to get access to specific technology that will then be available to the poor. Examples include the Kenya, CIMMYT, and SYNGENTA project to develop Bt maize for Eastern Africa; and IRRI's collaboration with European government labs and SYNGENTA to develop Golden rice for the poor; and the international collaboration on rice genomics led by IRRI (Byerlee and Fischer, 2001).

Recently, several new multi-country programmes to get access to technology for the poor have been initiated. The African Agricultural Technology Foundation (AATF) is a non-profit corporation funded initially by Rockefeller Foundation. It will license and hold technology from the major biotech firms with a humanitarian use license and then provide the technology free to scientists in poor African countries.[4] In addition the Australian-based institute, CAMBIA, is making information about patented technology more readily available and developing non-proprietary technologies for biotechnology researchers in poor countries. Another recent initiative is the IP - Clearinghouse programme in the United States which has the goal of making intellectual property from universities and government research institutes more readily available. This programme seeks to design a toolbox of biotechnologies for public sector researchers in industrialized and developing countries at an affordable rate.

Elements of successful collaboration

The joint ventures that have actually transferred technology or produced new technology have had several characteristics. First, both parties had something substantial to gain from these collaborations. The gains do not have to be financial, although financial gains may provide the strongest incentives for long term collaboration. Second, governments had the political will and ability to negotiate with private firms; in many countries this can be very difficult because of ideology and mistrust of the private sector. Third, both parties had to make long-

[4] See their website http://www2.merid.org/AATF/

term, sustained investments of time and money; research and the development of new products always takes longer than expected. Fourth, JVs required a budgetary commitment from the public sector partners which in the Egypt and Kenya cases were financed by foreign donors. Fifth, for weaker national systems some type of broker such as ISAAA or a CGIAR institute may be important in matching the technology with the needs of the country.

The number and variety of joint ventures is growing rapidly. A systematic study into what makes successful JVs work could be extremely useful at this time.

4 CONCLUSIONS

The dominance of the private sector in agricultural biotechnology research and commercialization has raised a number of concerns about who will benefit from biotechnology. Section 2 of the paper brings together the available empirical evidence on the impact of biotech research in developing countries. This evidence shows that farmers and consumers are the primary beneficiaries of GM crops so far. This is also the case in countries that have very strong intellectual property rights, reinforced by technical and other institutions to prevent unauthorized copying. These results suggest that even if GURTs are developed and commercialized, farmers would still obtain a substantial share of the benefits from research protected by restriction technologies.

Biotechnology research by itself can not eliminate poverty and food insecurity, but it can help reduce it substantially. The paper suggests three groups of policies that would provide more technology to the poor.

- First, policies to encourage private investment in research and marketing biotech that meets the needs of the poor. These include commercial incentives like more efficient biosafety regulations and stronger IPRs; government incentives for research for the poor; and financial prizes for research and technology for the poor.

- Second, more public research is needed on the problems of the poor. Sustainable public biotech research for the poor requires the development of groups who will lobby for the poor, which can be difficult. Nevertheless, with leadership from local anti-poverty groups and donors who are committed to reducing poverty, effective local support for public research to reduce poverty might be built. International support for the IARC biotech research programmes is also essential and hopefully can be built when the IARC biotech programmes start to prove their usefulness with the development of new technology for farmers.

- Third, public private joint ventures are needed to make efficient use of the propriety technology developed by the private and public sector in industrialized countries. Governments can take a number of actions to facilitate such joint ventures.

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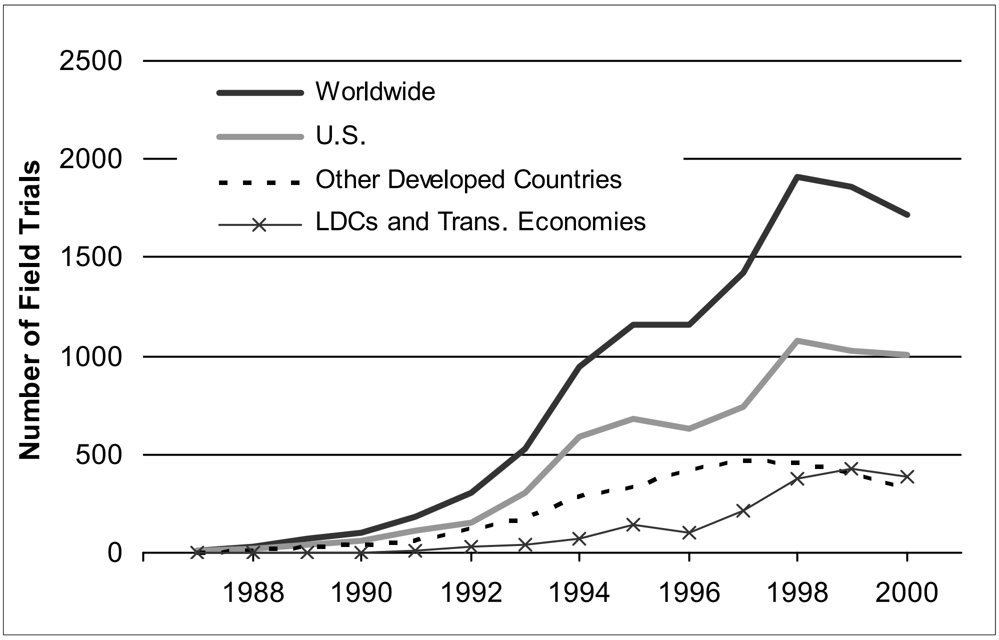
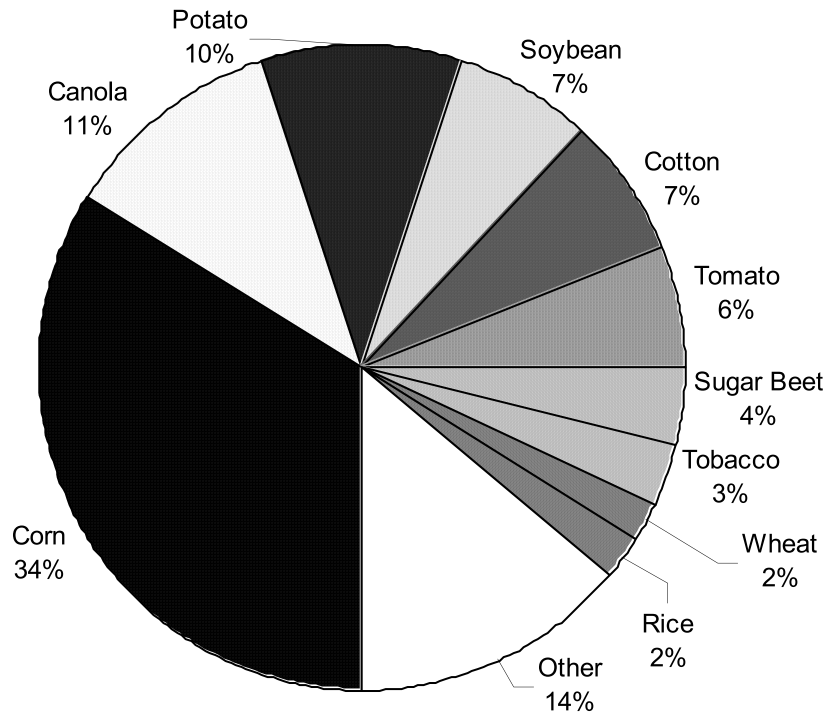
6 FIGURES, TABLES AND BOXES

Figure 1: GM Crop Field Trials Approved Worldwide



Source: Pray, Courtmanche, and Govindasamy, 2002.

Figure 2: Ten major GM Crops under Field Trials Worldwide (1987-2000)



Source: Pray, Courtmanche, and Govindasamy, 2002.

Figure 3a: GM Crops Traits Tested in Industrialized Countries (1987-2000)

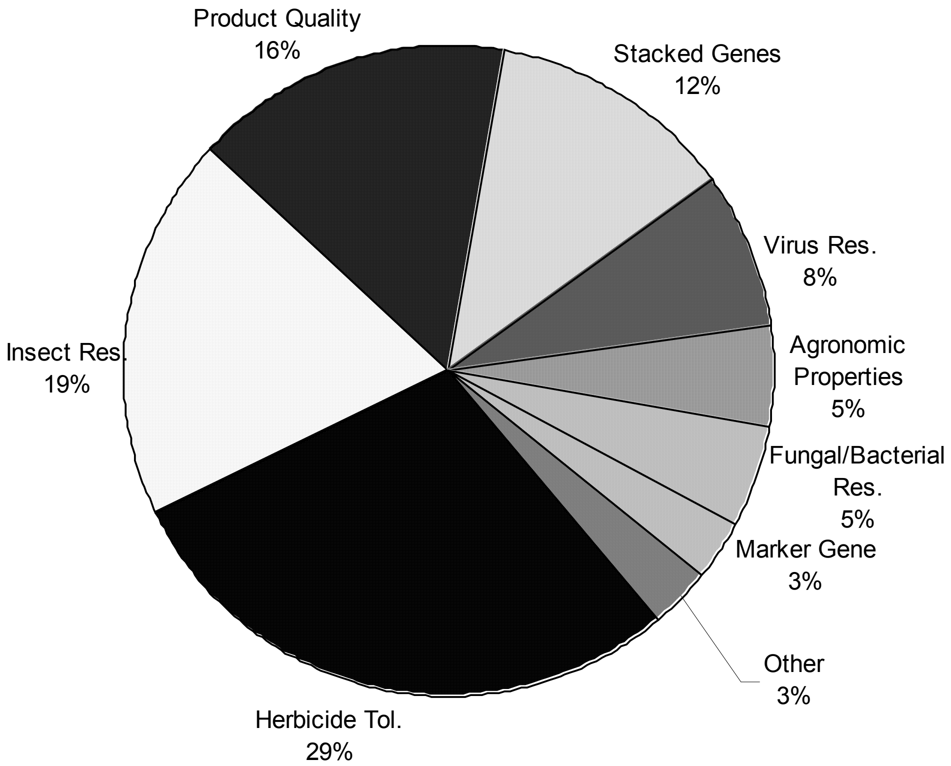
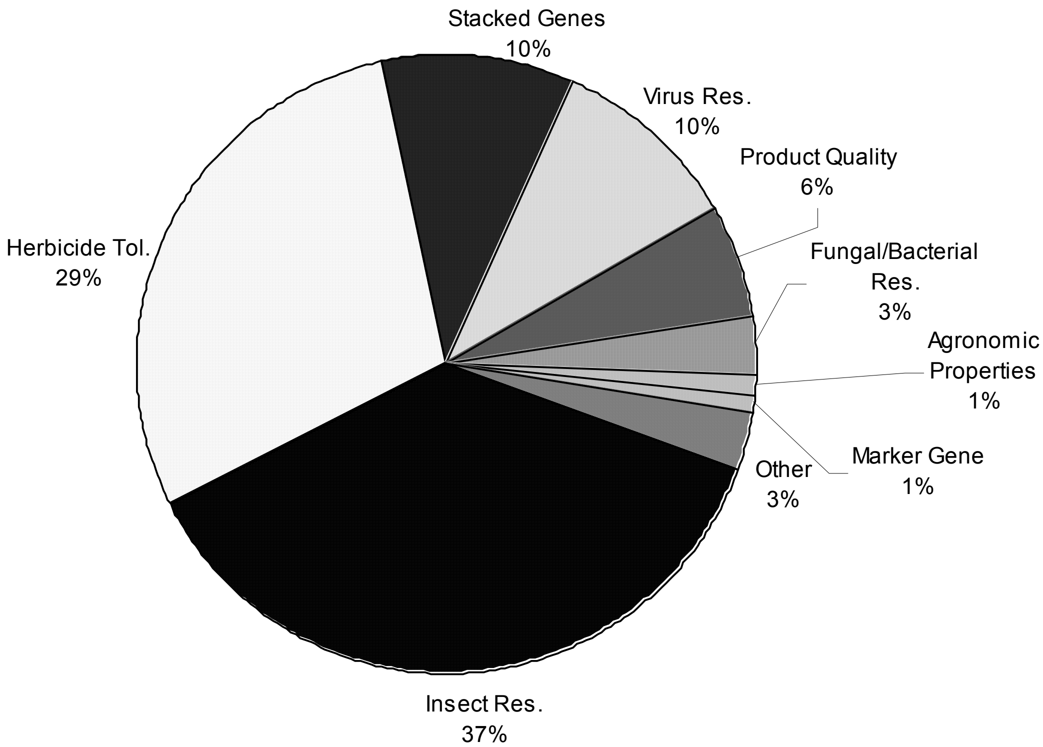


Figure 3b: GM Crops Traits Tested in Less Developed Countries (1987-2000)



Source: Pray, Courtmanche, and Govindasamy, 2002.

Figure 4a: Public/Private Research (Field Trials) of GM Crops in Industrialized Countries (1987-2000)

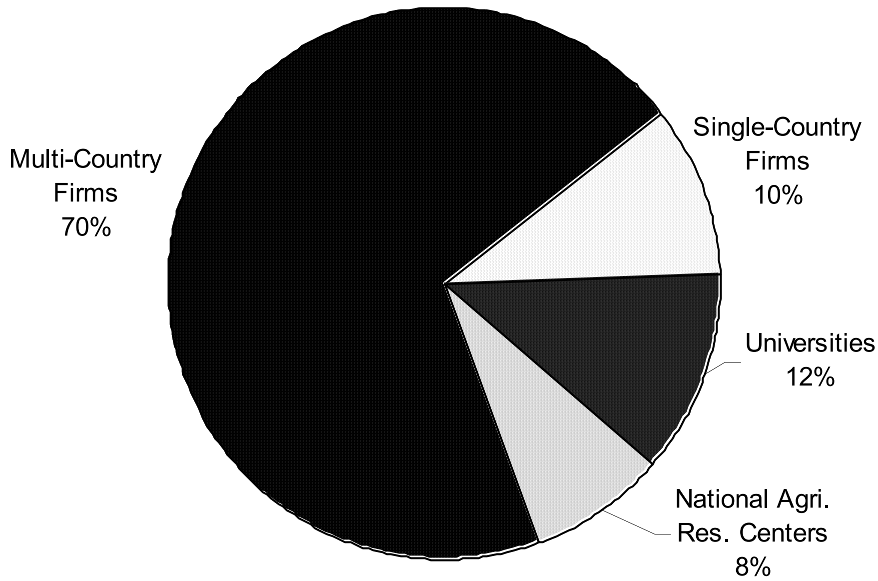
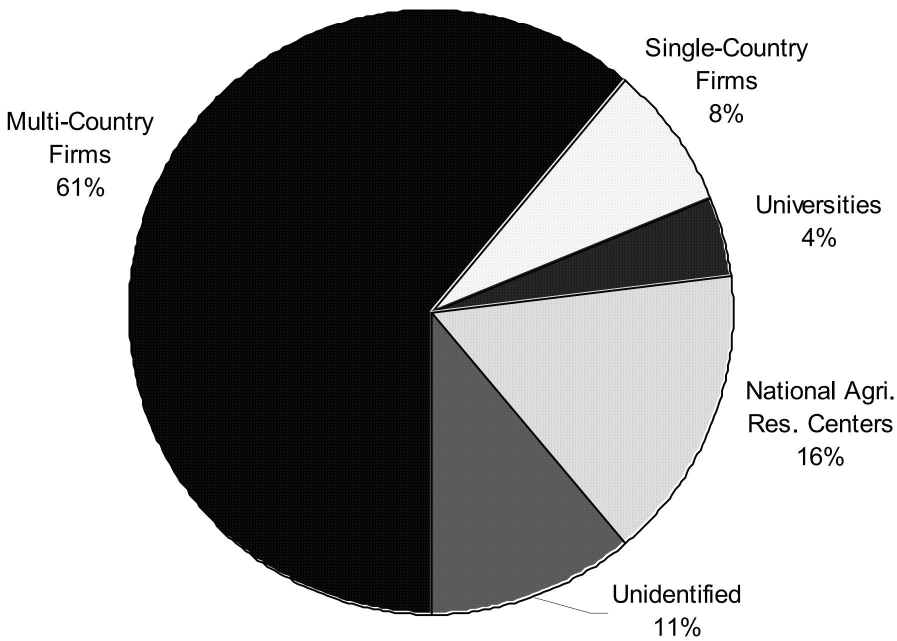


Figure 4b: Public/Private Research (Field Trials) of GM Crops in Less Developed Countries (1987-2000)



Source: Pray, Courtmanche, and Govindasamy, 2002.

Table 1: Field Trials by Crop and Region

	Maize	Canola	Potato	Soy bean	Cotton	To mato	Sugar Beet	Tobac-co	Wheat	Rice	Other	Totals
Total Number	**3881**	**1242**	**1088**	**782**	**723**	**654**	**394**	**308**	**232**	**189**	**1610**	**11105**
U.S. and Canada	2749	826	770	552	407	494	118	194	190	102	1087	7489
Europe/N.Z./Aus/Japan	452	366	227	20	72	89	237	61	23	36	316	1901
Transitional Economies	61	17	27	7	2	2	33	6	1	0	9	165
Developing Countries	619	33	64	203	242	69	6	47	18	51	198	1550
Percent of all Crops	**35**	**11**	**10**	**7**	**7**	**6**	**4**	**3**	**2**	**2**	**14**	**100**
U.S. and Canada	37	11	10	7	5	7	2	3	3	1	15	100
Europe/N.Z./Aus/Japan	24	19	12	1	4	5	13	3	1	2	17	100
Transitional Economies	37	10	16	4	1	1	20	4	1	0	6	100
Developing Countries	40	2	4	13	16	5	0	3	1	3	13	100

Source: Compiled by authors from government sources.

Table 2: Methods of Protecting Intellectual Property

Intellectual Property Protection Method	Description
Patents	Temporary exclusive rights to the use of an invention that is new and useful.
Plant Variety Protection (Plant Breeders' Rights)	Temporary exclusive rights to a new plant variety that is distinct, uniform, and stable.
Trade secret	Business or technical information that a business attempts to keep secret.
Trademark	Word or mark that serves to exclusively identify the source of the product or service
Government monopoly protection	Government gives one company exclusive control of an industry in a particular region
Biological Methods: Genetic Use Restriction Technologies (GURTs)	Restricts farmer duplication through a biology based mechanism which prevents them from using seed that they grew. Includes hybrids, which can be reused but with a major loss of productivity, and "terminators" which are a combination of genes which prevents germination of unauthorized saved seed

Source: Authors

Table 3: Agricultural Biotechnology Property Protection in Latin America and the Caribbean, circa 2000

Country	Discovery	Biological Process	Plants[b]	Plant Varieties[c]	Animals (Breeds)	Micro-organism	Genes
Argentina	×	✓	✓	✓	✓	✓	✓
Chile	×	✓	–	✓	✓	✓	–
Brazil	×	–	×	✓	×[d]	✓	–
Uruguay	×	×	×	✓	×	✓	×
Paraguay	×	×	×	×	×	–	–
Bolivia[a]	×	×	×	✓	×	–	–
Peru[a]	×	×	×	✓	×	–	–
Ecuador[a]	×	×	×	✓	×	–	–
Colombia[a]	×	×	×	✓	×	–	–
Venezuela[a]	×	×	×	✓	×	–	–
Mexico	×	×	✓	✓	×	✓	–
Costa Rica	×	×	×	×	×	–	–

Source: Trigo et al., 2002.

Note: ✓ indicates protection is possible; × indicates protection is not possible; and – indicates unknown.

a. Legislation is under the scope of Decision 344 of the Cartagena Agreement.
b. Genetic modification.
c. UPOV 1978 and/or 1991.
d. Possible in the case of animal breeds.

Table 4: Number of Patents on Vitamin A Rice by Country, Level of Rice Production and Exports

Country	*Rice Production (Mt), 1998*	*% Exported 1998*	*Number of Patents*
China	200.6	1.9	19
India	127.5	3.8	5
Indonesia	49.2	4.0	6
Bangladesh	28.3	0	0
Vietnam	29.1	0	9
Thailand	22.8	0	0
Myanmar	16.7	0.6	0
Japan	11.2	0	21
Philippines	10.2	0	1
USA	8.5	36.5	44
Brazil	7.7	0	10
Pakistan	7.0	26.6	0
Egypt	4.5	9.6	0
Nepal	3.6	0	0
Nigeria	3.3	0	0
Cote d'Ivoire	1.4	0	10
Uruguay	0.9	75.4	0
Senegal	0.1	0	0

Source: FAOSTAT (www.fao.org) and Kryder, Kowalaski and Krattiger, 2000.

Table 5: Summary of Breeding and Biotechnology Capacities of Different NARSs Types

	Type 1 NARSs-- Very strong	*Type 2 NARSs— Medium to strong*	*Type 3 NARSs-- Fragile or weak*
Markets size	**Large to very large**	**Medium to large**	**Small to medium**
Plant breeding	Strong national commodity programmes with comprehensive breeding programmes, including some pre-breeding.	National commodity programmes that are generally strong in applied breeding	Usually small and fragile programmes with success dependent on one or two individuals. Usually conduct own crosses although value added of local adaptation often low due to small market size
Use of IARC materials in breeding	Used as parents to obtain specific traits for breeding and pre-breeding, and sometimes released directly. Also use early generation materials	Very important as parents, and also as direct releases	Mostly direct releases after local screening and testing
Biotechnology research	Capacity in molecular biology as great or greater than most IARCs. Marker assisted selection being incorporated into breeding programmes. Considerable research on transgenics. Growing capacity in genomics and participants in international genomics networks.	Usually developing capacity in molecular biology but with considerable support from donors and IARCs. Potential to participate as partners in genomics.	Very little or no capacity in molecular biology although many have capacity in tissue culture.
Basic and strategic research	Often considerable capacity that can match that in many industrialized countries	May have capacity in specific areas	No capacity
Private sector	Private sector very active for hybrid crops and increasingly for non-hybrid commercial crops	Private sector activity increasing and usually involved in hybrid crops	Little private sector activity for food crops
Regulatory framework for biosafety and IPR	Framework in place although capacity to implement is modest and untried.	Most countries have, or soon will have framework, but weak capacity to implement	Most countries do not have regulatory framework

Source: Byerlee and Fischer, 2001.

Table 6: Impact of Private Biotech Research on Farmers, Seed/Biotech & Pesticide Company's Profits

		Farmers	Consumers	Biotech/ Seed Co.	Total surplus	Pesticide profits[a]
				Millions of U.S. $s		
Argentina	Bt cotton	0.77	0.00	1.70	2.47	-0.08
Mexico	Bt cotton	2.35	0.00	0.44	2.78	-0.13
S. Africa	Bt cotton	0.49	0.00	0.29	0.77	-0.05
China	Bt cotton	33.29	0.00	4.36	37.65	-3.77
India	Bt cotton	++	0.00	++		
				% of Total Surplus		
Argentina	Bt cotton	31	0	69		
Mexico	Bt cotton	84	0	16		
S. Africa	Bt cotton	63	0	37		
China	Bt cotton	88	0	12		
India	Bt cotton	66	0	34		

a. Calculated by multiplying the reduction in pesticide sales by 20 percent assuming pesticide companies have 20 percent profit margins.

Sources: Qaim and Traxler, 2002; Qaim and deJanvry, 2002; Traxler et al., 2001; Ismael, Bennett and Morse, 2001; Pray et al., 2002; and Qaim, 2002.

Table 7: Weakest to Strongest Intellectual Property Protection on Plants or Traits

IPR Legislation	Institutional – enforcement and competition	Biological/ Technical	Examples (biotech & nonbiotech)	Biotech/Seed Company % share of economic benefits*
None on plants	Public supplies seed	Pure-line varieties, open pollinated varieties	Green revolution rice and wheat in Asia	Small seed cos make limited profits
GM technology illegal	Small seed cos and farmers supply seed		RR soybeans in Brazil and Paraguay	Small seed cos make limited profits
None on plants	Public supplies seed in competition with private	Hybrids	Pearl millet, Sorghum in India	6 – 19
Plant variety protection	Weak enforcement, competition between public & private research	Pure-line varieties	Bt cotton in China	5 - 10
Just passed PVP – no protection yet	Biosafety regulations	Hybrids	Bt hybrid cotton in India	34
Patents & PVP	Strong enforcement, monopoly on trait, control seed	Pure – lines, farmers can't replant seed	Bt cotton S. Africa	35 - 40
Patents & PVP	Strong enforcement, monopoly on trait, control seed	Hybrids farmers can't replant seed	RR corn U.S., RR canola Canada,	??
Patents on plant varieties		GURTs	Not available yet	??

*: The numerator is companies' share on area where they can collect revenues. The denominator is increased profit that remains with all farmers using the improved technology after subtracting increased seed prices and technology fee plus the profits of farmers who used seed without paying technology fees.
Source: Authors.

Table 8: Assets of Public and Private Sectors in Agri-Biotechnology Research

	Public sector	*Private sector*
Performance measure	Social benefits including share to poor producers and consumers	Profits
National level research organization	**Public NARSs**	**Local seed companies**
Key assets	• Local diverse germplasm • Local knowledge • Breeding and evaluation programmes and associated infrastructure • Access to delivery system including extension • [Upstream capacity in Type I NARSs] • Positive public image	• Local knowledge • Breeding programmes and infrastructure • Seed delivery system • Marketing network
Regional and global level organizations	**CGIAR International Centers**	**Global life science companies**
Key assets	• Diverse germplasm • Breeding programmes and associated infrastructure • Global germplasm exchange and evaluation networks • Economies of market size • [Upstream capacity in a few centers] • Positive public image	• Biotechnology tools, genes, know how • Access to capital markets • Economies of market size • Skills in dealing with regulatory agencies • Negative public image

Sources: Byerlee and Fischer, 2001.

ESA Working Papers

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