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Abstract

This paper examines the economic determinants and impacts of agricultural research, particularly biotechnology research, with a view to understanding the potential of agricultural biotechnology to address the needs of the poor in developing countries. It surveys public and private agricultural research in developed and developing countries since the green revolution and discusses the public goods nature of much agricultural research. Unlike the research that launched the green revolution, agricultural biotechnology research is primarily being conducted by private firms in industrialized countries to address problems of temperate-zone commercial agriculture. These differences have important implications for the development and diffusion of new technologies to meet the needs of the poor.

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

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

1 INTRODUCTION

Agricultural research and technological innovation can create dramatic gains in agricultural production and productivity while stimulating broader economic growth that can lift millions of people out of poverty. The role of agricultural research in increasing agricultural productivity and production is well documented. Cereal production more than doubled between 1961 and 2001 for the world as a whole and almost tripled for developing countries (FAOSTAT). Almost all of the increase in cereal production during the green revolution came through higher yields rather than area expansion. Agricultural research – which led to the adoption of high yielding crop varieties and complementary inputs – was the driving force behind these gains (Lipton 2001).

Agricultural research also plays a critical role in breaking the vicious cycle of poverty and food insecurity. It does so in several ways but primarily through enabling poor farmers to increase their productivity and on-farm food production. Higher farm production – especially higher food staple production – in turn creates a ripple effect throughout the economy by lowering food prices for poor consumers, which raises real incomes not only for the urban poor but also for the food deficit farmers and rural labourers who constitute most of the poor in the developing world. Higher real incomes among the poor allow them to consume more and better food as well as a range of other goods and services – housing, education, health-care – with immediate gains for their well-being and concomitant stimulus for non-farm growth (Lipton, 2001). Higher incomes empower the poor providing them with greater opportunities for collective action (Garrity, 2002). Finally, given that food staples are the main source of nutrients in the diets of the rural poor, agriculture research, by increasing output and incomes, improves their health through greater consumption.

Numerous studies have shown that the economic returns to agricultural research investment tend to be very high. Despite these high rates of return, public investment in agricultural research slowed in most countries in the 1990s, with a few key exceptions in the developing world. In contrast with slowing public sector agricultural research, private sector investment has grown rapidly, especially in Europe and North America. Rapid advances in basic biology, driven by billions of dollars of medical and agricultural research, have led to the research tools that we call biotechnology. These tools allow scientists to develop crop and animal technologies that would not have been possible through conventional methods, and they can also greatly increase the productivity of plant breeding, pest management, veterinary science and animal husbandry research.

The promise of biotechnology has led some governments in both the industrialized and developing countries to view biotech as the next major engine of economic growth. This has led to major government investments in basic biology research, medical biotech research, and agricultural biotech research in the United States, Europe, China, India, Brazil, South Africa, and elsewhere. But the governments of some developing countries are questioning whether agricultural biotechnology is a good investment, given the high costs of research and regulation, concerns about patents and the roles of multinational corporations, and the escalating debate about food safety and environmental impacts.

This paper examines the basic economics of agricultural research: Why do governments invest taxpayers' money in research? Why do private firms invest in research? What are the economic payoffs from agricultural research? We then look at the current patterns of public and private agricultural biotechnology research and ask whether they are consistent with what these economic models would lead us to expect. Since the major advances in biotechnology, which 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 chapter focuses on plant biotechnology. A companion paper (Pray and Naseem, 2003) considers 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.

2 THE ECONOMICS OF AGRICULTURAL RESEARCH

The role of research as an engine of growth for the agricultural sector and the economy as a whole is now widely accepted by economists and a growing number of policy makers. How does this work? Simply put, research generates new technology that allows farmers to reduce their costs of production. Farmers adopt new technology if it increases their profits or welfare. As more farmers adopt the technology they start to push down prices of the product, and the benefits of lower prices are passed along to consumers. The industrial sector grows because there is more demand from the rural sector for agricultural inputs and consumer products. Industrial costs are held down because food is less expensive and labour is released from food production and moves into the industrial sector. This process can have profound benefits for the poor:

> The effect of agricultural research on improving the purchasing power of the poor—both by raising their incomes and by lowering the prices of staple food products—is probably the major source of nutritional gains associated with agricultural research. Only the poor go hungry. Because a relatively high proportion of any income gains made by the poor is spent on food, the income effects of research-induced supply shifts can have major nutritional implications, particularly if those shifts result from technologies aimed at the poorest producers (Alston et al. 1995:85).

If this story is a good model of the role of research, governments should be investing a lot of money in research and creating incentives for private firms to do the same. But agricultural research is an expensive, time consuming and risky investment. It requires scientists, labs, chemicals, electricity, experimental fields, and agricultural inputs. It takes time and patience to identify what farmers and consumers need, to develop the appropriate technology and to test the new technology to make sure it is effective, safe, and marketable. Private firms invest in agricultural research and offer new technology to farmers in the hope of making money, while governments invest in research to improve the welfare of farmers and other citizens. For private firms, research must promise to be profitable, while politicians need results that yield substantial and obvious social benefits while they are still around to claim the political credit.

2.1 Public Research

The basic justification for government expenditure on agricultural research is that in the absence of public intervention, private firms will under invest in research when the output of that research has the characteristics of a public good:

> New information or knowledge resulting from research is typically endowed with the attributes of a public good characterized by *nonrivalness* or jointness in supply and use and *nonexcludability* or external economies. The first attribute implies that the good is equally available to all. The second implies that it is impossible for private producers to appropriate through market pricing the full social benefits arising directly from the production (and consumption) of the good – it is difficult to exclude from the use of the good those who do not pay for it. A socially optimal level of supply of such a good cannot be expected if its supply is left to private firms.

> Because present institutional arrangements are such that much information resulting from basic research is nonexcludable, it has been necessary to establish nonprofit institutions to advance basic scientific knowledge (Ruttan 2001).

Much of the output of biotech research has one or both of these characteristics. For example, the knowledge about the structure of the rice genome can be used by any scientist without reducing the amount of knowledge available to other scientists, and once that knowledge is published in an academic journal or on the web, it is difficult to exclude other people from using it.

The development of a new rice variety through marker aided selection or genetic engineering, in contrast, is not a pure public good although it retains some public good elements. The genetic characteristics of the new variety are embodied in a seed that can be used up and is thus not available to all, and it is sometimes possible to exclude people from using the seed. However, farmers may be able to harvest the seed of the new rice variety and save it for planting the following year. Other seed companies may also reproduce the seed and sell it in competition with the inventor of the variety unless it is effectively protected by some type of legal intellectual property rights. Because it is difficult to exclude farmers and other seed companies from reproducing the seed, the inventor cannot charge prices that will capture all of the economic benefits that arise from the new technology, therefore much of the benefit from research is captured by farmers and rival companies. The inventor may not be able to charge enough for the seed to make the research profitable, and therefore will invest far less than is socially optimal in biotech research to develop improved plant varieties. Because research to develop new rice varieties has some of the characteristics of a public good – it is difficult to exclude unauthorized use – the private sector will greatly under invest in research and there is a need for public investment in research.

2.1.1 Social Returns to Public Research

Public investment in research is not justified simply because there are social benefits; many public investments will have social benefits, but research is only justified if the social rate of return is higher than for other ways in which the money might be used. The benefits to society from research are primarily measured as the reduction in the costs of agricultural production due to technology that improves productivity and saves inputs. The annual benefits can be calculated by estimating how much the supply of the product shifts outward due to the new technology and then measuring the gains that accrue to consumers, producers and society. In technical terms these gains are known as consumer surplus, producer surplus and net social welfare. The benefits from research can also be calculated from econometric estimates of the impact of research on agricultural productivity, agricultural costs, or agricultural profits. The benefits are then compared to the cost of research to calculate an internal rate of return to public investments in research.

Agricultural economists have conducted a large number of studies to measure the costs and benefits of government investments in agricultural research. These studies clearly illustrate that public investments in research are a very good government investment. Several recent studies have reviewed the available information accumulated and analyzed the data from 375 studies that have calculated the social rates of return to investments in agricultural research. Although these studies were carried out using a variety of different methods, they showed considerable consistency (Evenson 2001; Alston et al., 2000). As Table 1 shows, the average rate of return to investments in research calculated using the consumer and producer surplus evaluation methods was about 40 percent while the studies using econometric methods had a average return of about 50 percent. Considering that private companies and governments usually can obtain credit at interest rates below 10 percent and the rates of return on other types of government investments are considerably lower than 40 percent, these rates of return to research are very high and suggest that there is considerable underinvestment in agricultural research in both the industrialized and developing world.

Recent studies of the returns to investment in research by the International Agricultural Research Centres (IARCs) of the Consultative Group for International Agricultural Research (CGIAR) find that these investments contributed directly to agricultural productivity through the provision of improved germplasm for use by farmers or as parent stock for commercial varieties (Evenson 2001). The international crop research centres achieved very high rates of return to research (115 percent in Asia, 68 percent in Africa, and 38 percent in Latin America) which is considerably more than the average returns to investments by the National Agricultural Research Systems (NARS) in Asia and Africa.

Although some economists are sceptical of these high levels of returns, they still conclude that public sector research was a very good investment (Alston et al., 2000). These economists have also found that the investments in IARCs are beneficial not only to developing countries but that some benefits spill over to farmers and consumers in industrialized countries as well (Pardey et al., 1996).

2.1.2 Determinants of public research expenditure

Policy makers who determine the level of public investment in agricultural research respond to many of the same forces that influence the amount and direction of private research (Hayami and Ruttan, 1985). Public agricultural research increases when there are discoveries in basic science that increase the ease or reduce the costs of developing useful technological innovations. In private sector research models this is referred to as an increase in technological opportunity. The green revolution was made possible by the discovery of dwarfing genes in rice and wheat. These discoveries created the opportunity for plant breeders around the world to develop new varieties that would produce more grain in response to higher doses of fertilizer and good water conditions. These technological opportunities led to major increases in public sector plant breeding research around the world. Likewise, the tools of biotechnology have created a major shift outward in the innovation possibility frontier for plant breeding research and some governments have again responded by increasing their investments in research.

It has also been shown that changes in the demand for technology by farmers and consumers induces research to develop a particular type of technology (Hayami and Ruttan, 1985). For example, in Asia, population growth pushing against limited land increased land prices. This led farmers to demand and government scientists to develop technology in the form of high yielding varieties that allowed farmers to substitute biological technology and inexpensive fertilizer for land. Private firms did not attempt research to fulfil this demand because they could not make profit selling new rice varieties to pay for the research. Public scientists in Japan did attempt this research because consumers in Japan put pressure on the Japanese government to provide cheaper food and Japanese farmers had run out of land for expansion. The government put money into research that eventually delivered fertilizer responsive rice varieties.

In the case of biotechnology some of the key factors driving research have been the demand for ways to protect plants against pests and disease for which no genetic resistance seemed to exist; for more efficient and labour saving ways of controlling pests; for ways to reduce the cost of pesticide use, and methods to improve the quality fruits, vegetables and edible oils.

2.1.3 Levels and Trends in Public Research Expenditure

Worldwide public sector agricultural research expenditure almost doubled between 1976 and 1995 increasing from $12 billion to $22 billion (Table 2). Most of this growth came in the developing countries, which now accounts for about half of the public research worldwide. Growth in public research virtually ceased after 1990 in developed countries, and slowed down in most developing countries. Latin America and China were the exceptions, with public research investment accelerating in the 1990s. Public agricultural research expenditures in Africa grew much more slowly than in other developing country regions throughout the period 1976-95 and actually shrank after 1990.

The IARCs have been hit hard in recent years by waning donor interest in agricultural research. Figure 1a shows the growth and decline of funding for the Consultative Group for International Agricultural Research (CGIAR) centres for agricultural research. Some of the traditional crop centres such as the International Rice Research Institute (IRRI), which have been some of the most productive in terms of the benefits of their technologies to farmers and consumers, have been particularly hard hit with their funding being cut almost 50 percent since 1991 (Figure 1b).

2.1.4 Chronic Underinvestment in Public Research in Developing Countries

In some countries such as China, Brazil, and South Africa, the biotech revolution has created new opportunities for technological innovation in agriculture and stimulated new growth in public spending on research (Table 2). The very high rates of return to public research discussed above suggest, however, that there is a serious problem of underinvestment in public agricultural research, including biotechnology. The stagnant or slow growth rates for agricultural research in Africa – where research is most desperately needed – and the declining funding of the CGIAR are particularly worrying. Even in Latin America, which has seen some growth in public research in the 1990s, a recent assessment of the Latin American public agricultural system described the situation as one of chronic underinvestment (Trigo et al., 2002).

The aggregate data conceals the very high concentration of investments in a small number of countries. In Latin America, Brazil and Argentina account for almost 75 percent of total investments; and, if Colombia, Peru, and Venezuela are included, the figure grows to over 85 percent. On average, over 85 percent of the budgets go to researchers' salaries and makes it difficult to undertake an effective research program.

The public research in much of Africa is of particular concern. In many countries public research is almost non-existent, and sub-Saharan Africa as a whole is the one place where public research is declining. Only Kenya and South Africa have major research establishments which spend more than $100 million annually, have substantial research capacity and are making substantial investments. Nigeria is making investments but is starting from scratch. Only five or six universities in sub-Saharan Africa have sufficient biotech research capacity to be in a Rockefeller Foundation's African research network (Thomson, 2002).

Another indicator of underinvestment in public research is research intensity: the ratio of research expenditure to the size of agricultural GDP (Table 3). The size of a country's agricultural GDP is an indicator of the importance of agricultural in its economy and hence of the potential economic benefits it could reap from successful investment in research. It is also an indicator of a country's ability to pay for research. Typically wealthier countries invest a higher proportion of their agricultural GDP on research than poorer countries although they arguably need it less because of agriculture's relatively small size in their economies.

Overall developing countries invest about 0.6 percent of their agricultural GDP on public research. Research intensities in Africa are similar to those in Latin America, at about 1 percent. Despite having much stronger growth in research expenditures, Asian public research intensities are much lower than Latin America and Africa. Developed countries have public research intensities of 2.6 percent. If you add on private sector research expenditure, which exceeds public research in industrialized countries, the advantage of the industrialized countries is even greater: about 5.2 percent for industrialized countries compared with 0.8 percent for developing countries.

2.2 Private Research

Studies have shown that private firms cannot capture all of the benefits of their research through higher prices; rather farmers and consumers capture some of the benefits and thus there is a social gain to society as a whole from private research. Studies on rates of return to agricultural research, as in Table 1, show that the social return to private research is about 48 percent, which is similar to that for public research. This suggests that there is room for governments to improve social welfare with policy changes and investments that encourage private research. In this section we examine the determinants of private research and the level and trends of private agricultural research in developing countries.

2.2.1 Determinants of Private Research

Returns to Research

Private firms invest in agricultural research in the hope that it will increase their profits. If it does not, they will not continue to invest in research for very long. The profitability of agricultural R&D investments is determined by the costs and returns to the research activity, which are in turn influenced by several factors. The returns to private research improve in the presence of:

- Sizable expected demand for the products of research,
- Favourable business environment that permits efficient operations, and
- Availability of exclusion mechanisms that enable firms to appropriate part the benefits from the new product or process.

Potential demand for inputs and consumer products developed through research, and thus market size, varies among regions depending on the size of the population, the purchasing power of the prospective buyers, local agro-climatic conditions, and sectoral and macroeconomic policies that influence input and output prices. Local agro-climatic conditions set the bounds on the type of technologies that could be adopted and thus shape the nature of local demand. For example, maize varieties are sensitive to changes in day length, moisture and pests, which makes local breeding necessary although the parent germplasm may be imported.

Changes in the incentive environment affect the demand for research services and the speed at which countries can adopt new agricultural innovations. Macroeconomic and sectoral policies alter the relative profitability of agricultural activities that in turn affects the expected profitability of adopting different agricultural innovations, as well as the capacity of different segments of the farm community to acquire the new technologies. The effectiveness of agricultural support services delivery (public and private), in particular agricultural extension, and rural infrastructure (roads, markets, irrigation) will also have a major influence on the types and range of technologies introduced and the speed of adoption by farmers. Finally, bilateral and multilateral trade agreements reshape trading rules and influence market access and thus potential market size.

Government policies that affect the local business environment directly influence the returns to private research. Government marketing of inputs reduces the market share of private firms, while licensing and investment regulations such as the reservation of some agribusiness activities (like seed sales for small firms in India) can limit private investment in R&D (Pray and Ramaswami, 2001).

Appropriability is an important precondition for private for-profit participation in agricultural research. If firms can not capture (appropriate) some of the social benefits of their research, they can not make profits on their research investments and will stop investing. To capture some of the benefits from the innovation the innovating firm must be able to keep people who do not pay them royalties from using the innovation. The ability to do this is a function of the characteristics of the technology, the laws on intellectual property and their enforcement, the structure of the industry which is producing the technology and the industry that is using it. The legal means of protection against unauthorized use includes patents, plant breeder's rights, and trademarks (Table 4). They also control their use by keeping inventions or key parts of their inventions secret, which in some countries is protected by trade secrecy law. These legal means only give limited protection in developing countries as will be shown below.

Inventors can protect their inventions by biological means such as putting new characteristics into hybrid cultivars or including other technical means to prevent copying (i.e. genetic use restriction techniques (GURTs)). These techniques increase the size of the market for the new cultivar because farmers can not reproduce the seed on their own farm and use it the next year. In the case of hybrids the seeds will grow but the crop will yield 15 to 20 percent less. This is usually sufficient incentive for farmers to purchase new seeds each year. In the case of GURTs, some of the proposed techniques (none are in commercial use) would produce sterile seed. This would mean that farmers could not reproduce the seed for replanting at all. Some variations of these techniques would allow the seed to be fertile so farmers could reproduce the seed, but the farmers' seed would not have the new patented technology such as insect resistance unless the seed was treated with a chemical. The type of GURT that leads to sterile seed has caused considerable controversy because poor farmers in developing countries tend to save much of their seed. The companies are accused of trying to exploit poor farmers by forcing them to purchase seed every year.

The degree of appropriability achieved is a function of the strength of intellectual property laws, the degree to which government agencies can enforce the laws, other institutions such as biosafety regulations and the structure of industry that reduce the cost of enforcing IPRs, and the technical capacity of firms to protect their varieties through the use of hybrids or GURTs.

Costs of research

Private research investments are also determined by the potential costs of the agricultural research program and the associated risks (Pray and Echeverría, 1991). The cost of research is the combination of quantity and price of research inputs, the number of years that these inputs will have to be employed to develop a new technology, and the stock of knowledge in this area of science. Such costs decrease with the:

- Supply of research inputs,
- Available human capital for conducting research activity,
- Stock of existing knowledge and technology, and
- Presence of a favourable business environment.

The supply of research inputs and thus their price depends on the availability and accessibility of research tools and knowledge, many of which are produced by the public sector, both government institutes and universities, or international programs like the international institutes of the CGIAR. For example, improved populations of crop germplasm developed by public research programs may be used as parent material by private breeders to add desirable traits to new private varieties. The advances in biotechnology knowledge have led to a significant increase in private investment in agricultural research in the United States and Europe over the past two decades. This should reduce the marginal cost of applied agricultural research throughout the world.

Foreign direct investment policies, because they influence incentives for foreign firms to import externally developed technologies into a host country, also affect the availability of research inputs. Foreign seed firms import foreign germplasm which local firms can eventually use in their breeding programs. Foreign chemical firms import new methods of conducting and managing research.

The domestic supply and quality of human capital, a key input to the research activity, influences the level of research investments. In the Philippines, the availability and low cost of hiring local research personnel encouraged some multinational firms to transfer their research programs to teams of Filipino scientists (Pray, 1987). The domestic supply of skilled personnel is heavily dependent on the level and composition of public and private expenditures on education.

Several aspects of the business environment affect research costs and the productivity of research costs. Industrial policy can influence the degree of market concentration, the intensity of competition, and the prices of research inputs and outputs. Various government incentive programs, such as government contracts for new products and processes, grants and concessional loans, technical information services, and tax incentives, reduce research costs. Indirectly, the development of capital markets makes it easier for firms to raise funds for research (e.g., venture capital). Bilateral and multilateral agreements also improve trade opportunities by facilitating access to intermediate technologies.

Excessive product testing requirements and seed certification procedures can greatly increase the costs of commercializing research output. Regulations are essential to ensure that products developed using biotechnology are environmentally benign and safe for human consumption and to gain consumer acceptance, but they have greatly increased the cost of developing and releasing transgenic plant varieties. For example, seed companies have spent several million U.S. dollars over many years in India to bring Bt cotton varieties to market. This is more than the annual research budgets of most Indian seed companies. As a result, only the largest companies can afford to attempt to commercialize genetically modified crops.

2.2.2 Levels and Trends in Private Agricultural Research

Levels and trends in private sector agricultural research present a different pattern than public research. In both developed and developing countries there has been rapid growth in private research but in developing countries private research started from a very small base and remains a small share of total research. Private research expenditure over time is available only for a limited number of countries. It is estimated that private firms spend about US$ 10.8 billion worldwide on research with $0.8 billion spent in the developing world (Pardey and Beintema, 2001). In the industrialized countries, however, investment in private research has grown twice as rapidly as public research since 1981 (Figure 2a).

Private research now exceeds public research in the United States, the U.K. and the Netherlands. In Australia and New Zealand public research still dominates but private research grew very rapidly at 15.1 percent and 13.7 percent annually from a very low base. In part, the low share of the private sector in these countries relates to the absence of large pharmaceutical and pesticide industries which account for much of the private research in the United States and the U.K. (Alston et al., 2000).

In the developing countries of Asia private research expenditures grew in all countries, as did public research. In the three largest countries – China, India, and Indonesia – private investment grew much more rapidly than public investment, whereas public research grew more rapidly than private research in the smaller Southeast Asian economies – Malaysia, the Philippines and Thailand. At the end of the period, private sector investment accounted for about 10 percent of total agricultural research in Asia.

About half of the private R&D in the developing countries of Asia is conducted by multinational corporations, with the important exceptions of India, Pakistan, and Malaysia (Pray and Fuglie, 2001). In addition foreign firms are concentrated in the industries where private agricultural R&D has been growing fastest – chemicals, livestock, and seed – and play only a small role in private plantation and machinery research, where R&D growth has been slower.

There have been few case studies of the growth of private research in Latin America and Africa. In Brazil there was no clear trend in private research up to 1996 (Beintema et al., 2001). Colombia experienced rapid growth in private R&D led by research on export crops, financed largely by producers (Estrada et al., 2002). Private research in Chile was constant or has declined slightly as the economy liberalized and farmers were able to import agricultural technology directly from the U.S. In Kenya private agricultural research reportedly is growing with export crops leading the way (Ndii and Beyerlee, 1999).

Overall in developing countries, the amount of private research is very small relative to the amounts in the developed countries and compared to the size of their own agricultural economies. In aggregate, the private sector share of total agricultural research expenditures is estimated at 5 percent in developing countries (Figure 2b). In Asia public research is continuing to grow, but not nearly enough to catch up to developed country levels and the private sector share is still small. Public and private R&D together do not make up one percent of agricultural valued-added in any of the seven developing countries studied (Pray and Fuglie, 2000) while in the industrialized countries public research and private research together account for 5.5 percent of agricultural GDP (Pardey and Beintema, 2001).

3 AGRICULTURAL BIOTECH RESEARCH EXPENDITURES AND CHARACTERISTICS

How much of the public and private research described above is biotech research? Who is doing agricultural biotech research and where? What is the subject of biotech research? This section brings together available data on this topic.

Three types of biotechnology are currently useful in producing new technology for farmers and are the focus of most of the discussion about biotech in this chapter. The first is advanced tissue culture, which allows the development of plants from plant cells. The second is molecular breeding also known as marker assisted breeding which allows breeders to develop conventional or transgenic crops more quickly and efficiently. The third is genetic engineering which results in the production of transgenic plants or genetically modified plants (known as GMOs) which have been transformed with genes of another species. A more extensive list of what is included in biotech research in developing countries is found in Table 5.

Information on how much biotech research is being conducted around the world is very limited. To obtain an overview of biotech research around the world, we first review the available estimates of research expenditure on agricultural biotech. Then we look at data on field trials of GM crops, which is perhaps the only way to measure and characterize the applied biotech research by private firms.

3.1 Biotech Research Expenditures

Precise estimates of worldwide plant biotech research are not available; however, there are some preliminary estimates of biotech research expenditure (Byerlee and Fischer, 2001). We have used these estimates to construct Table 6. About 90 percent of the biotech research expenditure is in industrialized countries. This is where both the public and private sectors conduct most of the basic biotech research. The public sector tends to place more emphasis on basic research, but private firms are doing a remarkable amount of research on such upstream research as mapping genomes and identifying the function of specific genes. The private sector conducts a large amount of applied research to develop new GM crop varieties – considerably more than the public sector. In total there is more private than public biotech research but the public sector still plays a large role.

The data on biotech research expenditure in developing countries is incomplete especially for the private sector, but it is clearly much less than in industrialized countries. The largest expenditures in developing countries are by the national research systems, with foreign aid donors contributing about a third of the money spent by NARS. The IARCs spend about 8 percent of their budget on biotechnology research (Morris and Hoisington, 2000), but the total is considerably less that the amount spent by NARS. More recent evidence indicates that these estimates of the amount of public research in developing countries are too low. Huang and his colleagues estimated that China by itself spent over US$100 million on agricultural biotech research in 1999 (Huang et al., 2002).

Some private biotech research is conducted in developing countries, mostly by multinationals that are conducting trials of their transgenic varieties, but some is conducted by local research institutes. For example, local private sugarcane research institutes have fairly large biotech research programmes in Brazil and South Africa while several local seed companies, notably Maharashtra Hybrids, have biotech research programmes in India. The total investment of these private efforts is unknown but is undoubtedly less than the public sector is investing in biotech research in developing countries.

Both public and private investments in biotech research grew rapidly in the United States and Europe until around 2000 when Table 6 was constructed. Public research in biotechnology as a share of total research and in real expenditure has continued to grow in industrialized countries. Even in countries such as France and Germany, where there is considerable opposition to genetically modified crops, the governments continue to invest in biotech research.

The growth in private sector biotech research was fuelled at first by venture capital and stock offerings by small biotech companies and then by established seed and agricultural chemical companies investing in their own biotech research and in research of the smaller biotech firms. Since the late 1990s these companies have consolidated into a few major biotech companies that dominate agricultural biotechnology. These companies and some of the companies that they purchased are shown in Table 7.

Research funded by the major private firms has declined since 2000, according to their annual reports and other published information. Monsanto reduced its research expenditure, which is about 85 percent biotech and plant breeding, from US$588 million to $550 million between 2000 and 2001 (Monsanto, 2002). Syngenta's total agricultural research of which about 21 percent is biotech and 15 percent plant breeding declined from $745 million to $723 million (Syngenta, 2002). Recently Syngenta announced that they were closing their Torrey Mesa Research Institute. Of the Institute's 180 employees 106 will be relocated to North Carolina or into a joint venture with Diversa (Vogel, 2002). In 2001, Savia, the large Mexican conglomerate, cut the research of its biotech subsidiary, DNAP, in half. Dow Agrosciences also reported declining research.

The only firms that may be increasing their biotech research are Bayer who purchased Aventis to get into the biotech business, and BASF who also just started to participate in biotech research. Both firms announced that they would increase their biotech research.

Public sector biotech in developing countries is growing rapidly. It is being pulled along by large investments in Brazil, China, India, South Africa, Egypt and a few other large countries. India may be spending as much as $30 million and Brazil about $15 million annually on agricultural biotech. They are also increasing their public sector biotech research but not at the rate of China, where they were spending U.S.$112 million in 1999 and now plan to increase that amount by 400 percent by 2004 (Pray et al., 2002; Byerlee and Fischer, 2001).

3.2 Biotech research institutions in developing countries

Public agricultural biotech research is conducted and often financed by quite different institutions from the traditional agricultural research systems in developing countries. Conventional agricultural research is largely funded the Ministry of Agriculture and/or Agricultural Research Councils, and the research is primarily conducted in institutes of the Ministries for Food and Agriculture, provincial government research institutes or agricultural universities. Biotechnology research in most developing countries that have made big investments is funded by Ministries of Science and Technology (China and India) or in the case of Brazil a government research foundation called FAPESP. Biotech research is also funded by Ministries of Agriculture but often in smaller amounts. General universities play a larger role in the conduct of agricultural biotech research than Ministry of Agriculture institutes. A recent study of biotech research in Latin America indicates that the majority of the agricultural biotech R&D is conducted in public universities (44 percent), followed by public R&D centres (26 percent) and private firms (20 percent) (Trigo et al., 2001). The institutions that do the most applied biotech research – field trials of GM varieties – are predominantly in the private sector, particularly multinational input firms.

Biotech research in developing countries spans the entire spectrum of research from mapping plant and pathogen genomes in Brazil, China and India to applied research testing whether

GM crop varieties that were developed in the United States fit into the agricultural, climatic, and market conditions found in developing countries. Byerlee and Fischer (2001) have divided developing countries into three groups depending on their biotech and seed research capacity (see Table 8). Group one includes countries like China, India, and Brazil with capacity to do their own independent biotech research. They have strong plant breeding capacity and use the IARCs as sources of germplasm for plant breeding. They have biotechnology and basic research programmes that rival those of many industrialized countries. They have strong private sector seed companies and a biosafety regulatory system in place, although it is largely untried.

At the other end of the spectrum, many developing countries have no biotech research at all. Their plant breeding capacity is limited so they directly release varieties developed by the IARCs without further breeding. There is little capacity for basic research, little private research, and no biosafety regulations.

The governments that have made substantial investments in public sector agricultural biotechnology research in the developing world – Brazil, China and India – have several things in common. First, they have a strong scientific base. These countries along with the Republic of Korea account for three quarters of all the science that is conducted in developing countries (Trigo et al., 2001). Second, they have identified science and biotechnology in particular as an important engine of economic growth in both agriculture and medicine. Third, the agricultural sector is a large and important component of their economies. Fourth, public agricultural science has had substantial success in promoting rapid agricultural growth in all of these countries. For these countries, the potential payoffs from biotech research are high and the cost of biotech research is relatively low because they are adding to a large agricultural and medical research capacity that is already in place. Politicians in all of these countries have seen the explosive growth of information technology and its contributions to their economies and hope for similar growth through medical and agricultural biotechnology.

However, the enthusiasm of these countries for agricultural biotech research will be lost if the payoffs are long in coming; so far the only obvious payoffs are public Bt cotton varieties developed in China. Public and private varieties of GM soybeans have been developed in Brazil, but the approval GM food crops is stalled by concerns about how it will affect their exports and about biosafety for the environment and human health. Thus, in Brazil, although transgenic soybeans have been approved for commercial use by the government they are still tied up in its court. In India GM cotton was approved for planting but other GM crops have been held up by regulatory concerns. An obvious conclusion is that efforts to establish an effective, transparent, and efficient biosafety regulatory system are essential.

3.3 Biotech research measured by field trials

While biotech research expenditure is fairly evenly divided between public and private research the production of technology is almost entirely in the hands of the private sector. All of the plant biotechnology that has been commercialized in the world, with the exception of China, was developed by the private sector.

Field trials of GM crop varieties are an important indicator of the spread of agricultural biotechnology research worldwide. These trials are an essential early step in the process of bringing agricultural biotechnology to commercial markets (around year 7 or 8 in Figure 3). After much research and many glasshouse trials, a private company or public institution puts its newly discovered crop variety through a battery of tests to ensure that it does not have an adverse effect on agricultural production, the environment, or animal and human health. To do this, the firm must submit an application to the government for permission to conduct a GM crop release into the environment. (These are widely known as crop field tests, field trials or environmental releases.) After the crops have been approved for environmental and food-safety trials and tests have been successful, the company or institution submits an application to the government for deregulation (or general release) of the crop. Once the crop has been deregulated, the company can commercially release the crop for sale to farmers in some countries. In other countries the GM crop variety also has to go through the mandatory variety trials that are required of all new varieties.

Field trials of GM crops are measured herein by the total number of applications that were approved in each country by its appropriate governmental regulatory department. In our study we have used the U.S. counting system in which one application is for one event (a gene or series of genes transplanted in one variety) no matter how many locations this event is tested in.

3.3.1 Growth of biotech research over time

The field trial data collected from 1987-2000 indicates rapid growth in biotech research (see Figure 4). The United States has always been the leader in the number of field trials and the pace increased after 1993. In 1997, field trials in other industrialized countries peaked and have declined slightly since then. There was a significant reduction or plateau in GM crop research in Western European countries, Japan, Argentina and New Zealand. The leveling trend in Western Europe was probably caused by increasing negative consumer perceptions about biotechnology and environmental pressure for increased regulation in Europe. New Zealand slowed recently because of a voluntary moratorium on field trial applications since June 2000 while the government reviewed its biotech policy. Developing countries and countries in transition from socialism (mostly in Europe) have lagged behind the industrialized countries in starting to conduct field trials. In recent years, however, the number of field trials in those countries has increased.

3.3.2 Who is doing biotech research?

The private sector continues to heavily dominate in the research development of new GM crops[1]. Figures 5a and 5b show the division of GM crop research by public and private sectors in industrialized and developing countries. Less than 23 percent of the applications for field trials that have been approved by governments worldwide have been submitted by universities or government or international agricultural research centres. Additionally, many of those that have been submitted by the public sector have been submitted jointly with a private-sector or multinational life science partner. The transitional economies of Europe report the lowest public sector participation with only 7 percent of field trials being conducted by the public sector.

The multinational firms[2] are responsible for most of the field trials in industrialized countries (70 percent), with single-country firms[3] accounting for 10 percent of all field trials.

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1 Field trial data cannot be interpreted as representative of all biotechnology research being conducted in a country. It represents only the most applied R&D and only a piece of a country's agricultural research. Many types of agricultural research are being conducted in this sector, both private and public. The reader should not assume that the level of field trial data in a country represents a country's agricultural R&D.

2 Multinational firms are defined as companies that have applied for permission to conduct field trials in more than one country. More than 54 multinationals have conducted GM crop field trials worldwide.

3 Single-country firms are defined as companies that have conducted field trials in only one country thus far; there are 205 single-country firms.

Universities are conducting 12 percent of the GM crop research followed finally by the national and international agricultural research centres conducting 8 percent of all field trials in developed countries. In developing countries the only change from these statistics is that national and international agricultural research centres are conducting 16 percent of field trials with universities accounting for a mere 4 percent. This reflects the fact that most agricultural research in developing countries is conducted by the research institutes rather than universities (Pray and Umali-Deininger, 1998). Within the transitional economies of Europe 79 percent of all field trials are being conducted by multinational corporations, followed by a mere 1 percent by local firms and 7 percent of the research by national agricultural research centres. None of the trials are being conducted by universities.[4]

There has been concern that the consolidation of biotech and seed companies into life science companies has reduced the competition in these markets. We do not have direct data to test this hypothesis, but we can examine whether there still are a number of companies doing research in a particular country. We find that even in the countries where there have been a number of acquisitions by life science companies in the seed industry – Argentina, Brazil, and South Africa – there still are a number of companies working to develop new GM crop varieties as Table 9 indicates.

4 CONCLUSIONS

This paper reviewed the economic determinants and impacts of agricultural research. The private sector conducts research if it expects that the financial benefits will outweigh the costs. The size of the benefit is a function of the size of the market for new technology, along with the benefits from the new technology that the firm can appropriate through the use of intellectual property rights. Public agricultural research is justified because it provides public goods: goods that yield social benefits that cannot be captured by private firms and thus will not induce optimal private investment. Public research investment responds to markets for innovations and costs of research like private firms but must fulfil political as well as financial goals. Studies of public and private research find that they provide very high rates of return to the government money invested.

The review of trends in public and private agricultural research show that private research spending has caught up with public spending in the industrialized countries, but still lags far behind in developing countries. This pattern is mirrored in the available data for biotech research: more than half of the biotech research is conducted by the private sector and most of that is conducted in industrialized countries.

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 about who will benefit from biotechnology. These concerns are explored in Pray and Naseem (2003).

[4] Due to data limitations, 13 percent of the companies or institutions conducting the field trials in transitional economies could not be identified, but that percentage is most likely consists of multinational corporations.

5 REFERENCES

Alston, J.M., G.W. Norton and P.G. Pardey. 1995. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Ithaca, NY: Cornell University Press.

Alston, J.M., P.G. Pardey, C. Chan-Kang, T. Wyatt, and M.C. Marra. 2000. *A Meta-Analysis of Rates of Return to Agricultural R & D : ex pede Herculem?* International Food Policy Research Institute (Research Report), Washington, D.C., USA.

Alston, J.M., Pardey, P.G., and Smith, V.H. (2000) Financing Agricultural R&D In Rich Countries: What's Happening And Why? In: Fuglie, K.O. and Schimmelpfennig, D.E. (eds) *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications.* Iowa State University Press, Ames.

Beintema, N.M., A. Avila, and P.G. Pardey. 2001. "Agricultural R&D in Brazil: Policy, Investments, and Institutional Profile". Mimeo. IFPRI. Washington, DC. USA.

Byerlee, D. and K. Fischer. 2001. "Accessing Modern Science: Policy and Institutional Options in Developing Countries". *IP Strategy Today.* No.1-2001. downloaded from the web on February 5, 2003 at http://www.biodevelopments.org/ip/ipst1n.pdf .

Convent, B. 2000. The role of the private sector in providing biotechnology access to the poor. In M. Qaim, A. F. Krattiger and J. von Braun, eds., *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Estrada, R.D., F. Holmann and R. Posada. 2002. "Farmer and Industry Funding of Agricultural Research in Colombia." *Agricultural Research Policy in an Era of Privatization*. Cambridge, UK: CABI International.

Evenson, R. E. 2001. "Economic Impacts of Agricultural Research and Extension", *Handbook of Agricultural Economics*, Vol. 1.

Evenson, R. E. 2002. "Agricultural Biotechnology," in B. Steil, D.G. Victor and R.R. Nelson, eds. *Technological Innovation and Economic Performance*. Council on Foreign Relations. Princeton University Press. USA.

Garrity, D. 2002. Andreas Deininger (ed) *Attacking the Tragedy of Hunger and Desperate Poverty Through Pro-Poor Agricultural Science" Challenges to organic farming and sustainable land use in the tropics and subtropics : international research on food security, natural resource management and rural development*, Deutscher Tropentag 2002, Witzenhausen. Hrsg.:. -- Kassel : Kassel Univ. Press, 2002

Gollin, D. and R.E. Evenson. 2002. "Contributions of Public Sector Research Programs," forthcoming in R.E. Evenson, T. Paul Schultz, and P. Pingali (Eds.) *Volume 3 Handbook of Agricultural Economics, Agricultural Development.* North-Holland.

Hayami, Y. and V.W. Ruttan. 1985. *Agricultural Development: An International Perspective*. Johns Hopkins University Press. Revised edition. Baltimore, MD, USA.

Heisey, P.W. 2001. "Agricultural Research and Development, Agricultural Productivity and Food Security" Agriculture Information Bulletin Number 765-10, ERS/USDA, Washington, DC.

Huang, J., S. Roselle, C. E. Pray, and Q. Wang. 2002. "Plant Biotechnology in China". *Science.* Vol. 295. (25 January 2002). Pp. 674-677.

ISNAR (International Service for National Agricultural Research). 2001. Implications of developments in agricultural biotechnology in Latin America and the Caribbean for

IDB lending. ISNAR Report to the Inter-American Development Bank (IDB), the Hague, the Netherlands (contract no. EMD.0.072.00-F).

Lipton, M. 2001. "Reviving Global Poverty Reduction: What Role for Genetically Modified Plants?" *Journal of International Development.*

Monsanto Annual Report 2002.

Morris, M., and D. Hoisington, 2000. "Bringing the Benefits of Biotechnology to the Poor: the Role of the CGIAR Centers". *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor*. Qaim, M., A. F. Krattiger, and J. von Braun (eds.). Boston: Kluwer Academic Publishers.

Ndii, D. and D. Byerlee. 1999. "Realizing the Potential for Private Sector Participation in Agricultural Research in Kenya". Mimeo. Kenyan Agricultural Research Institute, Nairobi, Kenya.

Pardey, P.G. and N.M. Beintema. 2001. Slow Magic: Agricultural R&D A Century After Mendel. International Food Policy Research Institute, Washington, DC., USA.

Pardey, P., G. Philip, J.M. Alston, J.E. Christian, S. Fan. 1996. *Hidden Harvest: U.S. Benefits from International Research Aid*. International Food Policy Research Institute (Food Policy Statement), Washington, D.C. USA.

Pray, C. E. 1987. "Private Sector Research and Technology Transfer in Asia". *Policy for Agricultural Research*. Boulder and London: Westview Press.

Pray, C. E. and R.G.Echeverría. 1991. "Determinants and Scope of Private Sector Agricultural Research in Developing Countries". *Agricultural Research Policy: International Quantitative Perspectives*. Cambridge University Press, Cambridge, UK.

Pray, C. E. and D. Umali-Deininger. 1998. "Private Agricultural Research: Will it Fill the Gap?" *World Development*, Vol.26., No.6.

Pray, C. E. and K.O. Fuglie. 2000. "Policies for Private Agricultural Research in Asian LDCs". Paper presented at the XXIV International Conference of Agricultural Economists. Berlin, Germany.

Pray, C. E. and B. Ramaswami. 2001. "Technology, IPRs, and Reform Options: A Case Study of the Seed Industry with Implications for Other Input Industries". *The International Food and Agricultural Marketing Review, Special Issue*. Vol. 2.

Pray, C. E. and K. O. Fuglie. 2001. *Private Investments in Agricultural Research and International Technology Transfer in Asia*. ERS Agricultural Economics Report No. 805. November 2001. http://www.ers.usda.gov/publications/aer805/

Pray, C. E., J. Huang, R. Hu and S. Rozelle. 2002. "Five Years of Bt Cotton in China - the Benefits Continue". *The Plant Journal.* 31 (4).

Pray, C. E., A. Courtmanche, and R. Govindasamy. 2002. The importance of Intellectual Property Rights in the international spread of private sector agricultural biotechnology. Presented at 6th International Conference convened by ICABR on Agricultural Biotechnologies: New Avenues for Production, Consumption and Technology Transfer. Ravello (Italy), from July 11 to 14, 2002

Pray, C. E. and A. Naseem. 2003. "Biotechnology R&D: policy options to ensure access and benefits for the poor". ESA Working Paper No. XX-xx. FAO, Rome, Italy.

Ruttan, V. W. 2001. *Technology, Growth and Development: An Induced Innovation Perspective*. New York: Oxford University Press.

Syngenta Annual Report 2002.

Thomson, J. 2002. Personal communication, August 12, 2002. University of Cape Town, South Africa.

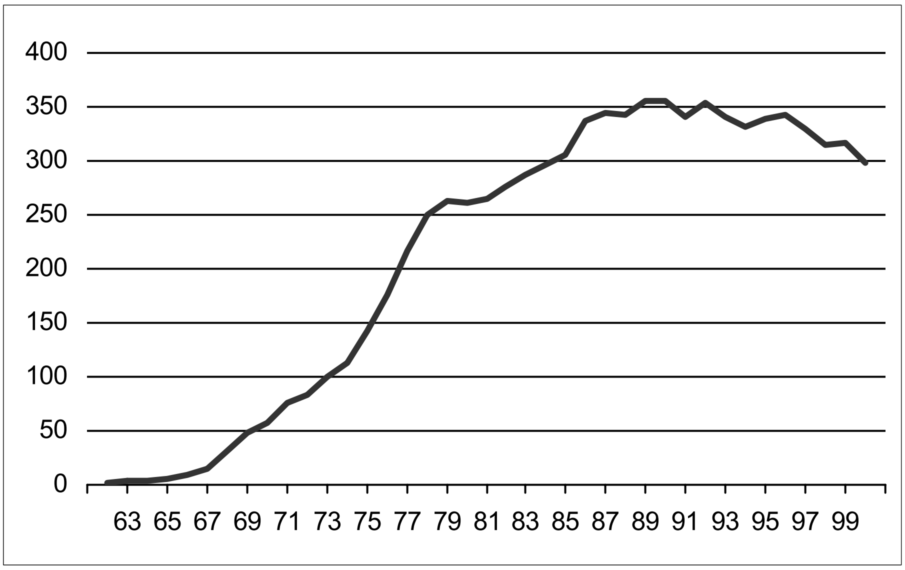
Trigo, E.J., G. Traxler, C. Pray, and R. Echeverria. 2001. *Agricultural Biotechnology and Rural Development in Latin America and the Caribbean: Implications for IDB Lending*. Sustainable Development Department, Technical Paper Series. InterAmerican Development Bank. Washington, DC.

Trigo, E.J., G. Traxler, C. Pray, and R. Echeverría. 2002. "Agricultural Biotechnology in Latin America and the Caribbean", in *The Future of Food: Biotechnology Markets and Policies in an International Setting*. International Food Policy Research Institute, Washington, D.C., USA.

Vogel, G. 2002. "Retreat from Torrey Mesa: A Chill Wind in Ag Research". *Science*. 298: 2106.

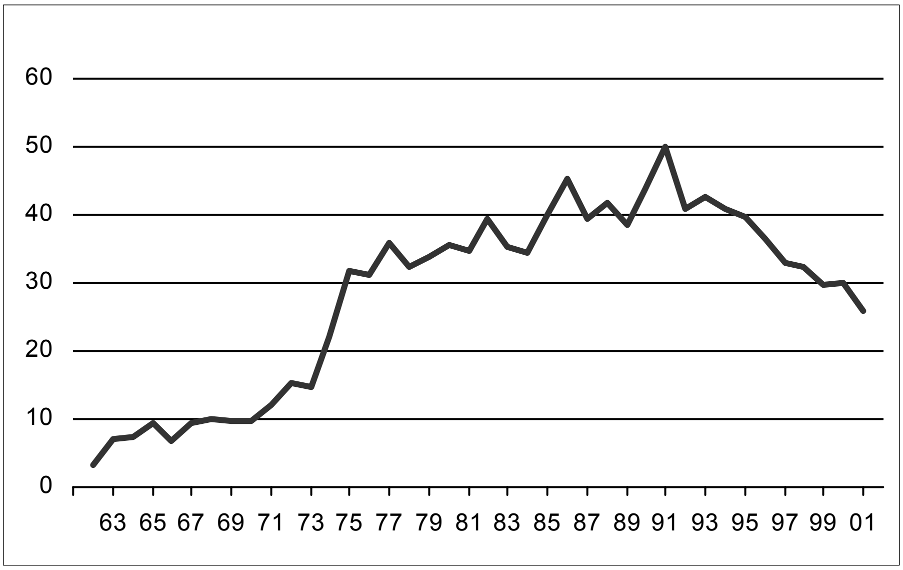
6 FIGURES, TABLES AND BOXES

Figure 1a: CGIAR Expenditure (Millions 1995 U.S. $)



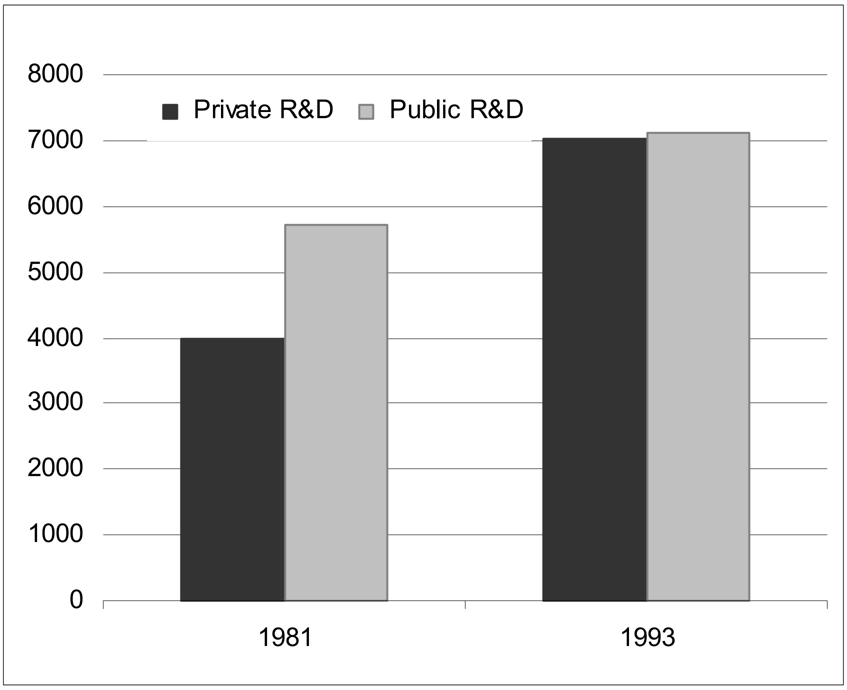
Source: CGIAR Secretariat

Figure 1b: IRRI Spending (Millions 1995 U.S. $)



Source: International Rice Research Institute

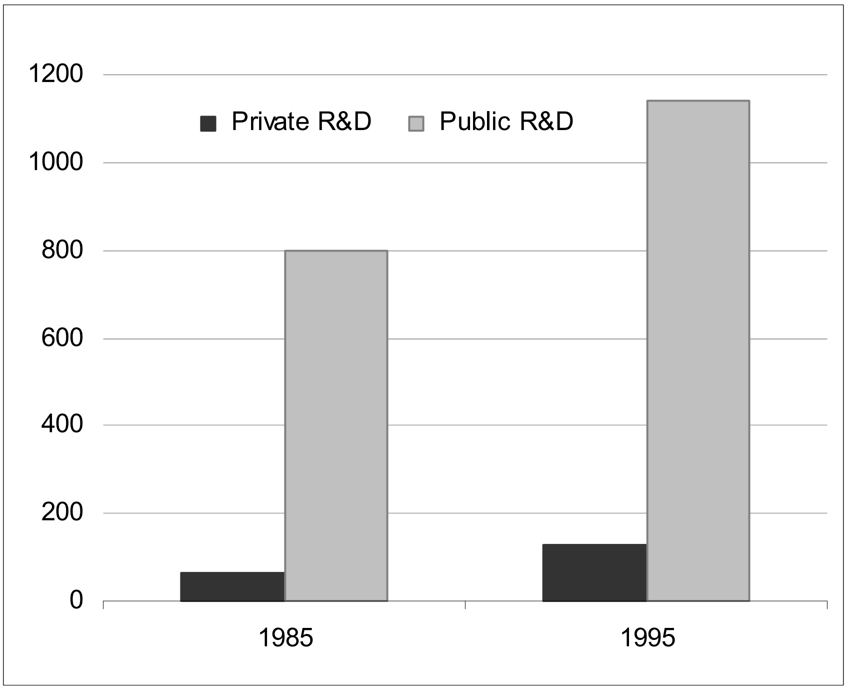
Figures 2a: Public and Private Agricultural R&D in 21 OECD Countries (Millions 1985 US$)



Source: Alston, Pardey, and Smith, 2000.

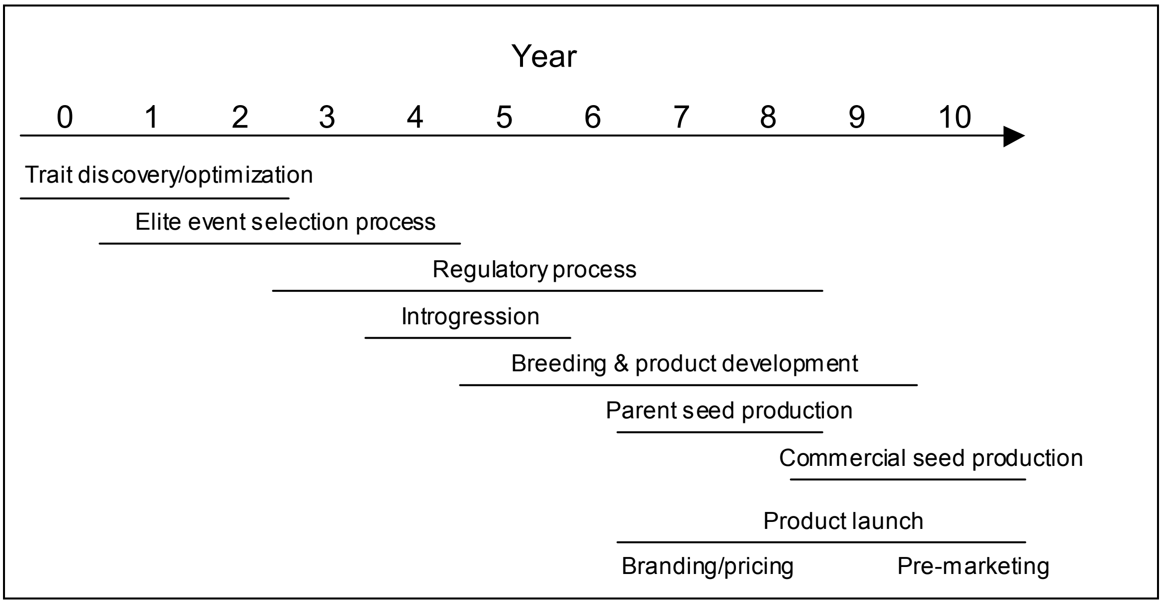
Figure 2b: Public and Private Agricultural R&D in 7 Asian LDCs

(Millions 1985 US$)



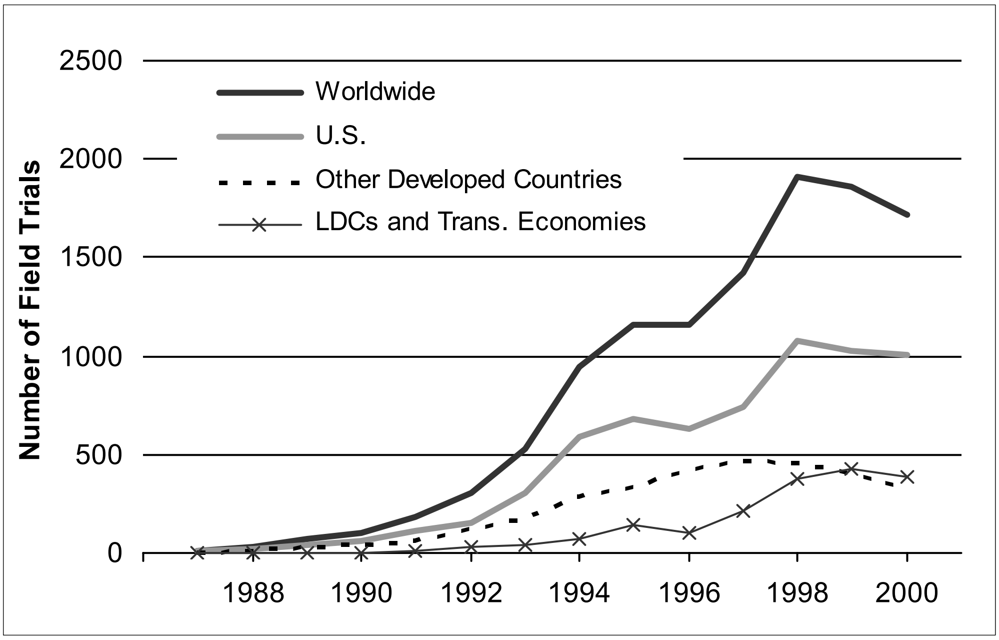
Source: Pray and Fuglie, 2001.

Figure 3: Discovery and development process of a transgenic crop variety



Source: Convent, 2000.

Figure 4: GM Crop Field Trials Approved Worldwide



Source: Pray, Courtmanche, and Govindasamy, 2002.

Figure 5a: Public/Private Research (Field Trials) of GM Crops in Industrialized Countries (1987-2000)

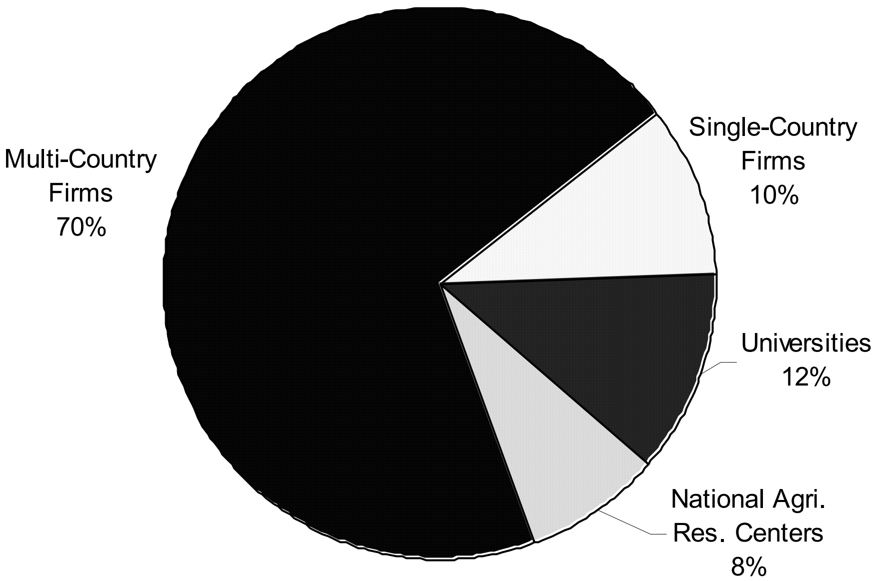
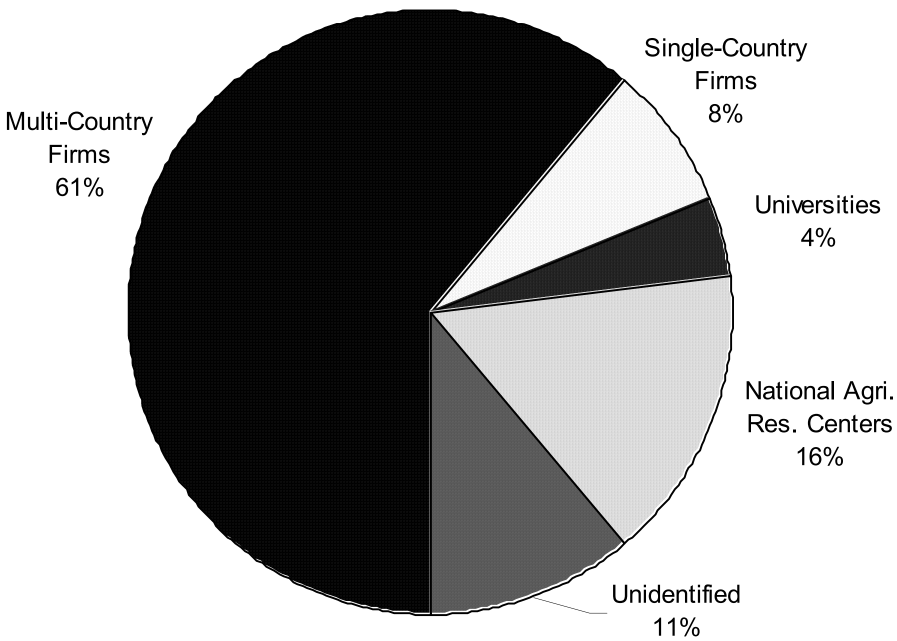


Figure 5b: Public/Private Research (Field Trials) of GM Crops in Less Developed Countries (1987-2000)



Source: Pray, Courtmanche, and Govindasamy, 2002.

Table 1: Rates of Return to Agricultural Research Investment: Summary of Estimates

	Number Reported	Distribution of IRRs					Approximate Median	SPIA Studies	
		0 – 20	21 – 40	41 – 60	61 – 100	100+		NARS	IARCs
Crop Research	207	.19	.19	.14	.26	.21	58		
Livestock Research	52	.21	.31	.25	.12	.09	36		
Aggregate Research	126	.16	.27	.29	.19	.09	45		
Private Sector Spill-in	11	.18	.09	.45	.27	0	48		
Ex Ante Studies	87	.32	.34	.21	.07	.06	42		
Agricultural Extension	81	.26	.23	.16	.21	.13	41		
By Methods									
Project Evaluation	121	.25	.31	.14	.24	.07	40		
Statistical	254	.14	.20	.23	.22	.20	50		
By Region									
OECD	146	.15	.35	.21	.17	.11	40		
Asia	120	.08	.18	.21	.26	.26	67	83	115
Latin America	80	.15	.29	.29	.22	.06	47	31	39
Africa	44	.27	.18	.18	.22	.05	37	9	68

Source: Gollin and Evenson, 2002.

Table 2a: Global public agricultural research expenditures, 1976-95

(Million 1993 international dollars)

Expenditures	1976	1985a	1995a
Developing Countries (119)b	***4,738***	***7,676***	***11,469***
Sub-Saharan Africa (44)	993	1,181	1,270
China	709	1,396	2,063
Asia and Pacific, Excluding China (23)	1,321	2,453	4,619
Latin America and the Caribbean (35)	1,087	1,583	1,947
Middle East and North Africa (15)	582	981	1,521
Developed Countries (34)	*7,099*	*8,748*	*10,215*
TOTAL (153)	**11,837**	**16,424**	**21,692**

Source : Pardey and Beintema, 2001.

Table 2b: Annual Growth Rates (percent per year)

Expenditures	1976-81	1981-86	1986-91	1991-96	1976-96
Developing Countries (119)b	***7.0***	***3.9***	***3.9***	***3.6***	***4.5***
Sub-Saharan Africa (44)	1.7	1.4	0.5	-0.2	1.5
China	7.8	8.9	2.8	5.5	5.2
Asia and Pacific, Excluding China (23)	8.2	5.1	7.5	4.4	6.5
Latin America and the Caribbean (35)	9.5	0.5	0.4	2.9	2.5
Middle East and North Africa (15)	7.4	4.0	4.2	3.5	4.8
Developed Countries (34)	***2.5***	***1.9***	***2.2***	***0.2***	***1.9***
TOTAL (153)	**4.5**	**2.9**	**3.0**	**2.0**	**3.2**

Source : Pardey and Beintema, 2001.

Table 3: Research Intensity - Public Research Expenditure as a Share of Agricultural GDP

Expenditures	1976	1985a	1995a
Developing Countries (119)b	***0.44***	***0.53***	***0.62***
Sub-Saharan Africa	0.91	0.98	0.95
China	0.41	0.42	0.43
Other Asia	0.31	0.44	0.63
Latin America and the Caribbean	0.55	0.72	0.98
Developed Countries	***1.53***	***2.13***	***2.64***
TOTAL	**0.83**	**0.95**	**1.04**

Source : Pardey and Beintema, 2001.

Table 4: 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 5: Biotechnology techniques and research focus in selected Latin America and the Caribbean countries, circa 2000

Description	Country													Total
	Argentina	Brazil	Chile	Colombia	Costa Rica	Ecuador	Guatemala	Jamaica	Paraguay	Peru	Trinidad and Tobago	Uruguay	Venezuela	
A. BIOTECHNOLOGY TECHNIQUES	*(number of applications of technique)*													
Cell Biology Techniques														**259**
Micropropagation	13	9	13	39	8	5	3	–	2	11	–	–	11	114
Anther culture	3	2	3	9	–	1	–	–	–	1	–	–	2	21
Embryo rescue	4	1	4	6	1	–	–	–	–	–	–	–	3	19
Protoplast fusion	–	1	–	2	–	–	–	–	–	–	–	–	–	3
In vitro germplasm conservation and exchange	5	3	3	14	4	2	–	–	–	1	–	–	10	42
In vitro insemination	–	2	–	1	–		–	–	–	–	–	–	–	3
Embryo manipulation and exchange	3	5	–	1	–	–	–	–	–	–	–	–	2	11
Animal cell cloning	–	3	–	1	–	–	–	–	–	–	–	–	–	4
Other—cell biology	3	3	5	21	3	1	–	–	–	–	–	–	6	42
Genetic Engineering Techniques														**124**
Agrobacterium mediated	11	12	6	7	4	–	–	–	–	7	–	–	4	51
Microprojectile bombardment	4	11	7	6	3	1	–	–	–	–	–	–	5	37
Electroporation	–	7	1	1	–	1	–	–	–	–	–	–	4	14
Microinjection	–	4	–	1	–	–	–	–	–	–	–	–	–	5
Other – genetic engineering	7	5	2	2	1z	–	–	–	–	–	–	–	–	17
Genetic Marker Techniques														**239**
RFLP	7	9	3	10	–	2	–	–	–	2	–	–	2	35
RAPD	15	24	11	14	2	6	–	–	–	4	–	–	5	81
Microsatellite markers	13	10	8	12	3	1	–	–	–	4	–	–	–	51
AFLP	13	6	7	8	1	1	–	–	–	4	–	–	–	40
Others	6	9	10	4	–	1	–	–	–	–	–	–	2	32
Diagnostic Techniques														**176**
ELISA	6	12	3	13	–	2	–	–	2	2	–	–	3	43
Monoclonal antibodies	1	5	2	4	–	1	–	–	2	1	–	–	1	17
Nucleic acid probes	1	5	1	1	–	–	–	–	–	1	–	–	4	13
PCR	10	29	12	11	–	1	–	–	–	1	–	–	4	68
Other	–	5	5	20	2	2	–	–	–	–	–	–	1	35
Microbial Techniques														**90**
Design–delivery biocontrol agents	1	3	2	7	–	–	5	–	–	–	–	–	–	18
Design–delivery of biofertilizers	2	2	–	2	–	–	–	–	–	–	–	–	1	7
Fermentation, food processing	2	4	–	17	–	1	–	–	–	–	–	–	–	24
Animal growth hormones	2	2	–	–	–	–	–	–	–	–	–	–	–	4
Rumen manipulation	–	1	–	–	–	–	–	–	–	–	–	–	–	1
Design–delivery of r–vaccines	5	–	–	1	–	–	–	–	–	–	–	–	–	6
Other – microbiology	6	1	2	17	2	1	–	–	–	–	–	–	1	30
Total	**143**	**195**	**110**	**252**	**34**	**30**	**8**	**–**	**6**	**39**	**–**	**–**	**71**	**888**

Table 5: Biotechnology tools applied in selected Latin America and the Caribbean countries, circa 2000 *(continued)*

Description	Country													Total
	Argentina	Brazil	Chile	Colombia	Costa Rica	Ecuador	Guatemala	Jamaica	Paraguay	Peru	Trinidad and Tobago	Uruguay	Venezuela	
B. PRODUCTION CONTRAINT OR NEED TARGETTED														
Plant production[a]	26	16	20	39	12	2	2	–	2	7	–	–	12	138
Plant health[b]	20	30	15	35	–	3	5	–	1	8	–	–	9	126
Animal production[c]	10	15	3	4	–	3	–	–	–	–	–	–	–	35
Animal health[d]	23	2	4	14	–	2	–	–	–	–	–	–	–	45
Genetic resources[e]	22	23	24	21	14	9	–	–	–	2	–	–	9	124
Food/pharmaceutical needs[f]	–	8	1	10	2	–	2	–	–	1	–	–	–	24
Genomics	1	2	–	–	–	–	–	–	–	–	–	–	–	3
Other	–	3	4	4	–	1	–	–	–	–	–	–	–	12
Total	**102**	**99**	**71**	**127**	**28**	**20**	**9**	**–**	**3**	**18**	**–**	**–**	**30**	**507**
C. CROP/LIVESTOCK BREEDING														
Cereals[g]	25	13	11	14	–	1	1	–	–	–	–	–	7	72
Roots and tubers[h]	10	10	6	23	7	13	–	–	–	11	–	–	9	89
Horticultural plants[i]	16	37	18	31	3	–	5	–	–	9	–	–	4	123
Fruit trees and forestry species	13	14	29	39	9	2	–	–	3	12	–	–	18	139
Medicinal, tropical, and native plants	6	6	8	13	8	2	2	–	–	–	–	–	14	59
Industrial crops[j]	3	5	1	42	5	–	1	–	–	1	–	–	14	72
Bovine, beef, and dairy	27	13	6	15	–	–	–	–	–	–	–	–	–	61
Other livestock[k]	18	19	2	12	–	–	–	–	–	–	–	–	–	51
Other livestock and organisms[l]	5	7	2	9	3	9	3	–	–	–	–	–	–	38
Total	**123**	**124**	**83**	**198**	**35**	**27**	**12**	**–**	**3**	**33**	**–**	**–**	**66**	**704**

Source: ISNAR, 2001.

a. Plant breeding, cloning, productivity, abiotic stress, other.
b. Protection, diseases, diagnostics, other.
c. Reproduction, productivity, other.
d. Protection, variability, selection, vaccines, diagnostics, other.
e. Characterization, variability, selection, conservation.
f. Nutritional quality, functional food, drugs, enzymes.
g. Wheat, barley, maize, and other cereals.
h. Potatoes, roots, and tubers.
i. Oilseeds, legumes, berries, and ornamental plants.
j. Coffee, sugarcane, tobacco, palm, and so on.
k. Swine, goats, sheep, horses, and poultry.
l. Aquatic animals, dogs, birds, insects, and so on.

Table 6: Estimated Expenditure on Crop Biotechnology Research (in U.S. $ millions)

	Biotech R&D Expenditure (Million $ /year)	Biotech as % of Sector's R&D
Industrialized		
Private Sector Seed/Chemical Multinationals (includes some LDC R&D)	1000-1500	40
Public Sector	900-1000	16
Developing Countries		
Public (from own resources)	100-150	5-10
Public (from foreign aid donors)	40-50	Na
CGIAR Centers	25-50	8
Private firms	???	
World Total	2065-2730	

Source: Byerlee and Fischer, 2001.

Table 7: Mergers and Acquisitions in the U.S. and European Agricultural Chemicals, Biotechnology, Seeds, and Food/Feed Industries

	Agricultural Chemicals	Biotech	Seeds	Food/Feed/ Industry
Monsanto (Merged with Pharmacia March, 2000 spun off entirely Aug, 2002)		Agracetus (1995) Calgene (1996) Ecogen (13%) Millenium Pharmaceutical (Joint venture for crops genes) Paradigm (2000, $50 million contract)	DeKalb (1996) Asgrow (1997) (corn and soybeans) Holden's Foundation Seeds (1997) Cargill International Seeds, Plant Breeding Intl. (1998) Delta& Pineland (Alliance not purchase 1994)	**Renassen a** joint venture for feed and food with Cargill (1998) Monsanto sold brands like Nutrasweet in 2000
Bayer (Bought Aventis Crop Sciences 2001)	Hoechst & Schering create Agrevo (1994) Hoechst(Agrevo) & Rhone-Poulenc (1999) Merger to create Aventis Bayer buys Aventis Crop Sciences Aug. 2001 for $6.6 billion.	Plant Genetic Systems (1996) PlanTec (1999) Lion Biosciences (11.3% 1999)	Nunhems, Vanderhave, Plant Genetic Systems,Pioneer Vegetable Genetics, Sunseeds (1997) Nunza (Vegetables) Proagro (India) & 2 Brazilian seed companies 1999	Solavista & Novance (alliances for starch & non-food oils).
Syngenta (Novartis+ Astra-Zeneca Ag.)	Formed by merger of Novartis agriculture division & AstraZeneca's Ag. Chemicals Dec.1999 Novartis buys Merck's pesticide business for $910 mil. (1997) Novartis formed by Ciba-Geigy and Sandoz (1996) Merger	Zeneca Ag. bought Mogen International N.V. (1997) Alliance with Japan Tobacco on Rice (1999) Alliance with Diversa 2002	1996 merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co.	Owns Gerber Foods Novartis formed Altus a joint venture with Quaker Oats on nutraceuticals 2000
Dow Chemicals	Dow purchases Eli Lilly's 40% share of Dow Elanco for $900 million. (1997) Rohm and Haas Ag.Chem (2001)	Mycogen (1996) Ribozyme Pharmaceuticals Inc. Proteome Systems Limited (1999 contract).	Mycogen buys Agrigenetics (1992) United AgriSeeds becomes part of Mycogen (1996) Danisco Seeds (JV 1999) Illinois Foundation Seed (agreement 1999) Cargill Hybrid Seeds U.S. (2000)	Agreement with Cargill on plastics from corn

DuPont		Alliances with Human Genome Sciences (1996) Curagen (1997)	Pioneer (1997) (20%) Hybrinova (1999) (France) Bought other 80% of Pioneer in 1999???	Quality Grain (1998 Joint venture with Pioneer), Protein Technologies (food), Cereal Innovation Centre UK JV with General Mills on soy protein. Working on fiber from starch. JV with Bunge on soy products 2003.
BASF	Bought Sandoz N.American Herbicide business 1996 American Cyanamid from AHP for $3.8 billion (2000)	SunGene (JV with Institute of Plant Genetics& Crop Plant Research) Metanomics (JV with Max Planc Institute) Plans to Invest $700 million in plant biotech over 10 years starting in 2000	Bought 40% of Svalöf Weibull 1999	
SAVIA (was Empresas La Moderna)		DNA Plant Technology (1996) is part of Bionova	Seminis (SAVIA's seed division) is made up of Asgrow (1994) (Sold corn & soybeans to Monsanto in 1997) Petoseed (1994) Royal Sluis	Bionova (fresh fruits and vegetables)

Source: Compiled by Authors

Table 8: 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 programs with comprehensive breeding programs, including some pre-breeding.	National commodity programs that are generally strong in applied breeding	Usually small and fragile programs 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 programs. 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 9: Comparison of Number of Private Firms with Field Trials in 1994 and 2000 in Selected Countries.

Country	1994	2000
Argentina	9	14 in 1999 (no field trials 2000)
Brazil	9 in 1997 (first year of trials)	5
South Africa	4	12

Sources: Argentina: CONABIA; Brazil: CTNBio; and South Africa: Directorate of Genetic Resources.

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