4-5-2006

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Wallace Huffman
Iowa State University, whuffman@iastate.edu

IOWA STATE UNIVERSITY

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April 2006

Working Paper # 06016

Department of Economics Working Papers Series

Ames, Iowa 50011

4/5/06

Economics of Intellectual Property Rights in Plant Materials

By Wallace E. Huffman*

Abstract: This paper presents an economic perspective on intellectual property in plant materials, including its value, and summary information on the U.S. seed industry. It first considers intellectual property rights--types, economic incentives that they bestow, and uses across developed and developing countries. Second, it considers the U.S. seed industry--characteristics for major crops, optimal pricing of a superior variety, and relative size of public and private research expenditures. Some conclusions and implications are presented in the final section.

Key words: Intellectual property rights, value of innovations, plants, seed industry.

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* Professor of Economics and Agricultural Economics, Iowa State University. This paper was first presented at a symposium for U.S. Plant Patent Examiners, Ames, IA, Sept. 2, 1992. It was subsequently revised March 16, 1994, for a NC208 symposium in Denver, CO. It is being placed in the Economics Working Paper series to increase accessibility. The author thanks Sue Hoover, Pioneer HiBred, for assistance with Table 6.

Economics of Intellectual Property Rights in Plant Materials

Intellectual property is attracting lots of attention these days. For more than two decades, empirical evidence has been accumulating that investments in R&D have enhanced the rate of growth of multifactor productivity of U.S. agriculture and of agriculture in several other countries (see Huffman and Evenson 1993; Ruttan 1982). The social rate of return on these investments has been positive and generally large. Finally the growth theorists have turned to models of endogenous economic growth in an attempt to better explain the dramatic differences in growth in real income per capita of Asian countries over the past three decades. Human capital has been a key factor in these models, but Romer's recent work has incorporated both human capital and intellectual property produced by inputs of human capital and the stock of previous inventions. His model produces perpetual real endogenous economic growth.

One form of intellectual property is improved plant materials (OTA 1992; National Research Council 1993). They are quite important because most of the world's population obtain a large share of their calories and nutrients from food that is from plants and plant parts. The types of property rights to the new plant materials seem likely to have important implications for the public versus private incentives/role for producing these advances, the international transfer of plant genetic materials, and the rate of economic growth (at least of agriculture).

The objective of this paper is to present an economic perspective on intellectual property in plant materials, including its value, and summary information on the U.S. seed industry. The paper first considers intellectual property rights--types, economic incentives that they bestow, and uses across developed and developing countries. Second, the paper considers the U.S. seed industry--characteristics for major crops, optimal pricing of a superior variety, and relative size of public and private research expenditures. Some conclusions and implications are presented in the final section.

Intellectual Property

The potential importance of intellectual property to modern economic growth has been exploited by Romer (1990) in his models of endogenous technological change. For nations having sufficient human capital, his models generates perpetual growth in real income per capita through the production of knowledge/new technology. For nations having sparse human capital, no new knowledge/new technology is produced, and these countries do not experience any (or very little) economic growth. Intellectual property in plant materials is only one of several forms of intellectual property that has the potential to contribute to economic growth.

Intellectual Property Rights

Intellectual property is the results or outputs from creative efforts of the human mind. These efforts include the creative works of scientists, inventors, artists, musicians, entrepreneurs, and farmers. Focusing on plant materials, intellectual property is created in processes that use existing genetic resources and technology or knowledge and human capital services. Some of the new plant materials are economically useless, but a few will have characteristics that are superior to previous ones. Among the superior ones, some represent large advances and others are only slight improvements, e.g., imitations. Considerable evidence exists that a science-based research and development system can produce relatively steady advances in major crop yields, e.g., corn, soybeans, rice, wheat (Huffman and Evenson 1993, Evenson 1993b, National Research Council 1993).

Intellectual property is costly to produce (for the first time) because it uses human capital services and other inputs, but it is relatively inexpensive to reproduce and distribute, given the initial discovery (Wright 1983; Romer 1990). Although several reward systems and innovation marketing systems could be employed for plant materials, national governments have tended to use only a few. When governments assign property rights in plant materials, they have generally chosen to give limited monopoly positions to the innovator (National Research Council 1993; van Wijk, Cohen, and Komen 1993; Siebeck 1993). The monopoly position of the innovator grants him the right to control the use of the innovation, e.g., to license its use for a fee or royalty or to sell the intellectual property. This income is a potential source of payment to the innovator for his creative efforts. Limiting the monopoly rights of innovators means innovations will be available at lower prices to potential users. This has the potential for increasing the social usefulness of innovations, given discovery.

IPRs Granted by Nations. Breeders' rights and patents are the most common IPRs given to innovators (National Research Council 1993; van Wijk, Cohen, and Komen 1993; Siebeck 1993). Plant breeders' rights are granted by a national government to plant breeders to exclude others from producing or commercializing materials of a specific plant variety for a specified period of time, generally 15-20 years. The criteria to be met for these rights generally requires that a variety be novel, distinct from existing varieties, and uniform and stable in successive generations. The applicant, however, is not required to disclose the scientific nature of his intellectual property, or his innovation.

Plant breeders' rights have several limitations. First, they apply only to the national boundaries of the country granting the IPR. A plant variety protected only by U.S. breeders' rights, a plant variety protection certificate, can be taken to Mexico for reproduction and sale in Mexico without violating U.S. or Mexican plant breeders' rights. Second, several exemptions exist that limit the plant breeders' right but that increase the benefits to others. The protected variety is available for research uses, i.e., the study of the nature of the innovation, without reproducing or multiplying it for commercial use. Other plant breeders can use the protected variety in a breeding program to create new varieties (or offsprings) which they can exploit commercially. Farmers who plant a protected variety can save part of their harvested seed for their own later plantings.

A patent is a right granted by a government to inventors to exclude others from imitating, manufacturing, using, or selling a specific invention for commercial use for a specific period of time, generally 17-20 years. The primary criterion applied by patent examiners is that the innovation must be novel or new, not obvious to someone skilled in the art, and potentially useful. In the patent application, the inventor must describe or deposit a sample of the invention, and in this way, he discloses his invention to the public. In particular, patent protection applies only to the invention disclosed in the patent application.

Some of the same limitations apply to patents as to breeder's rights. The patent holders' rights extend only to the national boundaries of the granting country. Within the granting country, the invention is available to others only for research uses, i.e., experimentation. However, it is an infringement on the rights of a patent holder for someone to use a patented variety in a breeding program without the permission of the patent holder or farmers to save seeds from patented varieties and plant them. Producing a patented variety outside the territory of the patent-granting country and selling it there is technically not an infringement on the patent holders' rights. Innovators, however, generally apply for patents in all countries where there is a significant market for their product.

Intellectual property in plant materials is a nonrival good (Cornes and Sandler). This means that the intellectual property, e.g., a variety is not used up when others use it in scientific research, commercial breeding programs, or for farm seeds. In developed countries, patent and breeders' rights make unauthorized use of the intellectual property excludable at a reasonable cost. Hence, this intellectual property is not a pure public good.

The property rights are created in such a way that the innovator is required to partly or fully reveal his innovation. This makes the innovation a useful input or resource in future research and breeding programs. Furthermore, because intellectual property is nonrival and of a long life, it can be accumulated almost without bounds (on a per capita basis). Human capital, which is embodied in people having finite length of life and yielding rival services, does not have similar potential for per capita accumulation or contributions to economic growth (Romer).

Although the innovator is granted a limited monopoly on the commercial use of his plant material, will generally be used to produce intermediate inputs; the seeds and plants for agricultural production. Although optimal monopoly pricing of intellectual property in plant materials may occur, superior materials will be available in the market and bought by farmers. Furthermore, Romer (1990) has shown that monopoly pricing of unique intellectual property does not cause an unreasonable drag on economic growth. It provides the economic incentives for endogenous or private sector advances in technology.

The intellectual property rights for the innovator are, however, incomplete. This is because of limitations imposed in the IPRs and because complete enforcement of the property right is not optimal. This means that knowledge spillovers, or positive external effects across innovators or across countries are likely to be economically important to technology production and transfer. The usefulness of direct plant material transfers is, however, limited by the geoclimatic specificity of most plants (Huffman and Evenson 1993; Evenson 1993a,b). This means that transferred plant materials have the greatest potential for use as breeding or parent materials rather than as varieties that farmers plant directly. Furthermore, local scientific expertise and breeding capacity must exist to do the applied research needed to create a new variety that is superior to old ones (National Research Council 1993b).

Intercountry comparisons. The highly developed countries have a unique set of institutions for protecting and marketing intellectual property in plant materials, and developing countries have another (Siebeck 1993; National Research Council 1993b; Evenson 1993a,b). All of the developed countries grant intellectual property protection through breeders' rights. To date only the United States provides protection through patents--both special plant patents (since 1930) and regular patents (since 1985). These countries have a highly developed private/commercial seed industry that engages in significant intellectual property creation and in the reproduction of seeds and plants and their marketing to farmers. They also have sufficiently superior intellectual property to export plant materials (Siebeck 1993; Evenson 1993a,b).

The developing countries as a group have had a very weak system of intellectual property rights in plant materials. Furthermore, they invest very little in enforcement of IPRs Why have the developing countries been so lax? They are largely importers of plant materials rather than exporters (Evenson 1993; Siebeck 1993; National Research Council 1993; Barton

1993). They do not generally have a significant private/commercial seed industry. The capacity to create new intellectual property in plant materials that exists in primarily in the public sector e.g., in Ethiopia, Kenya, Philippines, Indonesia, Columbia, India, Thailand, Mexico. The public national breeding programs in the developing countries have sometimes cooperated with the International Agricultural Research Centers (e.g., IRRI, CIMMYT). The result has been to develop a nonproprietary system of plant been free exchange of finished varieties, advanced breeding lines, and improved raw materials (Siebeck 1993; National Research Council 1993, p. 335). In this system, local multiplication and reproduction of varieties and distribution of seeds by local entrepreneurs and farmers has been encouraged.

No international property right law exists that has similarities to rights granted by national governments. The institutions that exist are the result of past international conferences and conventions that set out to provide a better structure. The Paris Convention for Industrial Property has emphasized equal treatment rather than common patent laws for member countries. This Convention established the right of equal protection of patent rights of a citizen of a granting country and of residents of other member countries. Over 100 countries are members of this Convention (van Wijk, Cohen, and Komen 1993).

The International Convention for the Protection of New Varieties of Plants (UPOV), which was first signed in 1961, has provided a framework for harmonizing property rights in plant materials. Twenty-four countries are currently members. It suggests the use of plant breeders' rights or plant patents by member countries. In the 1991 revision of the Convention, the plant breeders' rights were strengthened. First, it eliminated the breeders' exemption for "essentially derived varieties," i.e., new varieties that were breeding on an international scale for developing countries where there has almost identical to existing ones, and it attempted to eliminate farmers' use of seed harvested from protected varieties. The member countries, however, would not agree on a minimum standard, and national governments of member countries were left to make the final decision on this exemption to plant breeders' rights (van Wijk, Cohen, and Komen 1993).

Developing countries have become concerned about the possible loss of access to plant genetic materials. Some institutional changes tend to aid their cause. In 1983, FAO established a set of rules known as the "International Undertaking on Plant Genetic Resources." It primarily attempted to stop or slow the rapid and uncontrolled crop plant species by encouraging international conservation efforts. Both developing and developed countries agreed that plant genetic resources are part of a common heritage of mankind and that they should be available without restrictions to all. The Convention of Biological Diversity, the Rio de Janeiro Conference, signed in June 1992 by all attending developed and developing countries, except the United States, recognized the sovereign rights of nations over their germplasm resources (Siebeck 1993). This was an attempt to limit access of agents of developed countries to biological resources of developing countries.

The developed countries have chosen to use trade access in a bargain for stronger intellectual property rights in developing countries. In the recently completed GATT negotiations, the developing countries had to agree to advance their IPRs in order to obtain access to the markets of the industrialized countries. Second, by including IPRs in the GATT trade negotiations, GATT's dispute-settling mechanism can be used to facilitate quick and enforceable action against countries that violate GATT agreements on intellectual property. New international IPR standards were established for advanced technologies, including biotechnology. For plants, this means that member countries should provide equal patent treatment for its own citizens and residents of member countries.

U.S. Intellectual Property Rights in Plant Materials

Four types of intellectual property rights are available currently in the United States for plant materials. They are plant patents, plant variety protection certificates (PVPCs), regular patents, and trade secrecy. Patent authority in the United States originated in the Constitution, and the Patent Office was established in 1836 to handle patent applications. A valid patent must meet three tests: novelty (it must be new), usefulness (it must do what it is intended to do), and nonobviousness (it must not be an obvious or trivial extension of the state of the art). It must also disclose or remove from secrecy the essential features of the invention so as to "enable" others to make or use the invention. A patent holder or owner is given the right to exclude others from unauthorized use, sale, or manufacture of the product or process for 17 years from date of issuance.

Plants were not covered by the U.S. patent law until the Plant Patent Act of 1930. The plant patents covered only asexually reproduced crops, for example, grafted fruit trees, but excluded potatoes and Jerusalem artichokes. Sexually reproduced plants were excluded because it was believed at that time that sexually reproduced plants did not breed true and monopoly control over staple crops might occur (Knudsen and Hansen 1991). Plant patent protection does not extend to seed produced by protected plants, and others can reproduce the seed through sexual means. The use of plant patents has been generally limited, but did provide some protection to sugarcane varieties, fruit trees, and some ornamentals.

Plant breeders were granted patent-like protection for sexually reproduced plants by the Plant Variety Protection Act of 1970. It initially excluded celery, tomatoes, bell peppers, cucumbers, and okra, because of concerns expressed by the soup companies about possible effects on costs of soup-vegetables, but in 1980 the legislated was amended to include several additional vegetables. The applicant must show that a variety is distinct, uniform, and stable. The holder or owner is given a Plant Variety Protection Certificate (PVPC) which was first good for 17 years from the date of application but was extended in 1980 to 18 years. The USDA is in charge of PVPC applications (because the Patent Office did not see PVPCs as important property rights in 1970).

There are some important exemptions to the Plant Variety Protection legislation. First, varieties can be used in research programs. Second, farmers whose primary occupation is growing crops for nonseed purposes can use their harvested seed for planting and selling to others, so called bin-run seed. The basic requirements are that less than 49 percent of the seed is sold or less than 50 percent of the farm's income is from seed sales (Knudsen and Hansen 1991). Furthermore, farmers can trade seed among themselves for services or other seed. This second exemption has significantly weakened the basic property right granted to PVPC holders and has had important incentive effects in the U.S. seed industry.

Table 1 provides some evidence on the rate of PVPC application for selected crops. In field crops, a relatively large number of PVPCs have been issued for soybeans, wheat, and cotton. Few PVPCs were granted for field corn before 1985. The private sector accounts for a large share of the PVPCs in all crops except for a few, e.g., oats.

Since 1985, plant material has been covered by regular patents. This is the result of changes started in the 1980 *Diamond v. Chakrabarty* case in which the Supreme Court ruled that micro-organisms were patentable. In 1985, the *ex parte Hibberd* case extended the Chakrabarty ruling to plants, seeds, tissue cultures, hybrid plants, and hybrid seeds. Plants now can be protected with a patent provided they show utility, novelty, and nonobviousness.

A patent applies to both asexually and sexually reproducing crops, lasting for 17 years, and is issued by the U.S. Patent Office. Patents have been granted in particular to hybrid corn varieties and in 1992 for transgenetic cotton.

A patent has some advantages over a PVPC but other disadvantages. It does not contain a crop or research exemption clause, and it can cover multiple varieties or individual components of a variety (U.S. Congress, OTA, 1989; Knudsen and Hansen 1991). Disadvantages are that a patent holder must provide full disclosure of the technology and provide a detailed description that meets regular patent requirements. Also patent holders must have the patented material stored in a depository for about 35 years and filing and issue fees may be greater than for a plant patent or PVPC.

The broad scope of a 1992 patent on transgenetic cotton has sent minor shock waves through the U.S. seed industry. On October 27, 1992, the U.S. Patent and Trade Marks Office awarded Agracetus, a division of W.R. Grace and Co., the rights to all transgenetically engineered cotton produced in the U.S. by any means, for any variety, and in any form (Gibbs 1994). This means that W.R. Grace has the rights to royalties on all U.S. cotton seed or plants that carry a foreign gene, irrespective of how the transfer of the gene occurs. In principle, Grace could demand royalties for much of the research on new transgenetic cotton plants. Given the broad scope of the patent, Grace currently intends to freely grant licenses for university and government research. One might, however, expect that the scope of this patent on cotton will be narrowed by future court decisions.

Trade secrecy is possible when information on the technology used to produce the output is not apparent in the plant material. In crops, trade secrecy has frequently been relied on for protecting property rights in hybrid corn varieties because the parents are not generally revealed in the hybrid seed or plant. Modern biotechnical methods are greatly increasing the ability of scientists to explore the germplasm of plants and seem to weaken trade secrecy as a reliable method for maintaining property rights in plant materials.

With advances in the biotechnical method of genetic fingerprinting, a new form of scientific evidence is now available for use in court cases dealing with infringement on property rights in plant materials. When high quality laboratory procedures are used, genetic fingerprinting provides a method of providing evidence with very low probability of being wrong about the origins of plant material (Roberts 1992). Thus, genetic fingerprinting can be expected to significantly reduce the transactions costs of enforcing property rights in plant materials (although they still may be large in some cases) and result in a general strengthening of intellectual property rights in plant materials. In the long term, this method seems likely to be an asset to high quality private plant research programs and to society.

The U.S. Seed Industry

The products for sale by the U.S. seed industry have historically been the results of both public and private varietal developments. The new and stronger intellectual property rights in plant materials and the relatively slow growth in public sector agricultural research funds mean that the private sector will become generally more dominant in the development and sale of commercial seed.

A Few Characteristics of the Market

A relatively large quantity of seed is used in the production of wheat and soybeans but the private sector seed companies find hybrid seed corn to be the most profitable. Table 2 presents data on the total tonnage of seed used, and the quantity of wheat and soybeans used as seed are several times larger than for corn. However, the marketing of seed corn has some major advantages over wheat and soybeans because seed corn is for a hybrid plant but most wheat and soybean seed is of a nonhybrid type. With hybrid seed, the grain from the hybrid is not acceptable seed, and the genetic makeup of the plant is not obvious. Thus, all seed corn is commercially purchased seed. Table 3 provides additional data on the national and state average seeding rates for hybrid corn. As everyone knows, the production of corn is centered very much in the Midwest.

Although a large volume of seed is needed for seed wheat, only about 30 percent of the seed is purchased commercially each year. The use of purchased seed does differ across the wheat producing states, but Table 4 shows that in the major wheat producing states of Kansas, Oklahoma, Texas, and Colorado the rate of use of commercially purchased seed is less than 40 percent. In particular, Kansas accounts for about one-third of U.S. wheat acreage but only 27 percent of the wheat area was planted to commercially purchased seed in 1991. The extensive use of bin-run seed has resulted in a number of private seed companies pulling out of the wheat variety development business. Public sector developed varieties have been and will continue to be the primary source of new wheat varieties (Huffman and Evenson 1993, Ch. 6).

A relatively large quantity of soybean seed is needed each year to plant the crop. Table 5 shows that in1991 about 73 percent of the soybean acreage was planted to commercially purchased seed. This rate is an increase by 5 percentage points since 1989. Table 5 also provides information on the seeding rate for soybeans by major soybean producing states in 1991 and on the percentage of the acreage planted to purchased seed. In Illinois and Iowa, the two largest soybean producing states, the rate of use of purchased seed in 1991 was 73 and 81 percent, respectively. Although 30 years ago a large share of the soybean varieties was publicly developed (see Huffman and Evenson 1993, Ch. 6), private varieties have made major inroads during the 1980s. Table 6 shows the share of total soybean seed from purchased private seed in 1991. For Illinois and Iowa, the commercially purchased private varieties accounted for 63 and 78 percent respectively. In the south, commercially purchased private varieties, however, accounted for generally less than 50 percent of the total soybean seed in 1991. Soybean variety development is an area where private seed companies seem to have a good future.

The Economics of Pricing Varietal Innovations

When a company has property rights in new plant material due to traditional plant breeding or to biotech methods (Moffat 1992a,b; Kalton, Richardson, and Frey 1989), say a new variety, it must decide how to price the new material so as to increase company net income. We can consider a simple example of an innovation (x), say a new hybrid corn variety that is used to produce a final product (Q), say corn for grain. Furthermore, let's make a not unreasonable assumption that the use of the new innovation is proportional (1-to-1) to the output of Q produced. Also, we assume that the market demand curve for Q is $D_Q D'_Q$ in the upper panel of Figure 1 and the initial supply curve for Q (without the new innovation) is S_o. The innovation or new variety results in the reduction in the cost of production of Q to S_1 if it were totally free.

We can obtain the derived demand for the use of the innovation (x) or the corn variety, and it is represented in the lower panel of Figure 1. The derived demand for x is $d_x dd'_x$. This is a kinked demand curve for the services of x, and it has a marginal revenue curve of $d_x dfMR_x$, which is discontinuous. Furthermore, we assume that the marginal cost of providing x (say the seed of the new variety) is represented by constant marginal cost of MC_x in Figure 1.

Now we can ask what is the optimal price for the services of the new innovation? By optimal, I mean the price that maximizes the profits of the owner of the rights to the innovation or variety. It is at a rate of use where the marginal revenue equals the marginal cost. This is at the rate of use x*, and the profit maximizing price for the services of the innovation is R*.

When the cost of the innovation is added to the marginal production cost or the supply price of Q excluding the cost of x, the new supply curve for Q (after the innovation and with a charge for x) is S_1+R*. Thus, when the innovation is priced optimally for maximum profit, the market price of Q is reduced from P_0 to P_2 and the quantity consumed is increased slightly from Q_0^* to Q_2^*. Furthermore, the profit maximizing price for the new variety is not one that captures all of the cost reduction associated with its use. Some of the benefits go to consumers, and this is the source of what Evenson and I (Huffman and Evenson 1993, Ch. 7 and 9) have discovered to be a positive social rate of return on private sector R&D. Even when private firm optimally price their innovation, there are frequently additional benefits to society.

In a more complete analysis, one would need to take account of the rate of adoption of the innovation (Griliches 1960) and the development of substitutes for x by the owner of the rights to x and by others and use of bin-run seed for nonhybrid seed. Also, pathogens could develop that attack x and make it generally useless. Some innovations change the quality of the final product (Q) so it is worth more as a result of the innovation and shifts the demand curve. These are all issues in a more thorough analysis of the economics of plant innovations.

The Size of Public and Private Crop Research Activities

The public and private sectors are engaged in crop research activities. Table 7 presents information USDA, SAES, and of total public (USDA and SAES) research expenditures in 1980 (in 1990 dollars) and in 1990 for field crops and forages; fruits, vegetables, nursery, and greenhouse plants; and other crops or plants. These expenditures include both those oriented to plant improvement and to other plant related research. In 1980, expenditures on cotton, soybean, and corn research were similar at slightly more than $60 million. Soybean research accounted for slightly less, about $48 million. In 1990, corn and soybean research exceeded $70 million and wheat and cotton research remained at the $60+ million expenditure level. Perhaps surprising to some are the relatively large public sector expenditures on forage research (alfalfa, other forage legumes, and forage grasses). In 1980, the total expenditures were $81 million, but the decreased to $72 million in 1990. Taken as a group, total public expenditures on field crop and forage research were only 6.7 percent larger in real terms in 1990 than in 1980. This is a small overall increase, but increases for corn, wheat, and other oil seed research were much larger.

A surprisingly large amount of public agricultural research expenditures go to fruits and vegetables, more than $120 million each for 1980 and 1990. The major growth between 1980 and 1990 was in research expenditures on vegetables (20 percent).

The private sector is investing heavily in corn research. This is seen by examining the information in Table 8 on the number of full-time equivalent scientific personnel doing some time of plant breeding research for 1989. This information shows that about one-half of all the private sector plant breeders and about 40 percent of the plant-related biotechnology research is focused on corn. In field crops, soybean breeding research is second in importance. For both of these crops, the number of Ph.D. level private sector plant breeders is much larger than for the public sector. However, in wheat and forages plant breeding research, there are a larger number of public sector scientists than private sector scientists. These differences are due to differences in expected profitability of the different types of varietal research, especially the extent of use of bin-run seed.

Conclusions and Implications

The developed countries of the world have had well defined intellectual property rights in plant materials for more than two decades. Furthermore, most of these countries have been strengthening these rights. They have been a key factor behind the development and growth of a private seed industry and a general reduction in the relative importance of the public sector in commercial variety development. The developing countries are lagging three to five decades behind the developed countries in their intellectual property institutions. If these countries are going to make a transition to higher sustained real economic growth, they seem likely to need larger human capital investments and stronger intellectual property rights. Their attempts to continue to borrow plant technology from the developed countries seem likely to run into difficulties. First, the biology of plants are such that the locality of adaptation is relatively small, so plant materials from developed countries have the greatest potential for use directly as parent material rather than for commercial varieties. Second, the developed countries are applying greater economic incentives for the developing countries to participate positively in a common intellectual property system. Thus, the developing countries must face up to developing their own scientific expertise and capacity for applied crop research. Modern biotechnology seems to have increased the value of germplasm of unusual plant materials. This raises new issues about ownership and transfer of landraces, wild plants, and indigenous materials.

In the United States, the private sector will in general become an increasingly important source of improved plant varieties for agriculture. The public sector will undertake varietal developments only when it is unprofitable for the private sector, e.g., in wheat, forages, and other small grains. The public sector will shift its emphasis more heavily into pretechnology science which is needed for long term productivity of private sector improved plant material development and which is generally unprofitable work for private firms to undertake. The public sector should not establish a common practice of selling property rights to new plant materials (or other intellectual materials) to the private sector for commercial development. Public sector profiting directly from sale of intellectual property most likely reduces the profitability of private sector R&D activities and distorts the incentives for using public research resources away from advancing knowledge in the pretechnology sciences to applied science and technology development. It, also, has the potential for eventually undermining the "public goodwill" for public financial support of university research.

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Table 1. Plant Variety Protection Certificate Issued in the U.S. by Crop, 1971-1991

	1971-74	1975-78	1979-82	1983-86	1987-91	Total Issues	% Public
FIELD CROPS AND FORAGES							
Corn (field)	0	1	6	40	115	162	0.6
Sorghum						3	0
Wheat	13	42	60	30	97	242	30.2
Barley	0	12	2	23	5	42	7.1
Oats	0	11	5	1	8	25	56.0
Soybeans	34	69	135	155	106	499	15.8
Alfalfa	0	3	21	16	31	71	18.3
Cotton	22	31	38	31	53	175	13.1
VEGETABLES							
Lettuce	14	17	14	15	33	93	0
Garden Beans	32	39	21	29		121	0
Peas	20	48	46	61		175	0

Source: USDA, *Plant Variety Protection Official Journal*.

Table 2. Seed Use for Major U.S. Field Crops[a]

Crops	1988/89	1989/90	1990/91[b]	1991/92[c]
	-----------------------------1,000 tons-----------------------------			
Corn	515	529	540	556
Sorghum	42	31	36	37
Soybeans	1,751	1,664	1,722	1,670
Barley	360	320	350	357
Oats	433	361	306	275
Wheat	3,090	3,000	2,670	2,804
Rice	150	160	168	174
Cotton[d]	112	94	108	102
Total	6,453	6,159	5,892	5,975

[a]Crop marketing year.
[b]Preliminary.
[c]Projected.
[d]Upland cotton.

Source: USDA, *Agricultural Resources: Inputs*, AR-25, Feb. 1992.

Table 3. Corn for Grain Seeding Rates, Plant Population, and Seed Cost per Acre, 1991[1]

U.S./States	Acres Planted[2]	Rate per Acre	Plant Population per Acre	Cost per Acre
	Thousand	Kernels	Number	Dollars
U.S.				
1991 average	60,350	24,906	22,080	20.79
1990 average	58,800	24,700	21,040	20.50
1989 average	57,900	24,100	20,760	20.40
States – 1991				
Illinois	11,300	25,511	23,700	21.09
Indiana	5,800	25,027	22,400	20.26
Iowa	12,200	25,285	22,800	20.49
Michigan	2,600	24,279	21,800	20.49
Minnesota	6,600	26,602	23,900	22.98
Missouri	2,200	22,575	19,900	19.87
Nebraska	8,300	24,501	22,200	20.21
Non-irrigated	2,747	18,648	nr	15.64
Irrigated	5,553	27,397	nr	22.47
Ohio	3,800	26,442	23,200	22.51
South Dakota	3,750	19,111	17,500	16.03
Wisconsin	3,800	25,611	23,400	19.16

nr – Not reported

[1]States planted 80 percent of U.S. corn acres in 1991.
[2]Preliminary for 1991.

Source: USDA, *Agricultural Resources: Inputs*, AR-24 and AR-25, 1991 and 1992.

Table 4. Winter Wheat Seeding Rates, Seed Cost per Acre, and Percent of Seed Purchased, 1991[1]

States	Acres	Rate per Acre	Cost per Acre[2]	Acres with Purchased Seed
	Thousands	Pounds	Dollars	Percent
Arkansas	930	137	13.13	58
Colorado	2,300	45	3.52	36
Idaho	700	86	10.16	70
Illinois	1,400	110	14.22	59
Indiana	750	118	18.10	79
Kansas	10,800	60	7.49	27
Missouri	1,550	115	16.25	64
Michigan	1,900	58	4.69	30
Nebraska	2,100	62	5.20	25
Ohio	1,100	137	16.59	52
Oklahoma	5,000	73	6.42	21
Oregon	800	72	7.66	65
South Dakota	1,300	64	4.22	31
Texas	2,800	74	7.34	40
Washington	750	71	9.46	70
1991 average	34,180	74	8.65	36

[1]Preliminary. States listed harvested 86 percent of U.S. winter wheat acres in 1991.
[2]Based on data from those farmers who used purchased seed.

Source: USDA, Agricultural Resources: Inputs, AR-24-AR-25, 1991 and 1992.

Table 5. Soybean Seeding Rates, Seed Cost per Acre, and Percent Seed Purchased, 1991[1]

U.S./States	Acres Planted	Rate per Acre	Cost per Acre[1]	Acres with Purchased Seed
	Thousand	Pounds	Dollars	Percent
U.S.				
1991 average[2]	49,650	64	15.07	73
1990 average	48,250	62	14.20	71
1989 average	51,130	60	15.50	68
States - 1991				
Northern:				
Illinois	9,200	66	16.44	73
Indiana	4,450	67	15.85	82
Iowa	8,800	61	16.35	81
Minnesota	5,500	68	14.65	74
Missouri	4,500	65	15.20	61
Nebraska	2,500	61	15.80	78
Ohio	3,900	77	16.26	69
Southern:				
Arkansas	3,200	58	11.74	55
Georgia	650	49	10.24	81
Kentucky	1,150	61	13.54	64
Louisiana	1,450	52	12.12	95
Mississippi	1,900	53	10.38	78
North Carolina	1,350	65	14.09	73
Tennessee	1,100	53	10.07	55

[1]States planted 83 percent of U.S. soybean acres in 1991.
[2]Preliminary.
[3]Based on data from farmers.

Source: USDA, *Agricultural Resources: Inputs*, AR-24 and AR-25, 1991 and 1992.

Table 6. Soybeans: Commercially Purchased versus Bin-Run Seed, 1991

REGION/STATE	Purchased Seed		Bin-Run Variety
	Private Variety %	Public Variety %	%
MIDWEST			
Illinois	63	8	29
Indiana	65	15	20
Iowa	78	4	18
Minnesota	45	15	39
Missouri	42	18	40
Nebraska	72	5	24
Ohio	41	27	33
SOUTH			
Arkansas	54	9	37
Mississippi	47	16	37
Tennessee	52	9	39
Georgia	41	14	45
North Carolina	54	19	27
U.S.	70		30

Source: Private Industry Estimates

Table 7. Public Agricultural Research Expenditures by Crop, 1980 and 1990

	Expenditures 1980 ($ mil)[a]			Expenditures 1990 ($ mil)			
PLANT RESEARCH	SAES	USDA	Total Public	SAES	USDA	Total Public	% Change of Total 1980-90
FIELD CROPS AND FORAGES							
Corn	42.5	19.5	62.0	47.2	29.3	76.5	21.0
Sorghum	11.7	4.1	15.8	13.0	2.9	15.9	0.6
Wheat	30.2	17.6	47.8	42.1	24.1	66.2	32.6
Other small grains/cereals	23.6	10.4	34.0	21.5	11.4	32.9	-3.3
Soybeans	45.4	20.9	66.3	45.0	27.4	72.4	8.8
Other oil crops	14.0	9.5	23.5	18.0	10.2	28.2	18.2
Alfalfa							
Other forage legumes	58.3	22.4	80.7	48.5	23.2	71.7	-11.8
Forage grasses							
Cotton	26.4	41.9	68.3	22.8	39.2	62.0	- 9.7
Subtotal	**(252.1)**	**(146.3)**	**(398.4)**	**(258.1)**	**(167.7)**	**(425.8)**	**(6.7)**
FRUITS, VEGETABLES, NURSERY, GREENHOUSE							
Fruits and nuts	90.1	38.3	128.4	93.4	45.2	138.6	7.6
Vegetables	92.9	30.2	123.1	114.1	36.9	151.0	20.4
Ornamentals and turf	37.5	5 8.5	46.0	41.7	6.1	47.8	3.8
Subtotal	**(220.5)**	**(77.0)**	**(297.5)**	**(249.2)**	**(88.2)**	**(337.4)**	**(12.6)**
OTHER CROPS	28.1	25.9	54.0	33.7	19.9	53.6	-0.7
TOTAL	500.7	249.2	749.9	541.0	275.8	816.8	8.5

[a]Expressed in 1990 research dollars (by inflating current 1980 dollars by 1.726 (Huffman and Evenson 1992)).

Source: U.S. Dept. of Agriculture, *Inventory of Agricultural Research*, 1980 (1990).

Table 8. Ph.D. Level Scientific Personnel Involved in Plant Breeding, 1989 (Full Time Equivalent)

	No. Plant Breeding Research		
	Breeders/Geneticists		
CROPS	Public[a]	Private	Private Biotech
FIELD CROPS			
Corn	36.6	256.9	90.1
Sorghum	12.2	22.8	-
Wheat	38.4	25.2	1.1
Other small grains/cereals	39.4	14.8	0.7
Soybeans	32.7	59.7	17.3
Other oil crops	14.9	13.0	10.5
Alfalfa	27.1		2.1
Other forage legumes	9.3	28.3	-
Forage grasses	27.1	1.6	-
Cotton	15.2	11.1	7.2
Subtotal	**(252.9)**	**(433.4)**	**(129.0)**
FRUITS, VEGETABLES, NURSERY, GREENHOUSE			
Fruits and nuts	47.4	0.3	-
Vegetables	81.1	108.3	31.4
Flowers and nursery	13.2	16.4	-
Subtotal	**(141.7)**	**(125.0)**	**(31.4)**
OTHER CROPS	22.2	22.0	91.5
TOTAL	416.8	580.4	251.9

[a]Combined scientists in USDA-ARS and SAES.

Sources: Column (1) is from James (1990) and columns (2) and (3) are from Kalton, Richardson, and Frey (1989).

Table 9. Change in U.S. Patenting Activity 1985 to 1990 in Selected Fields of Science and Ties of New Patents to Intellectual Materials

				Average No. Citations by New U.S. Patents to:					
				U.S. Patents		Foreign Patents		Science Publications	
FIELD OF SCIENCE/ INSTITUTION	1985 (%)	1990 (%)	Change 1988-90 (%)	1985	1990	1985	1990	1985	1990
BIOTECHNOLOGY									
Corporate	42.5	44.5	40	5.3	4.3	0.8	1.5	4.8	4.3
Academic	10.8	11.0		3.6	3.2	.3	1.0	5.7	6.7
Other	46.7	44.5		-	-	-	-	-	-
Total	100.0	100.0	35	4.6	4.6	.7	1.6	3.4	4.4
BOTANY AND GENETICS									
Corporate	34.5	58.4	119	3.3	2.1	1.4	1.0	4.5	4.1
Academic	17.2	4.4		1.7	1.4	.7	0	5.0	4.0
Other	48.3	37.2		-	-	-	-	-	-
Total	100.0	100.0	67	2.0	2.7	1.2	1.6	2.9	3.6
AGRICULTURE (farm machinery, ag. chemical, ag. pharmaceutical)									
Corporate	48.3	42.4	-11	8.3	4.4	1.7	1.8	.3	.3
Academic	1.7	5.1		7.0	6.3	7.0	0	0	3.7
Other	50.0	47.5		-	-	-	-	-	-
Total	100.0	100.0	2	5.7	4.2	5.7	1.5	0.1	0.4

Source: Random sample of patents at U.S. Patent Office. Bob Evenson, Yale University, grouped patent classes into fields of science.

Figure 1. The derived demand and optimal pricing of an innovation (x) that is closely linked to a final product (Q)