The Changing Structure of Agricultural Research and Its Implications for PGR

(Summary of Presentation)

I. Global changes in investment in agricultural research by private and public institutions

Most of the monetary comparisons across countries in this chapter are made using international dollars, based on purchasing power parity conversions, rather than official exchange rates. This is because comparisons using official exchange rates tend to underestimate research investments in countries with low prices and overestimate research investments in countries with high prices.[1]

A. Investment in agricultural research

Long-term data series on private and public investment in agricultural research for both developing and developed countries are difficult to obtain.[2] Nonetheless, the available evidence suggests that since the Second World War, the public sector has financed most of the investment in agricultural research in developing countries. In industrialized countries, the level of private-sector investment in agricultural research has recently been more comparable to the level of public-sector investment, but historically the public-sector totals were higher in most countries. The composition of agricultural research in the two sectors has also been different. Research on basic biological science, plant breeding, livestock improvement or agronomy was more likely to be conducted by the public sector. In other words, public-sector research in most rich countries has been focused much more on the farm and, to a certain extent, on fundamental scientific research, while private-sector research has invested more heavily in farm-*related* markets, concentrating on food and related products, farm machinery and agricultural chemicals.[3]

In more recent years, private investment in agricultural research has grown much more rapidly than public investment. Depending on the indicator used, this acceleration in private investment might be dated to about 1980, about 1970, or even earlier. As an example of this acceleration, from about 1985 to about 1995, private-sector investment in agricultural research in industrialized countries grew by over 4% per year, while public-sector investment only grew at about 1.5% annually (Fig. 5.11.1). Over some periods, private-sector investment might have grown even faster in developing countries than in industrialized countries, albeit

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Acknowledgements: Editors for the first edition were Paul Heisey and José Falck-Zepeda. Editor for the second edition was Bonwoo Koo.

1 Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

2 Throughout this paper, no information will be presented for Eastern Europe and the Former Soviet Union, countries for which data are particularly difficult to find.

3 Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

from a very low base.[4] Private-sector investment in developing countries is still a fairly low proportion of all agricultural research expenditure in those countries (just over 5% of the total)[5] (Fig. 5.11.1).

Many factors are thought to have contributed to this rapid rate of increase in private agricultural research investment. These include new technological opportunities related to scientific advances, which have lowered the costs of doing research; changes in intellectual property regimes that have allowed private-sector firms to capture more of the benefits that result from research; new institutional structures for public- and private-sector research collaboration and technology transfer; and increased globalization of agricultural input markets.[6]

In developing countries, agricultural research has tended to be focused on plant breeding and farm-level agronomy. Perhaps because of the greater relative importance of public-sector agricultural research in developing countries, the rate of growth in public-sector investment has been much higher in developing countries than in developed countries. For example, from 1976 through 1996, public-sector research increased at an annual rate of 4.5% in developing countries, compared with 1.9% in developed countries.[7] Over the last five years of this period, public-sector research grew at a very slow rate in industrialized countries, and in some countries, such as the United States, probably declined.[8] Even though public-sector research investments have also decelerated in developing countries, they were still growing at 3.6% annually in the first half of the 1990s.[9]

This overall increase in public agricultural research investments in developing countries conceals some marked regional differences, however. Public agricultural research spending has grown very rapidly over much of the past 25 or 30 years in China, other Asian countries and the Pacific, as well as West Asia and North Africa. In Latin America, public research expenditures grew very slowly over much of the 1980s but picked up somewhat in the early 1990s. Public research investment in sub-Saharan Africa grew more slowly than in any other world region, including the developed countries, and in the early 1990s actually declined.

Growth rates in research investments are only one of several ways, however, that broad comparisons can be made among different countries or world regions. The levels of public research investment in developed countries imply that in the mid-1990s they were investing 2.6% of their total agricultural gross domestic product (AgGDP) in public research. If both public and private totals are included, industrialized countries would have been investing 5.4% of AgGDP in research. On the other hand, developing countries were only investing about 0.6% of their total AgGDP in public research, and this percentage would increase very

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4 Pray, C.E. and D. Umali-Deininger. 1998. The private sector in agricultural research systems: will it fill the gap? *World Development* 26:1127-1148.

5 Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

6 Shoemaker, R. (ed.). 2001. Economic issues in agricultural biotechnology. Agricultural Information Bulletin No. 762. Economic Research Service, US Department of Agriculture, Washington, DC.

7 Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

8 USDA Economic Research Service. 2000. Agricultural resource and environmental indicators, 2000. Resource Economics Division, Economic Research Service, USDA, Washington, DC. http://www.ers.usda.gov/publications/arei/

9 Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

slightly if private research were included. Developing regions where public research investments grew more slowly, such as Latin America and sub-Saharan Africa, were still investing a higher percentage of their AgGDP in research than other regions where public research expenditures grew more rapidly, such as China and other Asian countries.[10] In fact, because China's AgGDP also grew extremely rapidly between 1976 and 1995, the percentage of AgGDP that China spent on research remained almost constant, at just over 0.4%, the lowest figure for any major world region.[11]

B. Investment in plant breeding research and development

The agricultural research area with the strongest ties to the utilization of, access to and conservation of PGR is plant breeding. Activities related to plant breeding can be classified as (1) germplasm or PGR conservation, either *ex situ* or *in situ*, (2) basic research, (3) development of source material, (4) line development, (5) cultivar development, and (6) seed production and marketing.[12] These activities have alternatively been classified by Frey[13] as plant breeding research, more or less equivalent to basic research (2, above) but not including basic research on plant molecular biology; germplasm enhancement, roughly equivalent to (3 and 4, above); and cultivar development, equivalent to (5, above).

In general, the private sector has tended to take over more and more of these functions with the increasing commercialization of agriculture, beginning with seed production and marketing (Fig. 5.11.2). In addition to the level of commercialization, a number of other factors have influenced the distribution of plant-breeding activities between the public and private sectors across time, across crops and across political jurisdictions. A number of authors[14] have attempted to outline the factors determining the type and level of private-sector investment in plant breeding and, thus, the balance of investment between private and public sectors. These include the cost of research innovation, factors related to market structure (such as the perceived size of a seed market and the balance of farm size between large and small), industrial organization of the seed industry (or the relative size of different seed companies)

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[10] Agricultural research as a percentage of AgGDP did decline in sub-Saharan Africa between 1985 and 1995.

[11] Pardey, P.G. and N.M. Beintema. 2001. Slow magic: agricultural R&D a century after Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.

[12] Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

[13] Frey, K.J. 1996. National plant breeding study-1. Human and financial resources devoted to plant breeding research and development in the United States in 1994. Special Report 98. Iowa Agriculture and Home Economics Experiment Station, Iowa State University, Ames, Iowa.

[14] Griliches, Z. 1957. Hybrid corn: an exploration in the economics of technological change. *Econometrica* 25:501-522.

Rusike, J. 1995. An institutional analysis of the maize seed industry in Southern Africa. PhD dissertation. Michigan State University, East Lansing, Michigan.

Morris, M.L. (ed.) 1998. Maize seed industries in developing countries. Lynne Rienner Publishers, Boulder, Colorado.

Heisey, P.W., M.L. Morris, D. Byerlee and M.A. López-Pereira. 1998. Economics of hybrid maize adoption. *In* Maize seed industries in developing countries (M.L. Morris ed.). Lynne Rienner Publishers, Boulder, Colorado.

Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public sector plant breeding in a privatizing world. *Agricultural Information Bulletin* No. 772. Economic Research Service, US Department of Agriculture, Washington, DC.

Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

and the ability to appropriate the returns to research through some combination of technical means and intellectual property regime.[15]

In many industrialized countries, the public and private plant-breeding sectors have developed and coexisted for more than a century. Over the course of the 20th century, however, the general trend in these countries was for the private sector to become increasingly active in plant breeding. Available data suggest that over the last 30 or 40 years, trends in private and public investment in plant breeding in industrialized countries have followed trends in total agricultural research. In the United States, for example, plant breeding as a percentage of total private agricultural research rose from 3% in 1960 to 13% by the mid-1990s. Although this might still not seem large, it was accompanied by declines in the percentage of private research devoted to machinery (36% to 13%) and to food products and processing (45% to 29%).[16] Looking at available data in another way, private-sector expenditures in plant breeding in the United States have increased more than tenfold from 1960 to the mid-1990s, for an annual rate of growth averaging well over 7%. In contrast, public-sector expenditures on plant breeding rose more slowly until the early 1980s, after which they stagnated. They may even have fallen in recent years. In the United States, private-sector expenditures on plant breeding have surpassed public-sector expenditures since the late 1980s (Fig. 5.11.3). In a few developed-country cases, where plant-breeding expenditures for a given crop, both public and private, can be calculated as a percentage of the value of production, these percentages have tended to range between 0.3 and 0.9%.[17]

At the level of cultivar development and release, most discussions of plant breeding in industrialized countries have focused on the ability of private firms to appropriate a greater proportion of the returns to research. Private and social returns from plant breeding may diverge in cases where firms are unable to profit from the benefits of their research. For example, in the past, plant breeding for self-pollinating crops such as wheat, for which farmers can replant seed saved from the previous harvest, was often done by the public sector because private-sector firms could not charge enough for seed to make plant breeding profitable. On the other hand, open-pollinating crops, like maize, have permitted the development of commercial hybrids, for example, as early as the 1930s in the United States. These crops permit private firms to protect some of their research investment through knowledge of the inbred combination used to produce the hybrid, or knowledge of the composition of the inbred lines themselves. Farmers who replant seed of hybrid maize are faced with a marked deterioration of performance. Another consideration in capturing returns from research has been intellectual property protection, for example, through plant-variety protection laws and, more recently in the United States, through the use of utility patents.

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[15] Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public sector plant breeding in a privatizing world. *Agricultural Information Bulletin* No. 772. Economic Research Service, US Department of Agriculture, Washington, DC.

[16] The other component of private agricultural research in the USA that demonstrated large gains was agricultural chemicals, which rose from 13% to 37% of the total between 1960 and the mid-1990s (USDA Economic Research Service. 2000. Agricultural resource and environmental indicators, 2000. Resource Economics Division, Economic Research Service, USDA, Washington, DC. http://www.ers.usda.gov/publications/arei/).

[17] The notable exception is canola in Canada. In recent years, over 4% of the annual value of Canadian canola production has been invested in research on canola improvement (Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public sector plant breeding in a privatizing world. *Agricultural Information Bulletin* No. 772. Economic Research Service, US Department of Agriculture, Washington, DC).

Data on the origins of crop varieties planted in industrialized countries confirm the importance of hybrid crops and the protection of intellectual property in determining private-sector investment in plant breeding in industrialized countries, as well as some of the other factors identified above. The empirical data also bring to light some additional factors that were not previously identified. As expected, nearly all maize hybrids planted in developed countries today originate in the private sector, although as late as the 1970s in the United States, a substantial proportion of the inbred lines used by private seed companies originated in the public sector. Today nearly all maize inbreds, as well as the final commercial hybrids, are produced by the private sector. In the United States, plant breeding for cotton, a self-pollinating crop, began to shift from the public to the private sector at least 40 years ago, and today the private sector dominates. The private sector is also now much more prominent than the public sector in plant breeding for soybeans in the United States and canola in Canada, although this shift has occurred more recently, in the past 20 or 30 years. Many wheat varieties in Europe, particularly northern Europe, come from the private sector, as do wheat varieties in the eastern USA, where wheat is primarily a rotation crop. On the other hand, wheat breeding in Canada, Australia and the Great Plains and Pacific Northwest of the USA is still predominantly in the public sector. Some of the additional factors uncovered by the empirical record include technical factors other than hybridization (e.g., the need to gin and de-lint cotton seed), market factors (e.g., crops that are grown in rotation with other crops that already have strong private-sector plant-breeding programmes, such as soybeans or wheat in the eastern USA) and early research sponsorship by the product-output industry (e.g., Canadian canola and perhaps soybeans as well).[18]

By the late 1990s, in at least one area—agricultural biotechnology—the increasing role of the private sector was thought to be leading to the creation of multinational 'life sciences' giants, with dominant positions in pharmaceuticals, chemicals and other agricultural inputs such as seed.[19] However, by the end of the century, company executives began to realize that there were fundamental differences between the pharmaceutical and agricultural industries. Coupled with consumer resistance to agricultural biotechnology in some rich countries, these differences could result in a future division of the industry into distinct but related categories, such as large pharmaceutical firms, large chemical firms and large agricultural-input firms.[20] At the moment, there are several large multinational firms with headquarters in Europe and North America, with varying degrees of ownership of or joint ventures with agricultural-input firms such as seed companies. These include Monsanto, Syngenta (formed from a merger and spin-off between Novartis and AstraZeneca[21]), Aventis (created from a merger of Hoechst and Rhône-Poulenc), DuPont/Pioneer and Dow Agrosciences. A somewhat smaller Mexican company, Empresas la Moderna, is nonetheless the world's leading private supplier of vegetable and fruit seeds.[22]

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[18] Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public sector plant breeding in a privatizing world. *Agricultural Information Bulletin* No. 772. Economic Research Service, US Department of Agriculture, Washington, DC.

[19] Fertilizers and crop-protection inputs such as herbicides straddle the boundary between chemicals and agricultural inputs. (Enríquez, J. 1998. Genomics and the world's economy. *Science* 281 [August 14, 1998]:925-926).

[20] Wright, B. 2000. IPRs in biotechnology: agricultural applications. Presentation at the symposium, intellectual property rights: how far should they be extended? 3 February 2000. Board on Science, Technology, and Economic Policy, National Academy of Sciences, Washington, DC.

[21] Novartis and AstraZeneca were themselves products of mergers in the mid- to late 1990s.

[22] Empresas la Moderna also has a growing investment in biotechnology.

On the other hand, plant-breeding research in most developing countries is still dominated by the public sector for two reasons: the continued large significance of agriculture in the economies of many developing countries and the limited market opportunities for commercial seed sales to small-scale farmers who may be subsistence oriented. However, plant breeding in developing countries is also being affected by the commercialization of agriculture, the privatization of national seed industries, the strengthening of intellectual property rights and the erosion of public research capacity.[23] In most cases, monetary estimates of investments in plant-breeding research in developing countries are not available, but some indicators do allow comparisons across crops, regions and institutions.

By the late 1990s, although 38% of the maize area in developing countries was still planted to farm-saved seed (53% of the maize area in nontemperate developing countries), the total private-sector investment in maize breeding in these countries was greater than the public-sector investment in maize breeding. Just under one-half of the total came from multinational companies and another one-sixth from private, nationally based companies. Overall, only about a third of the maize-breeding investment was in the public sector. These overall trends were mirrored in Latin America, the region with the largest maize-breeding expenditures, and in East, South and Southeast Asia. Only in Eastern and Southern Africa did public-sector maize breeding still dominate, accounting for just over 70% of the total.[24] On the other hand, public-sector wheat breeding continues to be of overwhelming importance in developing countries. Private-sector wheat-breeding programmes are only found in the Southern Cone of South America and Southern Africa, and less than 4% of the developing-country wheat area is planted to private-sector wheat varieties, mainly in Argentina, Brazil and South Africa.[25] Adoption data on high-yielding rice varieties also suggests that public-sector varieties dominate in rice as well.[26] Hybrid rice is quite widely grown in China, but all the cultivars grown have been developed by the public sector. Private-sector soybean varieties may be important in Argentina and Brazil, but data to indicate this definitively are not presently available.

In addition to investments in plant breeding by national public-sector agricultural research programmes, and national and multinational private-sector companies, international agricultural research centres (IARCs) have played an important role in international plant-breeding efforts.[27] They have helped develop improved germplasm, played a role in the conservation of genetic resources and helped to strengthen the breeding capacity of national agricultural research systems (NARS) through training activities.[28] They have had a large impact (for example, over 75% of the developing-country spring bread wheat area worldwide and 95% of the irrigated lowland rice area in Asia are planted to IARC-derived modern

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23 Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

24 Morris, M.L. 2002. Impacts of international maize breeding research in developing countries, 1966-98. CIMMYT, Mexico, DF.

25 Heisey, P.W., M.A. Lantican and H.J. Dubin. 2002. Assessing the benefits of international wheat breeding research in the developing world: The Global Wheat Impacts Study, 1966-1997. CIMMYT, Mexico, DF.

26 Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

27 Evenson, R. and D. Gollin (eds). 2001. Crop variety improvement and its effect on productivity: the impact of international agricultural research. CABI, Wallingford, UK.

28 Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

varieties), which has been achieved despite the relatively small size of IARC breeding programmes. Accurate estimates of the exact amount of IARC expenditures devoted to plant breeding depend on the assumptions made, but by the late 1990s this may have been in the range of 150 million 1993 US dollars annually, using a broad definition of plant breeding. This is down from a high point of over 200 million 1993 US dollars annually in the late 1980s (Fig. 5.11.4). The TAC review of CGIAR plant breeding programmes, using a narrower definition, calculated a total of about 83 million (1993) dollars invested in plant breeding and biotechnology in 1999.[29]

The reader will have noted that most of the discussion of investments in plant breeding by both the public and private sector in both developing and developed countries has been focused on major field crops, for which most of the data are available. It is presumed that plant breeding for minor crops, to the extent that it is done at all, is more likely to be conducted by the public than the private sector, although this is a matter of conjecture. First, there is the matter of definition of minor crops. The definition may vary somewhat from country to country. Minor crops may consist of field crops that are grown in a rather limited area or for niche markets, fruits and vegetables, or some kinds of forage crops.[30] The empirical record for the United States, where some data based on the number of breeders are available, is mixed. The preponderance of vegetable and melon breeding appears to be done by the private sector, as is a greater proportion of forage legume breeding. Breeding for temperate fruit and nut crops, or forage grasses, on the other hand, is more likely to be conducted by the public sector.[31]

II. Implications of the structural changes on how PGR are utilized

The changing institutional structure of research in agriculture and plant breeding has several implications for the use of, access to and conservation of PGR.

A. Agricultural technology and utilization of PGR

Morris and Ekasingh[32] summarize the preceding discussion by categorizing crops according to current incentives for private-sector investment in plant-breeding research. They place crops on a two-dimensional grid, defined by whether the benefits from plant breeding are non-appropriable or appropriable, and whether producers are noncommercial or commercial. Of course, in reality both dimensions are continuous rather than discrete, but the resulting definitions are useful. In Morris and Ekasingh's scheme, 'non-appropriable' crops grown by noncommercial producers would include both self- and open-pollinating crops grown for home consumption in developing countries, as well as vegetatively propagated crops in these countries. 'Appropriable' crops grown by noncommercial producers consist of hybrid crops grown for home consumption in developing countries. 'Non-appropriable' crops grown by

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29 *Ibid.*

30 For some US definitions, see Frey, K.J. 1997. National plant breeding study-II. National plan for promoting breeding programs for minor crops in the US. Special Report 100. Iowa Agriculture and Home Economics Experiment Station. Iowa State University, Ames, Iowa.

31 Frey, K.J. 1996. National plant breeding study-1. Human and financial resources devoted to plant breeding research and development in the United States in 1994. Special Report 98. Iowa Agriculture and Home Economics Experiment Station. Iowa State University, Ames, Iowa.

32 Morris, M.L. and B.S. Ekasingh. 2002. Plant breeding research in developing countries: what roles for the public and private sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.) CABI, Wallingford, UK.

commercial producers would include self-pollinating crops grown for market in developing countries and most self-pollinating crops grown in developed countries. 'Appropriable' crops grown by commercial producers would include hybrid crops and cotton grown for market in developing countries, as well as hybrids and cotton in developed countries. Incentives for private-sector plant-breeding research are highest for 'appropriable' crops grown by commercial producers, lowest for 'non-appropriable' crops grown by noncommercial producers and intermediate for the other two categories.

As the empirical survey has indicated, any particular crop-country-time combination will have to be examined in more detail to determine the balance of private and public research more precisely. Furthermore, there is another factor related to but not identical with private-sector investment in plant breeding that will also help to determine the types of technology that result, and the ways PGR are utilized. This is the breeding history of the crop. Breeding history is partially determined by factors of commercialization and profitability, but it is also influenced by the size of the market and the nature of the breeding process. For example, wheat and rice are similar self-pollinating crops, but wheat has a longer breeding history because it is grown in both temperate and cool-season tropical environments around the world, while rice is more concentrated in hot environments, particularly in Asia. Furthermore, a greater proportion of the wheat crop is probably grown for market. Even focusing on developed countries, crops like wheat and maize would have a broader history of breeding effort than crops like oats or rye, because of the relative market sizes. Wheat also has a somewhat longer breeding history than maize, because the pedigree of breeding used for wheat was somewhat simpler to develop than the multiplicity of breeding possibilities found for maize, especially before the details of commercial hybrid production were worked out. And, of course, crops that reproduce through seed nearly always have a more intensive breeding history than crops that are vegetatively propagated.

The degree of private-sector involvement in plant breeding may also have several implications for the type of technology developed. Perhaps most obviously, the private sector is likely to give more emphasis than the public sector to the development of commercial hybrids in crops that have not already been successfully hybridized for commercial purposes.[33]

But there are other areas in which private- and public-sector plant breeding may take somewhat different approaches. Nutritional characteristics or environmental suitability of plant varieties may take the form of 'impure public goods'. This means that these attributes meet some, if not all, of the definition of what economists call 'public goods'. The basic economic argument in the case of a public good is that private individuals taking into account only their own preferences will produce less of the public good than would bring the greatest social benefit.[34] Disease resistance in plants is a particular example of an impure public

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[33] The waxing and waning of enthusiasm for commercial wheat hybrids is instructive. See, for example, Knudson, M.K. and V.W. Ruttan. 1988. Research and development of a biological innovation: hybrid wheat. *Food Research Institute Studies* 21(1):45-68; Lucken, K.A. 1987. H ybrid wheat. *In* Wheat and Wheat Improvement (E.G. Heyne ed.). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wisconsin; Jordaan, J.P. 1996. Hybrid wheat: advances and challenges. *In* Increasing yield potential in wheat: breaking the barriers (M.P. Reynolds, S. Rajaram, and A. McNab eds.). CIMMYT, Mexico, DF; Pickett, A.A. and N.W. Galwey. 1997. A Further Evaluation of Hybrid Wheat. *Plant Varieties and Seeds* 10:15-32.

[34] Alternatively the result of private individuals acting in isolation will be too much production of a 'public bad' such as pollution.

good.[35] Public-sector research programmes and policies are likely to devote relatively more effort to diagnosing needs in the areas of nutrition and environmental suitability of plant varieties, and searching for genetic and management means to achieve these ends.

This is not to say that private breeding research will neglect important areas like disease research. Any private company that wishes to stay in business will attempt to supply farmers with varieties having good disease resistance, if that is an important consideration in the target area. However, in research and seed systems with a long history of development, opportunities for complementary research may develop. The public sector may take the lead in doing research on basic mechanisms of disease resistance and finding a wide variety of possible sources of that resistance. The private sector may devote more effort to developing readily identifiable, proprietary genetic mechanisms for resistance such as the *Bt* incorporated into plants through genetic engineering.

B. Access to PGR

The main avenue through which growing privatization of plant breeding has affected access to PGR has been through the increasing emphasis on proprietary technology and the protection of crop varieties or individual genetic constructs through intellectual property institutions. The traditional view of PGR was that they were 'the common heritage of mankind', and for many crops and breeding institutions the ideal maintained was the free exchange of germplasm. Obviously, there were different degrees to which this ideal obtained in practice. Private firms in advanced hybrid maize seed industries tend to rely almost completely on their own germplasm, even though many years ago this germplasm was obtained from public sources and, ultimately, from farmers.

Beginning in the 1980s, academic researchers and agricultural activists motivated by increasing proprietary control of PGR began to criticize the growing application of intellectual property rights to these genetic resources. Their arguments focused on the role of farmers, particularly in the developing world, in developing the original crop landraces that have been the basis of all subsequent breeding. IPR, in some views, facilitated the exploitation of gene-rich farmers in developing countries by multinational corporations. Although much of the argument focused on 'farmers' rights', rather than the rights of countries, increasingly the ownership of PGR was seen as a matter of national sovereignty. Debates over PGR entered the international policy realm through trade negotiations, the Convention on Biological Diversity, the Cartagena Protocol on Biosafety and, most recently, the International Treaty on Plant Genetic Resources for Food and Agriculture.[36]

As a result of both the changed research environment and the increasing body of international undertakings that have effects on access to PGR, exchange of PGR has for some time come under increasing restrictions. Even institutions such as the United States National Plant Germplasm System (NPGS), the world's largest national genebank and largest international distributor of PGR, and the CGIAR genebanks and breeding programmes either use or are

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[35] Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public sector plant breeding in a privatizing world. *Agricultural Information Bulletin* No. 772. Economic Research Service, US Department of Agriculture, Washington, DC.

[36] Charles, D. 2001. Seeds of discontent. *Science* 294 (October 26, 2001):772-775. Van Dusen, E. 2001. The International Treaty on Plant Genetic Resources for Food and Agriculture. Presentation at USDA Economic Research Service, December 11, 2001.

moving toward the use of material transfer agreements (MTAs) in germplasm distribution.[37] Although these may only have the intent of preventing further application of intellectual property protection to the PGR involved, they do increase the transaction costs of the distribution and exchange of PGR, and thus have the effect of slowing access. These transaction costs include the costs of tracking the movement and use of PGR.

At least two important factors will interact to determine the future effects of increasing privatization and intellectual property protection on access to PGR. The first will be the continually evolving national and international institutional environment concerning the application of intellectual property laws to living material. Although the Trade Related Aspects of Intellectual Property Rights (TRIPS) agreement of the World Trade Organization (WTO) requires all members to apply some form of intellectual property protection to plants, there are still strong differences of opinion over the appropriate types and levels of such protection. Recent negotiations over the International Treaty on Plant Genetic Resources were marked by the refusal of groups of countries to include some crops in a negotiated multilateral system of materials from genebanks. The negotiations also featured disagreements over language defining restrictions on intellectual property protection on germplasm based on materials drawn from the proposed multilateral system.[38]

The second factor that will influence the future relationship between IPR and access to PGR will be evolving science. Currently, some of the most notorious international disputes over patenting of plant genetic materials have involved crops with relatively short breeding histories (e.g., castor seed, basmati rice). In these situations, patent protection may be granted to material that appears little different from germplasm grown for generations by farmers in developing countries. In the case of crops with longer breeding histories, there are instances of complicated patterns of material transfer through a number of countries and institutions and eventual patenting (e.g., the XA 21 gene for bacterial blight resistance, which originally came from rice). To date, there have been few cases of 'vertical' disputes (disputes over the contributions made by different actors in the breeding process) over ownership to PGR used in crops with a long breeding history.[39] This is perhaps because breeders for these crops tend to work with elite materials, and the chance of finding a single highly profitable allele that is easily incorporated into these elite materials is small. New molecular methods, however, may result in the discovery of useful alleles in landraces or wild relatives, even those that have been relegated to the sidelines because of their perceived lack of useful genetic material.[40] On the one hand, hope of exploitation of the perceived economic value of these alleles may lead to further restrictions on the exchange of PGR. On the other hand, advanced molecular

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[37] Smale, M., K. Day-Rubenstein, A. Zohrabian and T. Hodgkin. 2001. The demand for crop genetic resources: international use of the US National Plant Germplasm System. EPTD Discussion Paper No. 82. Environment and Production Technology Division (EPTD), IFPRI, Washington, DC.

[38] As an example of the complexities involved, at Treaty negotiations, US NPGS representatives were willing to accept language eventually ratified, but the USA abstained from approving the Treaty because industry representatives disagreed with any restrictions on patenting that would contradict US law. It is far from clear, however, whether even within the USA, the country that has gone further than any other in applying patent protection to plants, the final determination of the boundaries of patent law as applied to living material has been reached. (Charles, D. 2001. Seeds of discontent. *Science* 294 [October 26, 2001]:772-775; Van Dusen, E. 2001. The International Treaty on Plant Genetic Resources for Food and Agriculture. Presentation at USDA Economic Research Service, December 11, 2001.)

[39] Disputes instead tend to be 'horizontal': between two hybrid maize seed companies, for example.

[40] Tanksley, S.D. and S.R. McCouch. 1997. Seed banks and molecular maps: unlocking genetic potential from the wild. *Science* 277 (22 August, 1997):1063-1066.

methods may lead to greater recognition of the genetic combinations necessary to achieve desired results, and thus to fewer hold-ups based on a single gene.

C. Conservation of PGR

The economics literature on the valuation of genetic resources at any stage in the process from discovery to utilization in a commercial product is fraught with controversy, not least because of differing assumptions. Nonetheless, there is considerable consensus on several areas. First, both *in situ* and *ex situ* conservation of PGR are highly valuable activities, with positive social benefits. Second, the further back in the breeding process one goes, the fewer private incentives there are. This may be because of differences between social and private discount rates and risk preferences. Thus, conservation of PGR is in large part a public-sector activity, even if large private firms maintain their own collections of primarily elite breeding materials. Even private-sector organizations such as the American Seed Trade Association (ASTA) argue for the fundamentally public nature of PGR conservation.[41]

There are several practical problems, however, in maintaining support for national and international public-sector PGR conservation. First is the relatively stagnant level of public-sector resources devoted to research, as noted above. In rich countries there have been calls for more resources, reorganization and more extensive characterization and database management within national plant genetic resource systems. However, political support for public agricultural research systems has been built in part on the production of visible, 'downstream' results, thus making it difficult to place investment in PGR conservation high on the political agenda. Furthermore, a very large component of international PGR conservation will be in developing countries, and it will need to be supported by the international community.

A related problem will be working out the mechanisms of support to PGR conservation. The International Treaty on Plant Genetic Resources has proposed one such mechanism, in which commercial use of genebank materials will provide royalties to support conservation. However, as we have seen, not all potentially important crops have been included in this treaty; the USA, with the largest national genebank, abstained from the treaty, although it is expected to abide by its provisions; details about tracking the flows of genetic resources, the levels of royalties to be paid, and the distribution of those royalties have not yet been worked out; and the annual royalties are not realistically expected to be more than a few million dollars, and that only beginning some years from now.[42] Alternative mechanisms might involve other private support for PGR conservation, based not on royalties but on direct payments unrelated to the exact PGR used in breeding. Again, such agreements would depend on the development of mutual trust and careful protocols. The Latin American Maize Project (LAMP) and subsequent Genetic Enhancement of Maize (GEM) Project might provide one model for some possible private support to PGR conservation activities.[43]

Such measures, however, are likely to prove most successful for crops for which there is some commercial interest. Shortages of funds for PGR conservation are likely to be particularly

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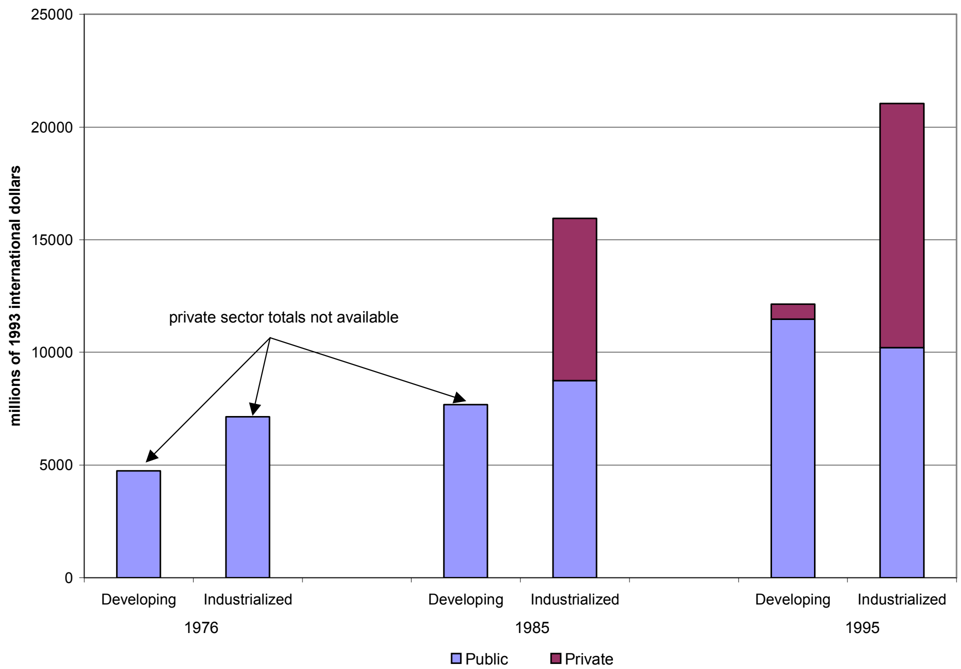
[41] ASTA. 1994. ASTA Corn and Sorghum Basic Research Committee: Recommendations for Public Corn and Sorghum Research. American Seed Trade Association, Washington, DC.

[42] Charles, D. 2001. Seeds of discontent. *Science* 294 (October 26, 2001):772-775.

[43] Knudson, M.K. 2000. The research consortium model for agricultural research. *In* Public-private collaboration in agricultural research: new institutional arrangements and economic implications (K.O. Fuglie and D.E. Schimmelpfennig eds.). Iowa State University Press, Ames, Iowa.

acute for crops for which there have also been shortages of funds for crop improvement, for example, important food crops such as cassava. PGR conservation for these crops is likely to continue to be funded almost entirely with public-sector resources. Intermediate between crops grown fairly widely on a commercial scale and crops with little commercial interest are crops that might reach more specialized markets. These crops are most likely to be marked by IPR disputes over PGR, but also relatively little private interest in PGR conservation.

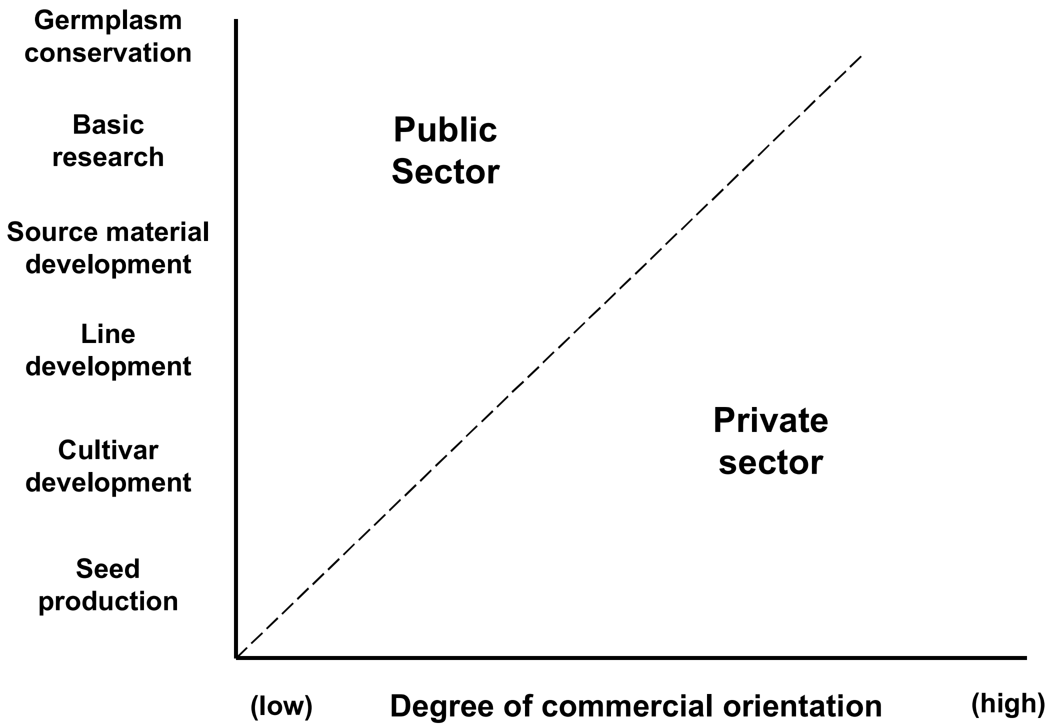
Over the long run, creating a more optimal system of PGR conservation will require both greater resources and trust of public and private sectors in both the developing and developed worlds, as well as careful attention to building appropriate institutions.[44] Privatization of agricultural research is unlikely to be reversed, but PGR conservation is a research area for which there are strong economic arguments for increasing public investment.



Source: Pardey, P.G. and N.M. Beintema. 2001. Slow Magic: Agricultural R&D a Century After Mendel. IFPRI Food Policy Report. IFPRI, Washington, DC.; Alston, J.M., P.G. Pardey and V.H. Smith (eds.). 1999. Paying for Agricultural Productivity. Baltimore and London: published for IFPRI by The Johns Hopkins University Press.

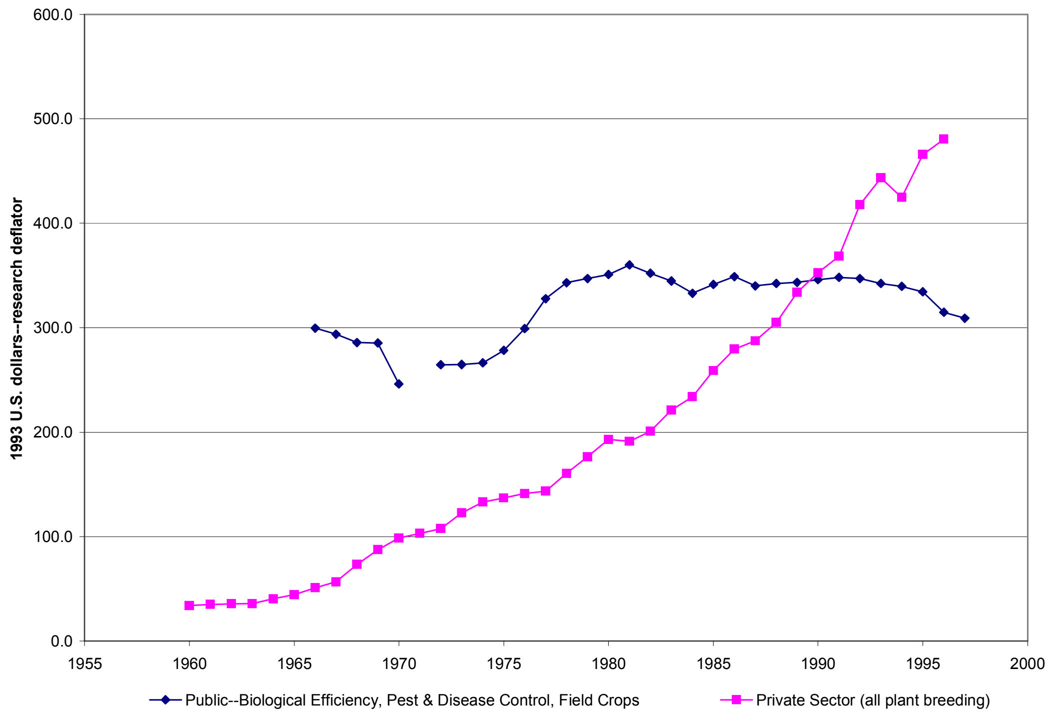
Fig. 5.11.1. Agricultural research and development (R&D) expenditures (excluding eastern Europe, Former Soviet Union)

44 Koo, B., P.G. Pardey and B.D. Wright. 2004. Saving seeds: the economics of conserving crop genetic resources ex situ in the Future Harvest Centers of the CGIAR. CAB International, Wallingford, UK.



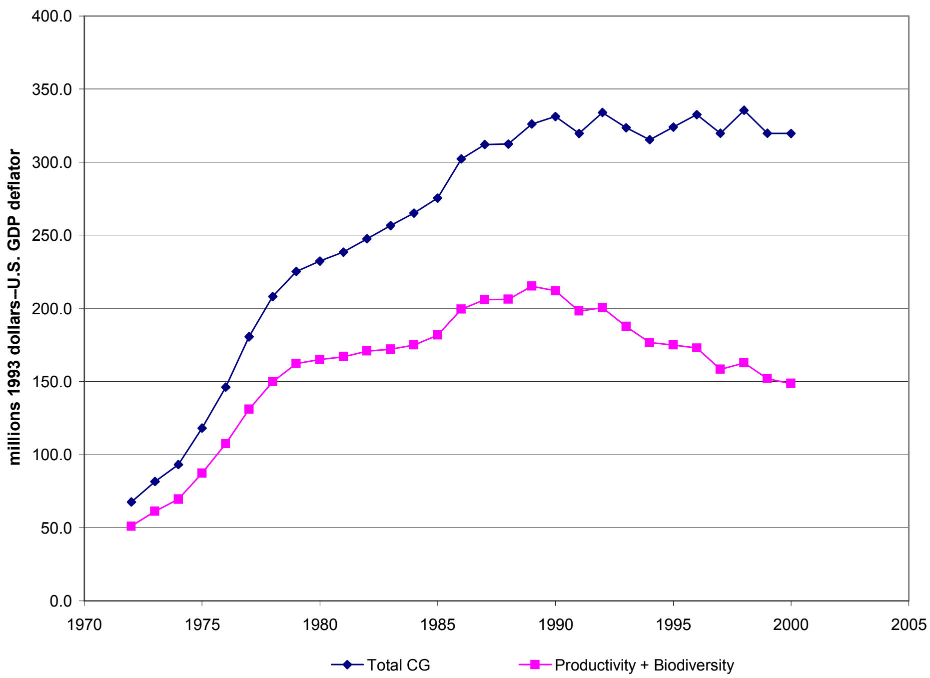
Source: Morris, M.L. and B.S. Ekasingh. 2002. Plant Breeding Research in Developing Countries: What Roles for the Public and Private Sectors? *In* Agricultural Research Policy in an Era of Privatization: Experiences from the Developing World (D. Byerlee and R. Echeverría eds.). CABI, Wallingford, UK.

Fig. 5.11.2. Natural domains for public and private plant breeding programmes



Source: Heisey, P.W., C.S. Srinivasan and C. Thirtle. 2001. Public Sector Plant Breeding in a Privatizing World. Agricultural Information Bulletin No. 772. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Fig. 5.11.3. Real public- and private-sector expenditures on plant breeding, USA, research deflator



Source: Consultative Group on International Agricultural Research (CGIAR). Various years. Annual Reports.; Alston, J.M., P.G. Pardey and V.H. Smith (eds.). 1999. Paying for Agricultural Productivity. Baltimore and London: published for IFPRI by The Johns Hopkins University Press.

Fig. 5.11.4. Total CGIAR investment and approximate CGIAR investment in plant breeding