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Creating, Protecting, and Using Crop Biotechnologies Worldwide in an Era of Intellectual Property

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Abstract

Proponents tout the positive incentive-to-innovate effects of intellectual property rights (IPRs), while others maintain that the expanding subject matter and geographical extent of IPRs are stifling crop research, especially research and development (R&D) dealing with developing-country crop concerns. Much of this debate relies on anecdotes and misleading or incomplete evidence on the extent and nature of the IPRs pertaining to crop technologies, including the jurisdictional extent of the property rights and their practice. In this paper we review the evidence on the scope of agricultural R&D worldwide, provide new data on the structure of crop-related IPRs, and summarize trends on the uptake of proprietary bioengineered crops.

Keywords: plant patents, utility patents, plant breeders' rights, crop varieties, public and private agricultural R&D, biotechnology

Creating, Protecting, and Using Crop Biotechnologies Worldwide in an Era of Intellectual Property

1. Introduction

Most crops are grown in places where they did not occur naturally—they were introduced, either incidentally or intentionally. In this way the development and dissemination internationally of new and improved seed varieties has been the basis for productivity improvement in agriculture since crops were first domesticated about 10 millennia ago. Initially the movement of plant material involved farmers carrying seed as they migrated to new areas. Columbus returned from his voyage to the New World in the latter part of the 15th century laden with new plants that ushered in an extended era of state-sponsored expeditions to gather and evaluate plant materials the world over. For most of that time, new crop varieties were largely treated as common property, shared freely among farmers and countries and generating billions of dollars of benefits worldwide.[1]

The era of free and unencumbered access to new crop varieties appears to be passing. This has implications beyond the movement and marketing of new crop varieties; it affects their creation as well. Scientific crop breeding, drawing on rediscovered Mendelian Laws of Heredity, began in earnest about a century ago. For many countries, varietal innovations continue to rely heavily on introduced germplasm, making the

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[1] While personal or corporate intellectual property rights for plant biotechnology are recent phenomena within most countries, attempts at asserting national property rights over breeding materials internationally are nothing new (Boettiger et al. 2003). Monopolization of valuable markets has long been accomplished by nation-states prohibiting access to breeding materials. Examples include the Dutch monopolization of the European tea supply (Juma 1989), the Italian prohibition on rice seed export famously violated by Thomas Jefferson (Fowler 1994; Root and de Rochemont 1976), and more recently Ethiopia's ban on the export of some coffee tree varieties (Fowler and Mooney 1990). These cases are, however, atypical; in general, traders, collectors, and breeders have had free access to landraces and farmers' varieties from around the world. For a review of the evidence on the benefits arising from crop-improvement research, see Alston et al. (2000).

international spillovers of germplasm, breeding techniques, and know-how integral to these crop improvement efforts. While substantial germplasm (much in the form of landraces and other primary plant materials) flowed from poorer countries into the rich ones, so too did enhanced germplasm subsequently move back to the poorer parts of the world. This reverse flow appears to have accelerated as the Green Revolution took hold, beginning in the 1960s, as developing-country farmers took up improved varieties in a big way and as local breeding efforts screened and adapted these varietal spillins to better deal with local agroecological realities and production constraints.

Throughout all these changes, crop improvement has been, and largely remains, a *cumulative* or *sequential innovation process*—new varieties build directly on the selection and breeding efforts of farmers and scientists of yesteryear. A new twist has come with the advent of modern biotechnology tools. Now the genetic makeup of new varieties are altered by the "conventional or classical" genetic manipulation techniques practiced formally by scientists for the past 100 years (and less formally by farmers for eons prior to that), or by bioengineered techniques involving the purposeful insertion of gene fragments into plants from other plants or other organisms using genomic and transformation technologies developed within the past two decades.[2] Like the crop varieties themselves, the tools of crop manipulation are increasingly encumbered by intellectual property,

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[2] All crops are genetically modified, making the mnemonic "GMOs" misleading in ways that seem to have profoundly affected peoples' perceptions about the latest set of crop-improvement techniques. Among the continuum of genetic modification methods, Drew and Pardey (2003) distinguish between classically bred crops using techniques like hybridization that became commonplace among scientific breeders beginning a century ago, and varieties whose DNA has been manipulated with bioengineering techniques like the ballistic gun or agrobacterium mediated transformations of DNA that form the forefront of present crop improvement methods. Confounding efforts to neatly classify crop varieties, some modern varieties are conventionally bred but incorporate herbicide tolerant genes identified using modern genomic methods.

making the future of crop-improvement inextricably tied to the future of the biotechnologies increasingly used to manipulate them.

Whether these changing market, scientific, and intellectual property regimes will help or hinder efforts to develop and disseminate varietal technologies in the future, and especially the crop innovations required by the developing world, is an open question. In this paper we survey and report newly compiled evidence on the research and, especially, the intellectual property landscapes regarding plant biotechnologies as a step toward resolving these questions.

2. Crop Biotechnology Creation

Crop biotechnologies are not necessarily used or protected where created. Here we investigate the location and structure of the relevant R&D sectors as a basis for analyzing the patterns of intellectual property rights in the resulting crop innovations and their uptake worldwide.

Research Spending. In 1995 about half a trillion (nearly $500 billion, 1993 prices) U.S. dollars was invested in all public and privately financed science worldwide—around 85 percent of it conducted in rich countries (Pardey and Beintema 2001). Agricultural research accounted for $33 billion of this total or nearly 7 percent of all private and public spending on science.

The public share of agricultural investment was substantial, but is now flagging. Worldwide, public investments in agricultural research nearly doubled in inflation-adjusted terms over the past two decades, from an estimated $11.8 billion in 1976 to nearly $22 billion in 1995. Yet for many parts of the world, growth in spending during the 1990s slowed dramatically. In the rich countries, public investment grew just 0.3 percent annually between 1991 and 1996 compared with 2.3 percent per year during the 1980s. In Africa, there was no growth at all. In Asia, the 4.4 percent annual growth figure compared with 7.5 percent the previous decade.

The distribution of spending on agricultural research has shifted as well. In the 1990s, for the first time, developing countries as a group spent more on public agricultural research than the developed countries. Among the rich countries, $10.2 billion in public spending was concentrated in just a handful of countries. In 1995 the United States, Japan, France and Germany accounted for two thirds of this public research, about the same as two decades before. Just three developing countries—China, India, and Brazil—spent 44 percent of the developing world's public agricultural research money in 1995, up from 35 percent in the mid-1970s.

By the mid-1990s about one third of the $33 billion total public and private agricultural research investment worldwide was private (Table 1). But little of this research takes place in the developing world. The overwhelming majority ($10.8 billion, or 94 percent of the global total in 1995) is conducted in developed counties, where private research is over half of all expenditures. In developing countries, the private share of research is just 5 percent, and public funds are still the major source of support.

[Table 1: *Private and Public Agricultural R&D Investments, circa 1995*]

Private agricultural research is displacing public research generally, and specifically in areas like commercial crop breeding for the seeds of crops with high commercial value. This tendency is especially pronounced in countries like the United States where private agricultural R&D was 90 percent of public spending in 1960, growing to 133 percent by

1996, the latest year for which comparable public-private data are available. Private investments, fueled by agricultural biotechnology research, gravitate to techniques which promise large markets, are protected by intellectual property rights, and are easily transferable across agroecologies. These included food processing and other post-harvest technologies and chemical inputs including pesticides, herbicides and fertilizers. Hence, while private research is much more geographically concentrated than public research, many of its fruits may be more easily transferred across borders and agroecological zones. Even so, private research is far less likely in products or methods with small markets, weak intellectual property protection, and limited transferability, precisely the situations in which most poor farmers are found.

Research Intensities and Stocks of Knowledge. One way to gauge the commitment of agricultural research funds, public or private, is to compare them to national agricultural output, rather than measuring them in absolute terms. This relative measure captures the *intensity* of investment in agricultural research as a percentage of agricultural GDP, not just the *amount* of total research spending. In 1995, as a group, developed countries spent $5.43 on public and private agricultural R&D for every one hundred dollars of agricultural output compared with just 66 cents per hundred dollars of output for developing countries. The eightfold difference in total research intensities illustrates the size of the technological gap in agriculture between rich and poor countries. Moreover, the situation is growing worse. The difference in public research intensity ratios was 3.5−fold in the 1970s, compared with 4.3−fold now (an even wider gap would have opened up if private spending was also factored in).

These trends may actually understate the scientific knowledge gap. Science is a cumulative endeavor, with a snowball effect. Innovations beget new ideas and further rounds of innovation or additions to the cumulative stock of knowledge. The sequential and cumulative nature of scientific progress and knowledge is starkly illustrated by crop-improvement. It generally takes 7−10 years of breeding to develop a uniform, stable, and superior variety (with improved yield, grain quality, or other attributes). But breeders of today build on a base of knowledge built up by breeders of yesteryear. The cumulative nature of this process means that past discoveries and related research are an integral part of contemporary agricultural innovations. Conversely, the loss of a variety (or the details of the breeding histories that brought it about) means the loss of accumulated past research to the present stock of knowledge. Providing adequate funding for research is thus only part of the science story. Putting in place the policies and practices to *accumulate* innovations and increase and preserve the stock of knowledge is an equally important and almost universally unappreciated foundation.[3]

Estimates of the stocks of scientific knowledge arising from public and private research conducted in the United States and Sub-Saharan Africa have been developed by Pardey and Beintema (2001). Historical research spending (running from 1850 for the United States and 1900 for Africa and allowing for a gradual diminution of the effect of distant past R&D spending on money measures of the current stock of knowledge) was

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[3] Discoveries and data that are improperly documented or inaccessible (and so effectively exist only in the minds of the relevant researchers) are lost from the historical record when researchers retire from science. These "hidden" losses seem particularly prevalent in cash-strapped research agencies in the developing world, where inadequate and often irregular amounts of funding limit the functioning of libraries, data banks and genebanks, and hasten staff turnover. There can also be catastrophic losses, tied to the political instability that is a root cause of hunger. Civil strife and wars cause an exodus of scientific staff, or at least a flight from practicing science.

compared with the gross domestic agricultural product for 1995. The accumulated stock of knowledge in the United States was ten times more than the amount of agricultural output produced in that year. In other words, for every $100 of agricultural output there existed a $1,000 stock of knowledge to draw upon. In Africa the stock of knowledge in 1995 was actually less than the value of African agricultural output. The ratio of the U.S. knowledge stock relative to U.S. agricultural output in 1995 was nearly 12 times higher than the corresponding amount for Africa. Stocks of knowledge measures provide a better basis for evaluating the developed versus developing country capacities for actually carrying out crop biotechnologies, and in fact the overall differences may understate the effective gaps for this advanced area of agricultural R&D. These gaps also underscore the immensity, if not the outright impossibility, of playing "catch-up," in addition to the need to transfer knowledge across borders and continents.

Biotechnology Trials. Absent meaningful data on "crop-related biotechnology research" spending, the only indication of the location of crop biotechnology research is data on the number of field trials conducted internationally.[4] Pardey and Beintema (2001) compiled data on the number of field trials conducted on bioengineered crops from 1987 through December 2000 grouped by the regions in the world where the trials were conducted (Table 2).[5]

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[4] Precisely what is meant by "crop-related biotechnology research" is difficult to determine. "Biotechnology" can run the whole gambit from conventional breeding, through culturing methods, to genomic and bioengineering (including transgenic) techniques. In addition, and as discussed regarding the patent data reported below, many biotechnology techniques developed with spending directed to the health sciences, for example, have agricultural applications as well.

[5] As indicators of the level of bioengineering research effort, these data must be taken with a grain of salt. To meaningfully assess the distribution of transgenic crops being tested in the ground, one would like the notion of "field trial" to be standardized across countries. One option is to count each location as a separate instance. But in the United States, for example, a "location" can have many sites. For example, test 01-024-26n in the APHIS database contains Pennsylvania as one location, but there are 313 sites comprising a total of 1,838 acres. Likewise, Canada lists field trials conducted at multiple sites within a province as one field trial, but it is not clear if all the data for all the other countries are reported similarly.

According to these data, a total of twenty seven countries conducted trials on 14 different crops and 183 different "events."[6]

[Table 2: *Field Trials of Bioengineered Crops by Regions of the World*]

Eighty four percent of the world's trials were conducted in rich countries; two thirds of the total was in the United States and Canada alone. This points to a biotechnology-research gap between rich and poor countries that is even more pronounced than the gap in overall agricultural R&D spending (wherein 64 percent of global agricultural R&D was conducted in rich counties). Two fundamental factors may account for much of the marked spatial asymmetry in agricultural biotechnology research: specifically, who conducts the research, and the nature of the science itself. First, as indicted in Table 2, the preponderance of these biotechnology trials are conducted by private firms and most of the world's private agricultural R&D (about 94 percent, Table 1) takes place in rich counties. Second, this type of cutting-edge research requires access to highly skilled scientists, well functioning scientific infrastructure that provides ready access to reagents and a myriad of laboratory equipment and supplies, along with technical information, and the appropriately trained support staff to help carry out the research. Even though most of the trials are conducted by private firms, the sophistication of the research involved and its pace of change mean that "applied" aspects of the biosciences are likely to receive significant spillovers from on-going basic research, and from accumulated stocks of scientific knowledge arising from past research, both elements that are much more readily supplied in rich than poor countries. Indeed, it is the localized spillovers from university research (often involving tacit

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[6] An event involves the insertion of a specific gene in a particular crop, resulting in the expression of a trait in that crop. For example, insertion of the Bt cry1(c) protein producing gene into a particular cotton variety is considered an event.

knowledge embodied in the scientific and technically trained people that form part of university communities) that influences the location of industrialized R&D (Adams 2001).[7]

3. An Economic Primer on Intellectual Property Rights

Research and development (R&D), like almost all other aspects of life, is an economic activity. Who pays for the research, who performs what research where, and who gains and looses (and by how much) as a consequence are all influenced by economic incentives. The degree to which innovators can appropriate the fruits of their endeavors lies at the heart of the incentives to invest, giving rise to pervasive policies worldwide to assign property rights to innovations in an effort to better align private incentives with social interests.

The conventional rationale for protecting intellectual property by patents or other means is to provide some proprietary or “monopoly” rights to an invention—albeit circumscribed and exclusionary in nature—in exchange for public disclosure of the details of the invention (Nordhaus 1969). What is disclosed may be useful for further innovation. But the monopoly right also encourages invention directly, and the social value of the right tends to include surplus above the private value. Thus, the (private and social) benefits of patents include wide diffusion of the creation of aspects of new or advanced technologies. The costs are transitory (for the life of a patent) and entail higher-than-otherwise prices or constrained choices of innovations subject to some monopolistic behavior. However, this conventional, static, one-off view of invention does not fully reflect the dynamic nature of a large part of research and development.

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[7] See also Graff, Rausser, and Small (2003).

Much technological change comes in the form of cumulative innovation processes, whereby the fruits of innovation frequently materialize as the embodiment of a sequence of prior innovations. While strong patent protection may stimulate the earlier-than-otherwise development of a research tool, it can also delay or deter follow-on innovation due to the transaction costs of negotiating a license or merger and the ability to prevent competitors from introducing similar technology (Merges and Nelson 1990, Heller and Eisenberg 1998). Thus the *dynamic cost* of a patent within a cumulative innovation scheme—which includes the accumulated costs of delayed follow-on inventions—is an important policy consideration that is often neglected when counting the conventional (i.e., static) social cost of a patent (Koo and Wright 2002).

A special case of cumulative innovation involves the development of a research tool, that is a product or process whose only value is as an input to follow-on innovations. In agricultural biotechnology, a research tool can be a patent on a DNA sequence modified to enhance the expression of a trait such as insect-resistance, while the follow-on innovation may be a new transgenic variety of cotton. Since the patentee of a research tool can capture revenue only through direct production of the follow-on innovations, efficient compensation of the patentee, through licensing, joint ventures, or other means, is critical in providing the incentive to innovate research tools. In addition, these efficient mechanisms also reduce the transaction costs incurred by those contracting for use of the rights, thereby encouraging the utilization of research tools by follow-on innovators.

One way of reducing dynamic costs and encouraging technology transactions is to clarify property rights. The Bayh-Dole Act of 1980 and subsequent legislation, which allowed U.S. universities, other non-profit institutions, and government labs to patent and exclusively license federally funded inventions, was intended to achieve this purpose. Firms are often unwilling to invest significantly in developing and disseminating innovations lacking clearly defined property rights. This point was clearly captured by the 1945 Report of the U.S. House of Representatives, which stated that "…what is available for exploitation by everyone is undertaken by no one (cited from Jaffe 2000, p.534)." The main objective of the Bayh-Dole Act is to foster markets for the transfer of technology, and there is some evidence the Act has achieved these aims (Jensen and Thursby 2001). However, the Bayh-Dole Act is most effective when inventions require heavy expenditure in downstream technology and product development, which is not the case for all technologies. In addition, some have argued that the Act may actually constrain and delay the flow of fundamental scientific knowledge (as "prior art" concerns impede open scientific discourse through seminars and the professional literature) and shift the emphasis of university research from fundamental basic research toward more applied research that is potentially more rewarding financially for the university (or its research faculty) but not necessarily for society as a whole over the longer run (Mazzoleni and Nelson 1998).

The impact of a patent system also depends on the type of technology itself. Agriculture seeds have special attributes, most significantly their almost costlessly reproducible nature, which merit special attention. Under plant variety protection schemes, farmers may legally save and reuse (and sometimes sell) seeds in following seasons, so that seed firms are faced with only the residual demand for their seeds in subsequent seasons. This problem, together with the difficulty of monitoring and enforcing property rights to seed, makes its legal protection less valuable than other forms of protection on other products. Private seed markets have responded to the appropriability problem by developing hybrid varieties or pursuing genetic use restriction technologies (GURTS), both of which prevent seeds from effectively reproducing, a form of “biological” rather than legal property protection.

What evidence is there that intellectual property rights (IPRs) stimulate inventive activity? Although there are no readily measurable markets for IPRs in which the benefits and costs of patents, for example, can be easily evaluated, a few studies have sought to measure the overall inventive effects of patents. Findings from survey studies suggest that innovators rely primarily on other means (like trade secrets or first-mover advantages) rather than patent protection to appropriate the returns from their innovative investment, with the exception of pharmaceuticals (Levin et al. 1987, Cohen et al. 2000). Some have estimated the private value of patent protection using patent data, concluding that the distribution of patent-rights values is sharply skewed, with most of the value concentrated in a small number of patents (Lanjouw et al. 1998). Using European patent renewal data, Schankerman (1998) estimated that the private value of patent protection was about 15-25 percent of the related R&D expenditure, suggesting a small impact of patent rights on innovative behavior.

Most empirical studies, all using U.S. data, have generally found weak or indeterminate empirical evidence to suggest that plant breeders’ rights are effective in stimulating investments in varietal-improvement research (Perrin et al. 1983, Knudson and Pray 1991, Alston and Venner 2002). Some point out that plant variety protection does not provide patent-like *ex ante* investment incentives, nor generate substantial *ex post* licensing and enforcement activity (Janis and Kesan 2002). Alston and Venner (2002) found that varietal rights for wheat in the United States had little measurable impact on the rate of technical change in that crop, and may simply have served as a marketing tool.

Given evidence of the general lack of appropriability from patent or plant variety protection, why do innovators continue to apply for IP protection? Even accepting the claims that practicing patents may not be the primary means by which large firms recoup their R&D investments, it can still be an important incentive mechanism for smaller new entrants and the venture capital firms that often fund them. Patent portfolios may be critical to obtaining venture capital or to maintaining control of the technology while downstream innovation is pursued or production and sales capabilities are established (Kitch 1977, Mazzoleni and Nelson 1998). In addition, firms (large and small alike) use patents to block products of their competitors, and as bargaining chips when negotiating cross-licensing agreements, as is the case of the semiconductor industry (Hall and Ziedonis 2001). Strategic patenting behavior that relies on larger patent portfolios is consistent with rising rates of patenting and high patent-to-R&D spending ratios, even absent any perceived increase in the appropriable value of patents. For some developing countries with newly introduced plant variety rights such as China, a surge in PVP applications may be explained by an over-optimistic view of the prospective value of varietal rights even though the current size of the seed market and the cost and effectiveness of protection do not seem to economically justify the extent of protection presently being sought (Koo et al. 2003).

4. Crop Biotechnologies as Property

Creating new crop biotechnologies is one thing, protecting the intellectual property embodied in them is an altogether (but not unrelated) other thing, with its own set of economic costs and benefits. Notwithstanding the incentive-to-innovate arguments broached in the previous section, one view is that intellectual property rights over plant biotechnologies in rich and poor countries leads to a lock-out phenomenon: the growth in intellectual property is restricting access to proprietary research results in ways that curtail the freedom to operate for research conducted in or on behalf of poor countries, to the detriment of developing-country food-security prospects. This view is commonly held, absent evidence on the international pattern of intellectual property protection, or a clear understanding of the effect this has on the rate and direction of inventive activity, the use to which these inventions are put, and the trade in agricultural products arising from this research. What follows is a first pass at describing the IPR evidence for plant biotechnologies internationally.

Plant Variety Protection

Global trends. Table 3 shows the pattern of applications for plant breeders rights (PBRs) since 1971 for 36 countries grouped into four per-capita-income classes. More than 136,000 PBR applications have been lodged worldwide since 1971.[8] During the 1970s and 1980s, rich countries accounted for 92 to 96 percent of the total applications. Their share throughout the 1990s declined to average 77 percent in 2001-02. PBR applications filed in upper-middle-income countries—including Argentina, Brazil, Chile, Czech Republic, Hungary, Poland, Slovakia, South Africa, and Uruguay—grew steadily since the early 1970s, while reported PBR applications in lower-middle-income countries—that now

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[8] Some applications were lodged before 1970, but the number is small compared with the totals reported in Table 3.

includes Bulgaria, Colombia, Romania, and the Russian Republic—began increasing a decade later.

[Table 3: *Plant Breeders Rights Applications—Countries Grouped by Per Capita Income, 1971-2002*]

The shifting geographical pattern of plant varietal protection arises for several reasons. The growth in the total number of applications for high-income countries is largely due to an increase in the rate of applications per country per year. Most high-income countries had PBR legislation in place for most of the period reported here. In contrast—and setting aside some initial "start-up" blips in PBR applications—, the majority of middle-income countries showed no general tendency to increase their rates of application over time.[9] In fact some countries in this group experienced a decline in application rates. For this group, the preponderance of growth was due mainly to an increase in the number of countries offering plant breeders rights (3 countries in 1971, 5 in 1985, 8 in 1990 and 13 in 2002).[10] An exception was the lower-middle-income countries where there was a particularly marked jump from 131 applications during 1991-1995 to 2,437 applications

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[9] Koo et al. (2003) describe a start-up phenomenon in China when it began issuing PBRs in April 1999, where an initial blip in applications was taken to reflect pent up demand for these anticipated rights being satisfied. Note, China is not included in the UPOV series reported here.

[10] Plant breeders' rights have been available in many rich countries for at least the past three decades. Germany, for example, has issued plant breeders rights since at least the 1950s and likewise for a few other European countries. The United States began issuing plant variety protection certificates (PVPCs) in 1971 for sexually reproduced plants: asexually reproduced plants (like grape vines, fruit trees, strawberries, and ornamentals that are propagated through cuttings and graftings) have had recourse to intellectual property protection since 1930 when the Plant Patent Act was passed. Many middle-income counties passed PVP legislation during the 1990s in compliance with their *sui generis* obligations to offer the intellectual property rights over plant varieties enshrined in article 27(3)b of the 1995 Trade-Related Aspects of Intellectual Property (TRIPS) agreement in the World Trade Organization (WTO). An indication of the geographical extent of plant breeders' rights is the listing of member countries of the International Union for the Protection of New Varieties of Plants (UPOV). At its inception in 1961, UPOV had 5 member countries (Belgium, France, Germany, Italy, and Netherlands, all of them high-income countries), growing to 20 countries by the end of 1992, then increasingly rapidly to 53 countries—21 high income, 27 middle income and 5 low income—as of September 2003. Notably, under the TRIPs agreement, the "least developed" countries (a WTO designation) are exempt from complying with article 27(3)b until 2005.

during 1996-2000. Applications lodged in the Russian Federation (which reports applications beginning in 1994) grew rapidly to 825 in 2001, and there were much smaller but still sizable increases in Colombia and Bulgaria as well during the late 1990s. Increasing rates of protection may reflect legal-cum-economic as well as institutional factors. One would expect applications to increase over time as awareness of the existence and effectiveness of PBRs in a particular country increased and as the economic costs of applying for and evaluating applications declined with improved bureaucratic procedures.[11]

Notably, the number of plant breeders rights sought in low-income countries is negligible. Since 1971 they accounted for just 145 (0.106 percent) of the global total of 136,234 recorded PBR applications, with almost 85 percent of these rights being sought in the Ukraine alone. The principal proximate cause of this situation is the lack of rights on offer in poor-countries. More fundamentally, it reflects a range of economic influences regarding the costs and benefits of securing breeders rights in a particular jurisdiction.

To capture this cost-benefit calculus, Koo et al. (2003) use an option value model to characterize the crop breeders' decision to apply for and retain varietal protection. While the costs of gaining and securing plant variety protection are known with reasonable surety, the sequence of future returns from a varietal right is highly uncertain for many reasons. There are uncertainties about the size of the appropriable seed market for a given crop, the probability of commercial success of the protected variety, and the extent of enforcement of assigned property rights. Where required, breeders make periodic (often annual) renewal

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[11] In addition, some countries have expanded the scope of crops eligible for protection overtime. In China, for instance, a total of 10 species were eligible for protection in September 1999, growing to 30 species by March 2002 (including 5 major cereals, 2 oil crops, 2 roots and tubers, 10 vegetables and fruits and 11 flowers and grasses but excluding cotton).

decisions, preserving the right to pay renewal fees and exercise their exclusionary rights in future periods. Thus applying for, and subsequently renewing, PVP rights is a way of reserving the rights to potential future revenues, even if revenues in the short term are negligible. Thus the expected value of holding plant variety rights consists of the current returns captured from the coming year and the option to renew the right in the subsequent year.

Decisions taken by individual breeders to obtain PBRs in a particular jurisdiction, and the factors that affect those decisions, are directly relevant for efforts to account for variations across countries in the total number of PBRs sought. Specifically, other things being equal, countries with weaker *effective* property rights (be they related to plant biotechnologies or crop varieties in particular, or more broadly, including the rights encompassed by commercial contract law) and those with smaller sized seed markets are likely to have less PBR applications than countries with larger seed markets and more effective property rights.

To test this notion, we regressed the total number of PBR applications for 42 countries ($i = 1,\ldots., 42$) during the period 1997-2001, $PBRT_i$, against the total value of crop production in 2002, VC_i, the per capita income of each country in 2002, PCI_i, and the period of time in years since varietal rights applications were first lodged, PT_i. The value of crop production was deemed indicative of the value of the corresponding seed markets,[12] per capita income was used as an instrumental variable measuring the effectiveness of PBRs, while the number of years since varietal rights were first on offer proxied the

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[12] For those counties in which we had overlapping data, regressing the value of crop production against the proximate value of seed sales (obtained from ISF 2003) revealed a reasonably strong association—specifically a correlation coefficient of 0.72.

transactions costs involved in securing and maintaining rights (the longer the PBR legislation has been operative, presumably the lower the costs). Our regression results are reported in Table 4. Choice of functional form is always problematic, so we tried two commonly used forms. Regression (1) is a double-log specification, wherein both the dependent and all the independent variables were logged, and regression (2) is a semi-log specification wherein only the right-hand side variables are logged.

[Table 4: *Plant Variety Rights Applications—Regression Results*]

Obvious omitted variable and other empirical issues caution against over-interpreting these results. But they are nonetheless suggestive, not least because well over 40 percent of the cross-country variation in total PBR applications (as indicated by the error sums of squares, R^2) is accounted for by the included variables. Greater numbers of varietal rights applications are associated with more valuable seed markets and more effective IPR protection (as indexed by the per capita income variable, *PCI*). Even after controlling for differences in market size and IPR effectiveness, lowering the transactions costs involved in applying for protection (as proxied by *PT*) also generates statistically significant increases in PBR applications.

Foreign PBR Applications. The UPOV data on varietal rights applications allows us to distinguish between domestic and foreign applicants. Overall, 33 percent (16,548 of a total of 48,675) of the applications filed during 1997–2001 were lodged by foreigners, an indication of the extent of potential spillovers of varietal improvement research done in one locale on seed market and production developments elsewhere in the world. Just on two thirds of the total foreign applications were filed in rich countries and only one percent in low-income countries. Middle-income countries make up the balance, with 26 percent of the foreign applications being lodged in upper-middle income countries.

The *intensity* of foreign participation in domestic varietal rights markets differs markedly. Looking regionally, 61 percent of the PBR applications in upper middle-income countries were lodged by foreigners, 32 percent of the low-income applications are foreign, as are 31 percent of the applications in high-income countries and 22 percent of those lodged in lower-middle income countries. The country-by-country participation of foreigners is even more variable. For example, 84 percent of the applications in Switzerland are foreign as are 82 percent of the Canadian applications. For the United States the share is 54 percent, and lower in other European countries (e.g., 37 percent in the United Kingdom, 16 percent in the Netherlands and Germany, and 11 percent in France). Foreigners account for 23 percent of the PBR applications lodged in Japan.

Regressions (3) and (4) in Table 4 were run to assess if there was any systematic sources of variation in the foreign intensity of national PBR applications using the same variables we used to account for cross-country variation in total PBR applications. Between 22 and 25 percent of the variation in foreign intensity ratios was explained by our variables. All the explanatory variables had the expected signs, with the size of the domestic seed market being the statistically most significant explanator of the degree to which foreigners participate in local PBR markets.

European and United States Trends. Worldwide, seed sales are estimated to be $30 billion annually (ISF 2003). While the economic value of seed markets within the European Union (about $5.2 billion in total) are a little less than U.S. seed sales ($5.7 billion), there have been three times more PBR applications lodged throughout Europe than the United States since 1971 (Table 5). This may partly reflect the different forms of varietal protection effectively on offer in Europe versus the United States. Plant varieties have been subject to utility patents in the United States since 1985, whereas utility patents for plant varieties in Europe is still not an established practice (Henson-Apollonio 2002). Overall, there are more than twice as many plants for which protection is sought under the 1930 U.S. Plant Patent Act as PVP applications, trending toward a higher proportion of plant patent versus PVP applications over time. Another explanation is the historical practice of multiple applications for the same variety among different national jurisdictions in Europe, whereas only one application is required per variety in the United States.

[Table 5: *Plant Breeders Rights Applications in the European Union and the United States*]

Four countries—the Netherlands, France, Germany and the United Kingdom—account for most of the European applications. Adding applications lodged with the Community Plant Variety Office (CPVO) to those filed nationally, the Netherlands accounted for 35 percent of the European total, France 22 percent, Germany 16 percent and the United Kingdom 8 percent.[13] The number of PBR applications filed with the CPVO has increased over time, offsetting declines in the number of applications lodged with national protection offices. In 1996, there were 1,385 applications lodged with the CPVO and a total of 2,766 applications made to individual national systems. By 2000, almost equal numbers

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[13] Prior to April 27, 1995 when the Community Plant Variety Office (CPVO) was established, a breeder seeking protection for a variety throughout the European Union was required to submit an application to each of the member states. Now with a single application to the Community Plant Variety Office (CPVO), a breeder can be granted varietal protection rights throughout the European Union. This European-wide system—CPVO members currently include Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom—operates in parallel with respective national systems, although the owner of a variety cannot simultaneously exploit both a community plant variety right (CPVR) and a national plant breeders right in relation to that variety. Individuals or companies from member states of UPOV, but not a member of the European Union, can also apply, provided that an agent domiciled in the Community has been nominated. The duration of CPVR protection is 25 years for most crops, and 30 years for potato, vine and tree varieties.

of PBR claims were filed with the CPVO and the respective national offices (about 2,000 applications each), and in 2001 CPVO applications (2,158) exceeded those filed with national offices (1,864)(UPOV 2002).

About 85 percent of the PVP applications made in the United States since 1971 were filed by private companies (Table 6). Universities accounted for 11 percent of the total overall, with comparatively few applications from private foundations or government agencies such as the U.S. Department of Agriculture. Just four private firms—Dupont (including Pioneer HiBred), Seminis, Monsanto, and DeltaPine—accounted for 31 percent of the total PBR applications since 1971. The only two public entities to appear among the top 15 applicants are the Texas and Minnesota agricultural experiment stations (ranked 8th and 9th respectively), with up to 150 applicants accounting for the remaining 57 percent of the total. Notably the pattern of PVP applications has become less, not more, concentrated over time. The top four applicants overall accounted for the same share in 1981-90 as in 2001-02, while the share of the 16th and lower ranked applicants grew from 54 to 62 percent.

[Table 6: *US Plant Variety Protection Certificate Applications by Applicant*]

Regarding the types of crops for which varietal protection is sought, oil and cereal crops—in descending order of importance, soybeans, wheat and corn—accounted for 55 percent of the U.S. total since 1971, while vegetable crops and grasses made up another 30 percent (Table 7). Ornamental plants accounted for only 2 percent of the U.S. total. This contrast with European patterns of protection, where 60 percent of the PBR applications lodged with the CPVO since 1995 were for ornamental plants, 23 percent for agricultural crops, and 10 percent for vegetables (Table 8). However, if 88 percent of the U.S. plant patents were for clonally propagated ornamentals (a feasible share), the types of material for which protection is sought in the United States would be in line with European practices.

[Table 7: *US Plant Variety Protection Certificate Applications by Crop Category*]

[Table 8: *CPVO Plant Breeders Rights Applications by Type of Crop, 1996-2002*]

Biotechnology Patenting Patterns

An initial foray into examining the international dimensions of patent activity in biotechnology and specific sectors, such as agriculture and health, is presented in Figure 1. Numbers of patent applications submitted to the World Intellectual Property Organization (WIPO) under the Patent Cooperation Treaty (PCT) (Panel a) and patents granted by the European Patent Office (EPO) (Panel b) are plotted against the year published. For this analysis, patent documents were selected on the basis of the International Patent Classification (IPC) scheme used by the patent offices. Data were obtained for documents satisfying criteria for "biotechnology" and further sub-divided into "agricultural biotechnology" and "health biotechnology."[14] The numbers of the two sub-divisions add to more than for biotechnology as some documents fit into both categories. While initially agricultural biotechnology patent documents exceeded health related documents both at EPO and WIPO, the situation reversed in 1999. Furthermore, the spectacular rise in patent filings in the late 1980s and through the 1990s appears to be leveling off.

[Figure 1: *Biotechnology Patents*]

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[14] For this work, "biotechnology" refers to "the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services", a definition used by the OECD (see "Statistical definition of biotechnology" 12 June 2002 in the Biotechnology, Statistics section of www.oecd.org)

The data presented here contrast with recently reported analyses of Graff et al. (2003) who noted drops in patent grants in plant biotechnology at the EPO after peaking in 1994-1995. The differences may be due to disparities in the definition of plant or agricultural biotechnology. Their definition comprises a description of the scope of technologies, such as genetic engineering of plants, plant genes, and plant breeding methods. They appear to choose only those documents having one of a small subset of IPC codes and specific technology keywords. In contrast, our definition encompasses many aspects of plant biotechnology, including genetic modification of plants, biocides, organismal or enzymic-based methods for preservation of foods, microbiological treatment of water and soil, compositions containing micro-organisms or enzymes, and processes using micro-organisms or enzymes. The definitional differences are highlighted by the order of magnitude difference in the number of documents that satisfy the criteria. For example, in 2000, we obtained 8,859 PCT patent filings and 5,097 EP patent grants for inventions concerning agricultural biotechnology compared with around 625 PCT applications and 50 EP patent grants for the narrower area of "plant biotechnology" reported by Graff et al. (2003).

The percentage of PCT applications in agricultural biotechnology has been on the rise. In 1985, agricultural biotechnology applications were 4.0 percent of the total submitted. By 1990, they were 7.5 percent of the total, and in 2000 had risen to 9.7 percent of the total. In 2000, ag-biotech patents granted in EPO were 18.5 percent of the total granted. Clearly further examination of patent activity with an eye to the commercial and public good consequences encompassing the changing geographical and institutional origins of biotechnology innovations on a global scale, and their spillovers or transfer to other countries, will be sensitive to the patents included in the source set of documents.

5. Crop Biotechnology Use

The evidence on the worldwide dissemination of contemporary, bioengineered crop technologies is usefully viewed in the context of the diffusion of the classically bred crop varieties that preceded them.

Classically Bred Crop Varieties

Worldwide, around 95 percent of major cereal production gains during the past four decades came from increased yields, which have more than doubled since 1961 (Runge et al. 2003). Increasing yields result from increased use of inputs such as agricultural chemicals (including fertilizers, herbicides, and pesticides), irrigation water, and improved crop varieties. In the developed world at least, the growth in crop yields began picking up pace several hundred years ago. Looking in detail at developments in U.S. wheat varieties since 1800, Olmstead and Rhode (2002), for example, estimated that roughly one-half of the U.S. growth in labor productivity in that crop between 1839 and 1909 was attributable to biological innovations. Pardey et al. (1996) showed that wheat varietal change in the United States accelerated during the 20th century—an average of 5.1 commercially successful wheat varieties were introduced each year from 1901 to 1970, the rate jumped to 21.6 varieties per year during the period 1971 to 1990. Moreover, the creation of these new varieties continued to rely heavily on foreign germplasm. By the early 1990s, one-fifth of the total U.S. wheat acreage and virtually all the spring-wheat cropped in California were sown to varieties with CIMMYT ancestry.[15]

There are still long lags between committing R&D dollars and realizing the returns on that investment. Even in the United States it took decades to build up the genetic resource base and train and deploy the scientists skilled in classical genetic manipulation techniques before reaping the really big dividends during the latter half of the 20th century. In the developing world, scientific crop breeding lagged well behind. Beginning in the 1950s and 1960s, improved varieties became increasingly available to farmers and yields rose: wheat went from 1 ton per hectare or less in China and India in the mid-1960s to over 2.5 tons in India, and almost 4 tons in China, by the late 1990s. Table 9 shows the rapid spread of modern rice, wheat and maize varieties throughout the developing world. Asia embraced these new varieties most rapidly, while adoption lagged in Sub-Saharan Africa. A striking feature of these data, however, is the limited uptake of scientifically bred crop varieties throughout most of the developing world as late as 1970. When virtually all the cropped acreage in rich countries was sown to scientifically bred rice and wheat varieties, less than one-third of the developing world's rice acreage and just one-fifth of its wheat acreage were planted to modern forms of these crops.

[Table 9*: Share of Area Planted to Modern Varieties of Rice, Wheat, and Maize*]

For these three food staples much of the crop improvement research involved publicly funded and conducted research. The big innovation of the 1960s and 1970s for rice

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[15] CIMMYT is the Spanish acronym for the International Maize and Wheat Improvement Center based in El Batãn, Mexico. Pardey et al. (1996) estimated that the improved genetic makeup of wheat varieties between 1970 and 1993 was worth almost $43 billion (1993 prices) to the United States—equivalent to 10.6 percent of the present value of wheat production during this period—, and that up to $13.6 billion of that total benefit was attributable to varietal spillins from CIMMYT alone.

and wheat was the development and release of increasing numbers of semi-dwarf varieties by national and international research agencies bred using plant material and crop transformation techniques that were entirely public domain. Almost all the resulting improved varieties were made available without personal or corporate intellectual property rights. The public sector performed most of the research, and in few jurisdictions were IPRs over the varieties themselves or the techniques used to transform them even a legal option at that time.

For corn the story is a different. While publicly bred varieties were, and remain, a feature of this crop, the private sector presence is much more pronounced. Hybrid corn technologies that took off in the United States in the 1930s (and later elsewhere) offered significant protection for the intellectual property embodied in them. This made it possible for breeders to appropriate a larger share of varietal benefits than was possible for the self-replicating forms of varietal transformations featured in rice and wheat.[16] For hybrid corn varieties, as long as the in-bred lines were kept secret (and laws were in place in the United States and elsewhere to help preserve these trade secrets), the cost of imitation was prohibitively large enabling inventors to appropriate significant shares of the benefits stemming from their efforts.

Table 9 indicates the developing-country uptake of modern maize varieties has also been substantial, but less extensive than the move to improved forms of rice and wheat worldwide. This could partly be due to the greater proprietary (and private sector) nature of

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[16] Hybrid technologies were also pursued for rice and wheat but less extensively so. Knudson and Ruttan (1988) document efforts to develop hybrid wheats in the United States. Hybrid rice is grown extensively in China, beginning in the mid-1960s. Since then, the area under hybrid rice has increased steadily to about 23 percent in 1981 and 61 percent in 2001 (Fan et al. 2003). Notably, profit potentials were not a contributing factor to the development of this technology in China where the research was a government undertaking.

maize varietal changes, but a whole host of other influences could be operative as well. About 86 percent of the improved acreage world wide is sown to hybrids, the rest to open pollinated varieties.

Varietal Spillovers. While the agroecological specificities of much agricultural R&D—and especially many crop biotechnologies—limits the geographical scope of agricultural innovations, there is overwhelming evidence that spatial spillovers of technologies have played a pivotal part in productivity improvements worldwide. In reviewing the economic studies of this phenomenon, Alston (2002) concluded that interstate or international R&D spillovers might account for half or more of the total measured productivity growth.

Spillovers of crop varietal technologies have flowed in all sorts of directions. Looking at the spillins to the United States of varietal improvement research done at the international research centers, specifically CIMMYT in Mexico and IRRI in the Philippines, Pardey et al. (1996) estimated that the U.S. economy gained at least US$3.4 billion and up to US$14.6 billion—depending on the benefit attribution methods deployed—from 1970 to 1993 from the use of improved wheat varieties developed by CIMMYT. In the same 23-year period, they found that the U.S. economy realized at least US$30 million and up to US$1 billion through the use of rice varieties developed by IRRI.

In more recent research, Pardey et al. (2002) quantified the benefits from crop improvement research in Brazil and attributed them between the Brazilian national agricultural research agency (Embrapa), other public and private agencies operating in Brazil, and spillovers from the CGIAR and the United States. They found that 64 percent of the total benefits from varietal improvement for upland rice in Brazil (which had a present value of US$1,683 million in 1999 dollars over 1984-2003), were from non-Embrapa sources. Likewise, 67 percent of the total benefits from varietal improvement research for edible beans (which had a present value of US$677 million in 1999 dollars over 1985-2003) came from non-Embrapa sources, mostly within Brazil, whereas 77 percent of the total benefits from varietal improvement research for soybeans (which had a present value of US$12,473 million in 1999 dollars over 1981-2003) was due to non-Embrapa sources, with 22 percent of the benefits attributable to spillins from the United States.

Bioengineered Crop Varieties

Where the crop varieties and bioengineered traits embodied in them perform well and been given approval for commercial use, the rate of uptake has been rapid (although contrary to some claims, not entirely unprecedented, even for biological innovations used in agriculture).[17] James (2002) estimates that 58.7 million hectares were planted to bioengineered crops worldwide in 2002, an increase from 52.6 million hectares in the previous year and well up on the 2.8 million hectares planted in 1996.[18]

Despite this growth, the geographical, crop, and technological scope of bioengineered crops is still small. In 2002, the preponderance of the area under these crops consisted of bioengineered soybean (62 percent of the total bioengineered cropping area sown to this crop): 21 percent of the area was sown to bioengineered maize, 12 percent to cotton, and 5 percent to canola. Just 4 countries accounted for 99 percent of the global total in 2002 (Figure 2). Two-thirds of this global total was planted in the United States, 22

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[17] Griliches (1957) studied the uptake of hybrid corn technologies in the United Sates and showed that Iowa, for example, went from 0 to 50 percent of the state's corn acreage sown to hybrid varieties in just 6 years (1932 to 1938), reaching 90 percent by 1940.

[18] The Flavr-Savr™ tomato, genetically engineered to delay softening so the tomato could ripen on the vine and retain its "fresh picked" flavor was the first bioengineered crop to be grown commercially (in 1994).

percent in Argentina, 6 percent in Canada, and 3 percent in China. Two traits dominate the picture—herbicide tolerance (mainly in soybeans and canola) and insect tolerance (mainly in corn and cotton)—with some limited use of bioengineered viral resistance in papaya and squash.

[Figure 2: *Area Sown to Bioengineered Crops Worldwide*]

Figure 2 shows that the developing-country share of global bioengineered crop area has grown: from 14 percent of the world total in 1997 to about 27 percent in 2002. Notably, it is plantings in just four countries—soybeans in Argentina, and cotton in China, South Africa, and for the first time in 2002, India—that accounts for the lion's share of the developing-country bioengineered acreage. Finding bioengineered traits that deal successfully with local production constraints is one thing, expressing them in specific crop varieties that compete well locally against landraces and conventionally bred varieties of the same crop (absent the bioengineered trait) is an altogether other thing. Not surprisingly, the bioengineered traits are being grown in developing-country areas that are agroecologically similar to the rich countries for which the traits were first developed, and in most cases involve the identical crop varieties.[19] This is precisely where the spillover costs are smallest (consisting mainly of local screening and regulatory approval costs along with the costs of marketing the technology). That is, disseminating these particular bioengineered crop varieties involves only adaptive or imitative technology development costs beyond the initial discovery costs—a much smaller cost than inventing entirely new

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[19] For example, all the officially approved Monsanto/DeltaPine bioengineered cotton varieties grown in China are the same varieties grown in the United States, while most of the bioengineered Chinese varieties are based on older DeltaPine varieties introduced into China in the 1940s and 1950s (Pray et al. 2002). Likewise the transgenic cotton varieties grown in Mexico are from the United States (Traxler et al. 2003), and in South Africa, NuCotn 37-B, an American variety, is widely used (Thirtle et al. 2003).

bioengineered traits and successfully expressing those traits in locally superior varieties of locally important crops.

The site-specificity of many agricultural biotechnologies arises from agroecological aspects, which defines the size of the relevant market in a way that is much less common in other industrial R&D. As Alston and Pardey (1999) described, one way to think of this is in terms of the unit costs of making local research results applicable to other locations (say, by adaptive research), which must be added to the local research costs. Such costs grow with the size of the market.[20] Economies of size, scale, and scope in research mean that unit costs fall with size of the R&D enterprise, but these economies must be traded off against the diseconomies of distance and adapting site-specific results (the costs of "transporting" the research results to economically "more distant" locations). Thus, as the size of the research enterprise increases, unit costs are likely to decline at first (because economies of size are relatively important) but will eventually rise (as the costs of economic distance become ever-more important).

Given the United States dominates the world totals, its trends are worth scrutinizing. Table 10 shows the trend in bioengineered acreage in the United States since 1996, differentiating among crops and technology types. Ranked in terms of total acreage, the world and U.S. crop relativities for 2002 are the same—soybeans dominate, followed by corn then cotton. However, the intensity of use of bioengineered versus classically bred crops differs between the Unites States and the rest of the world.

[Table 10: *Bioengineered Cropping Patterns in the United States*]

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[20] A close analogy can be drawn with spatial market models of food processing in which processing costs fall with throughput but input and output transportation costs rise with throughput so that when the two elements of costs are combined a U-shaped average cost function is derived (e.g., Sexton 1990).

The United States uniformly makes more intensive use of bioengineered crops than the rest of the world (Figure 3). While 77 percent of the U.S. canola crop was sown to bioengineered varieties in 2002, the corresponding rest-of-world share was 28 percent. Likewise, bioengineered soybeans covered 71 percent of the U.S. soybean acreage and only 28 percent of the rest-of-world soybean area.[21] For cotton the corresponding shares were 71 percent for the United States and 11 percent for the rest of the world; for corn it was 34 percent for the United States and 1.4 percent elsewhere. This reflects both technology and market realities. While the dominant bioengineered traits (to date targeting mainly budworm/boll weevil complexes in cotton, European stem borers in corn, and Roundup® and Liberty Link® resistance in soybeans and canola) have yield enhancing or cost reducing consequences for rest-of-world farmers, they are especially consequential for U.S. producers. And, given their earlier regulatory approval in the United States, these traits are now incorporated into a myriad of locally optimized crop varieties.

[Figure 3: *Bioengineered Cropping Intensities—United States vs Rest-of-the-World, 2002*]

6. Summing Up

In this paper we showed that the preponderance of research conducted on bioengineered crops is carried out in rich countries (which is where the overwhelmingly large share of biotechnology acreage is still to be found), and much of the product development work is done by private firms. Moreover, most of the bioengineered traits and the specific crop varieties that are planted in developing countries are spillovers from, or adaptive

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[21] In some U.S. states, the share of 2002 soybean acres planted to Roundup Ready® soybeans approached 90 percent (Marra, Pardey and Alston 2003).

modifications of, rich-country research. Only when we achieve a reasonable rate of inventor appropriability of the returns to the technologies that are applicable in less-developed countries, combined with an economic infrastructure that facilitates adoption of those technologies, can we expect a significant private-sector role to emerge in the poorer parts of the world.

We also drew attention to the comparatively low rates of investment in public agricultural R&D in developing countries, where government revenues may be comparatively expensive (because it is comparatively expensive to raise government revenues through general taxation measures), or have a comparatively high opportunity cost.[22] Many less-developed countries are characterized by under-investment in a host of other public goods, such as transportation and communications infrastructure, schools, hospitals, and the like, as well as agricultural science. These other activities, like agricultural science, might also have high social rates of return.[23]

Even among the rich countries of the world, most have not had very substantial private or public agricultural science industries; so why should we expect the poorest countries of the world to be more like the richest of the rich in this regard? [24] The lion's

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[22] Alston and Pardey (2003) develop these and related ideas in more detail.

[23] As Alston and Pardey (2003) point out, there are also political factors at play here. In rich countries, agriculture is a small share of the economy and any individual citizen bears a negligible burden from financing a comparatively high rate of public investment in agricultural R&D (for instance, in the United States expenditure of $2 billion on agricultural R&D amounts to less than $10 per person per year). The factors that account for high rates of general support for agriculture in the industrialized countries can also help account for their comparatively high public agricultural research intensities. In many less-developed countries, where agriculture represents a much greater share of the total economic activity, and where per capita incomes are much lower, a meaningful investment in public agricultural research might have a much more appreciable impact on individual citizens—and the problem is that this burden is felt now, while the payoff it promises may take a long time to come, and will be much less visible when it does.

[24] As noted by Pardey and Beintema (2001), the geographical concentration among countries of particular classes of research—for instance research into agricultural chemicals or machinery—is even greater than that for agricultural R&D in total.

share of the public (as well as private) investment in agricultural science has been undertaken by a small number of countries, and these have also been the countries that have undertaken the lion's share of scientific research, more generally.[25] An important consideration is economies of size, scale, and scope in research, which influence the optimal size and portfolio of a given research institution. In some cases the "optimal" institution may efficiently provide research for a state or region within a nation, but for some kinds of research the efficient scale of institutions may be too great for an individual nation (e.g., see Byerlee and Traxler 2001). Many nations may be too small to achieve an efficient scale in much if any of the relevant elements of their interests' in crop biotechnology research, except perhaps in certain types of adaptive research.

Historically there have been large spillovers of improved varieties (and the technology and know-how embodied in them) among countries. However, as Alston and Pardey (2003) emphasize, we cannot presume that the rich countries of the world will play the same roles as in the past. In particular, countries that in the past relied on technological spillovers from the North may no longer have that luxury available to them in the same ways or to the same extent. This change can be seen as involving three elements:

- The types of technologies being developed in the rich countries may no longer be as readily applicable to less-developed countries as they were in the past (the agenda in richer countries is shifting away from areas like yield improvement in major crops to other crop characteristics and even to non-agricultural issues)
- The private presence in rich country agricultural R&D has increased and many biotech companies are not as interested in developing technologies for many less-developed country applications, and even where they have such technologies

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[25] Pardey and Beintema (2001) report that the United States conducted 42 percent of the world's total investment in all science in 1995.

available, often they are not interested in pursuing potential markets in less developed countries, for a host of reasons

- Those technologies that are applicable and available are likely to require more substantial local development and adaptation, calling for more sophisticated and extensive forms of scientific research and development than in the past (for instance, more advanced skills in modern biotechnology or conventional breeding may be required to take advantage of enabling technologies or simply to make use of less-finished lines that require additional work to tailor them to local production environments)

In short, different approaches may have to be devised to make it possible for less-developed countries to achieve equivalent access, to tap into technological potentials generated by rich countries; and in many instances less-developed countries may have to extend their own R&D efforts farther upstream, to more fundamental areas of the science.

Some argue that strengthening intellectual property regimes in poorer countries is one way of stimulating investments in developing-country R&D as well as efforts to commercialize crop technologies developed elsewhere. Others argue that the number and breadth of patents, plant breeders' rights and other forms of intellectual property is already hindering the R&D required to tackle food security concerns of poor countries. Binenbaum et al. (2003) studied the situation for the 15 staple food crops of the world and concluded there was undue concern that intellectual property rights were currently limiting the freedom to operate for research on developing-country food staples. This paper reinforced the IP evidence they assembled for some key enabling technologies used in agriculture—IPRs concerning crop biotechnologies are overwhelming concentrated in rich-country jurisdictions, meaning poor-country research can proceed largely unencumbered by any intellectual property restraints. Binenbaum et al. (2003) also showed that bilateral trade in food staples from poor- to rich-country jurisdictions—where the IP was presumptively in force—was meager (and limited to just a few crops from a few poor countries), meaning the results of this research can be disseminated and used with few if any IP impediments if the intent is to feed and cloth poor people in poor countries.

As things stand today, the constraints to conducting modern crop biotechnology research in developing countries appear to lie largely beyond IP concerns. Market considerations limit substantial private interests for many crops in many developing countries, and the intensity of public investments is generally low for reasons that do not seem likely to change soon.[26] Intellectual property rights may have a role to play in stimulating efforts to commercialize crops in developing countries, especially helping to harness spillin technologies developed elsewhere, but, at least in the nearer term, they will be no substitute for rich and poor country governments alike reinvesting in the R&D required to maintain and continue adding to the crop yields necessary in the decades ahead.

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[26] Some even see a scientific apartheid taking shape, with large parts of the developing world being left behind or denied the prospects science has to offer for growth, development, and prosperity (Serageldin 2001).

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Table 1*: Private and Public Agricultural R&D Investments, circa 1995*

	Expenditures			Shares		
	Public	Private	Total	Public	Private	Total
	(*million 1993 international dollars*)			(*percent*)		
Developing countries	11,469	672	12,141	94.5	5.5	100
Developed countries	10,215	10,829	21,044	48.5	51.5	100
Total	*21,692*	*11,511*	*33,204*	*65.3*	*34.7*	*100*

Source: Pardey and Beintema (2001).

Note: Drawing together estimates from various sources meant there were unavoidable discrepancies in what constitutes "private" and "public" research. For example, the available data for Asia includes nonprofit producer organizations as part of private research, whereas Pardey and Beintema opted to include research done by nonprofit agencies as part of public research in Latin America and elsewhere when possible.

Table 2: *Field Trials of Bioengineered Crops by Regions of the World*

	Number of Approved Events/crops[a]			Field Trials[a]			
				Number of		Share of	
	Countries	Events	Crops	Countries	Trials	Global total	Private in-country total
						(percentage)	
Developed Countries	19	160	14	20	9,701	84.2	na
United States	1	49	14	1	6,337	55	83.4
Canada	1	49	4	1	1,233	10.7	63.9
All others	17	62	5	18	2,131	18.5	na
Developing Countries	8	23	4	19	1,822	15.8	na
Argentina	1	7	3	1	393	3.4	90.1
China	1	5	4	1	45	0.4	na
All others	6	11	3	17	1,384	12	na
Total	*27*	*183*	*14*	*39*	*11,523*	*100*	*na*

Source: Pardey and Beintema (2001).

Note: na stands for not available.

a. Data through to December 2000 where available. For the United States and Canada, and perhaps other countries, a single "trial" may consist of tests conducted at multiple (maybe many) different sites.

Table 3: *Plant Breeders Rights Applications—Countries Grouped by Per Capita Income, 1971-2002*

Income group	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2002	Total
					(*counts*)			
Number of Applications								
High income country (21)[a]	1,491	6,607	10,865	20,431	31,362	34,276	12,981	118,013
Upper middle income country (9)	66	206	402	1,658	3,555	5,493	2,515	13,895
Lower middle income country (4)	25	34	57	57	131	2,437	1,440	4,181
Low income country (2)	-	-	-	1	27	117	-	145
Total	*1,582*	*6,847*	*11,324*	*22,147*	*35,075*	*42,323*	*16,936*	*136,234*
Application rates					(*counts per year*)			
High income country (21)	298	1,321	2,173	4,086	6,272	6,855	6,491	3,688
Upper middle income country (9)	13	41	80	332	711	1,099	1,258	434
Lower middle income country (4)	5	7	11	11	26	487	720	131
Low income country (2)	-	-	-	0	5	23	-	5
Total	*316*	*1,369*	*2,265*	*4,429*	*7,015*	*8,465*	*8,468*	*4,257*
Share of Total					(*percentage*)			
High income country (21)	94	96	96	92	89	81	77	87
Upper middle income country (9)	4	3	4	7	10	13	15	10
Lower middle income country (4)	2	0	1	0	0	6	9	3
Low income country (2)	0	0	0	0	0	0	0	0
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Source: Authors compiled from data obtained from UPOV (2003).

a. Bracketed numbers indicate number of countries in each income class based on the classification by the World Bank (2002).

Table 4*: Plant Variety Rights Applications—Regression Results*

	Dependent variable Total PBR (PBRT)		Dependent variable Foreign PBR (PBRF)	
Variable Name/Definition	log(PBRT)	PBRT	Log(PBRF)	PBRF
Regression number	(1)	(2)	(3)	(4)
VC/log value of crop production (US$)	0.544 (0.122)**	475.7 (119.9)**	0.294 (0.175)*	152.2 (50.4)**
PCI/log GDP per capita (US$)	0.267 (0.367)	755.5 (350.6)*	0.470 (0.513)	291.1 (147.4)*
PT/History of PVP implementation (years)	0.044 (0.017)**	28.96 (16.57)*	0.053 (0.024)**	4.908 (6.968)
Constant	-5.676 (4.224)	-14040.5 (4153.0)**	-5.179 (6.075)	-4822.1 (1746.2)**
Number of observations	35	35	35	35
F value	11.27	9.32	4.12	4.8
Adjusted R^2	0.475	0.423	0.215	0.251

Source: Authors calculations.

Note: Standard errors in parenthesis.

* indicates significantly different from zero at the 10 percent level of confidence.

** indicates significantly different from zero at the 5 percent level of confidence.

Table 5: *Plant Breeders Rights Applications in the European Union and the United States*

Country/region	Before 1970	1971-75	1976-80	1981-85	1986-90	1991-95	1996-2000	2001-02	Total
				(*counts*)					
European Union[a]	**598**	**843**	**4,369**	**6,374**	**13,254**	**20,290**	**19,232**	**7,471**	**72,431**
Netherlands	140	213	518	1,369	4,252	6,838	4,278	1,386	18,994
France	-	-	2,151	2,046	3,206	3,395	2,326	686	13,810
Germany	212	244	436	1,007	2,275	3,042	1,306	472	8,994
UK	2	6	8	6	500	2,365	1,334	359	4,580
Italy	-	-	-	-	-	1,349	384	67	1,800
Others	244	380	1,256	1,946	3,021	3,301	960	121	11,229
CPVO[b]	-	-	-	-	-	-	8,644	4,380	13,024
United States	**3,495**	**1,313**	**1,587**	**2,039**	**3,111**	**3,594**	**5,609**	**1,908**	**22,656**
Plant Variety Protection	-	600	614	934	1,228	1,505	1,943	562	7,386
Plant Patent	3,495	713	973	1,105	1,883	2,089	3,666	1,346	15,270

Source: Authors compiled from data obtained from the US Patent Statistics Report and Technology Assessment and Forecast Report for the US Plant Patent, the US Plant Variety Protection Office Crop Database for the US plant variety protection, UPOV (2003) for data of European Union countries, and CPVO (2002) for CPVO data.

a. Footnote 13 includes a list of the countries included in this total.

b. CPVO stands for Community Plant Variety Office. See CPVO (2002) for further details. Around 35 percent of these applications are lodged from the Netherlands, 16 percent from Germany, 14 percent from France, 19 percent from elsewhere in the European Union and 16 percent from outside the European Union since it was first implemented in 1995.

Table 6: *US Plant Variety Protection Certificate Applications by Applicant*

	Counts of PVP applications					Share of PVP applications				
	1971-80	1981-90	1991-00	2001-02	Total	1971-80	1981-90	1991-00	2001-02	Total
	(*number of applications*)					(*percentages*)				
Types of institutions										
Private	1,027	1,900	2,941	436	6,304	85	88	85	78	85
University	138	229	358	84	809	11	11	10	15	11
Foundation	43	19	96	18	176	4	1	3	3	2
Public	6	14	53	24	97	0	1	2	4	1
Total	*1,214*	*2,162*	*3,448*	*562*	*7,386*	*100*	*100*	*100*	*100*	*100*
Top 15 applicants										
Dupont	36	165	508	102	811	3	8	15	18	11
Seminis	110	208	281	36	635	9	10	8	6	9
Monsanto	132	252	204	33	621	11	12	6	6	8
Delta and Pine Land Company	18	32	129	10	189	1	1	4	2	3
Advanta	48	83	48	3	182	4	4	1	1	2
Exelixis	38	89	42	-	169	3	4	1	0	2
Turf-Seed, Inc	5	53	67	3	128	0	2	2	1	2
Texas Agricultural Experiment Station	11	20	36	7	74	1	1	1	1	1
Minnesota Agricultural Experiment Station	5	17	29	7	58	0	1	1	1	1
W. Atlee Burpee Company	49	6	1	-	56	4	0	0	0	1
Del Monte Corporation	-	2	53	-	55	0	0	2	0	1
Pickseed West Inc.	5	24	19	4	52	0	1	1	1	1
Stoneville Pedigreed Seed Company	13	11	19	8	51	1	1	1	1	1
Cebeco	2	18	28	1	49	0	1	1	0	1
FFR Cooperative	11	13	25	-	49	1	1	1	0	1
Others	731	1,169	1,959	348	4,207	60	54	57	62	57
Total	*1,214*	*2,162*	*3,448*	*562*	*7,386*	*100*	*100*	*100*	*100*	*100*

Source: Authors' calculations based on data from US Plant Variety Protection Office Crop Database.

Note: Data reported based on all mergers and acquisitions activities as of November 2002.

a. Includes applications lodged jointly with Monsanto (which total 176 through to end of 2002).

Table 7: *US Plant Variety Protection Certificate Applications by Crop Category*

Crop	Counts					Share				
	1971-80	1981-90	1991-00	2001-02	Total	1971-80	1981-90	1991-00	2001-02	Total
	(*number of applications*)					(*percentages*)				
Oilcrops	367	587	957	140	2,051	30	27	28	25	28
Cereal	210	508	1,062	200	1,980	17	23	31	36	27
Vegetable	209	410	453	65	1,137	17	19	13	12	15
Grass	175	341	489	80	1,085	14	16	14	14	15
Pulses	146	198	224	32	600	12	9	6	6	8
Ornamental plants	42	40	69	5	156	3	2	2	1	2
Roots	-	-	116	31	147	0	0	3	6	2
Fruit	19	30	40	6	95	2	1	1	1	1
Spices	28	30	17	1	76	2	1	0	0	1
Tobacco	14	14	19	1	48	1	1	1	0	1
Others	4	4	2	1	11	0	0	0	0	0
Total	*1,214*	*2,162*	*3,448*	*562*	*7,386*	*100*	*100*	*100*	*100*	*100*

Source: Authors' calculation based on data from US Plant Variety Protection Office Crop Database.

Table 8: *CPVO Plant Breeders Rights Applications by Type of Crop, 1996-2002*

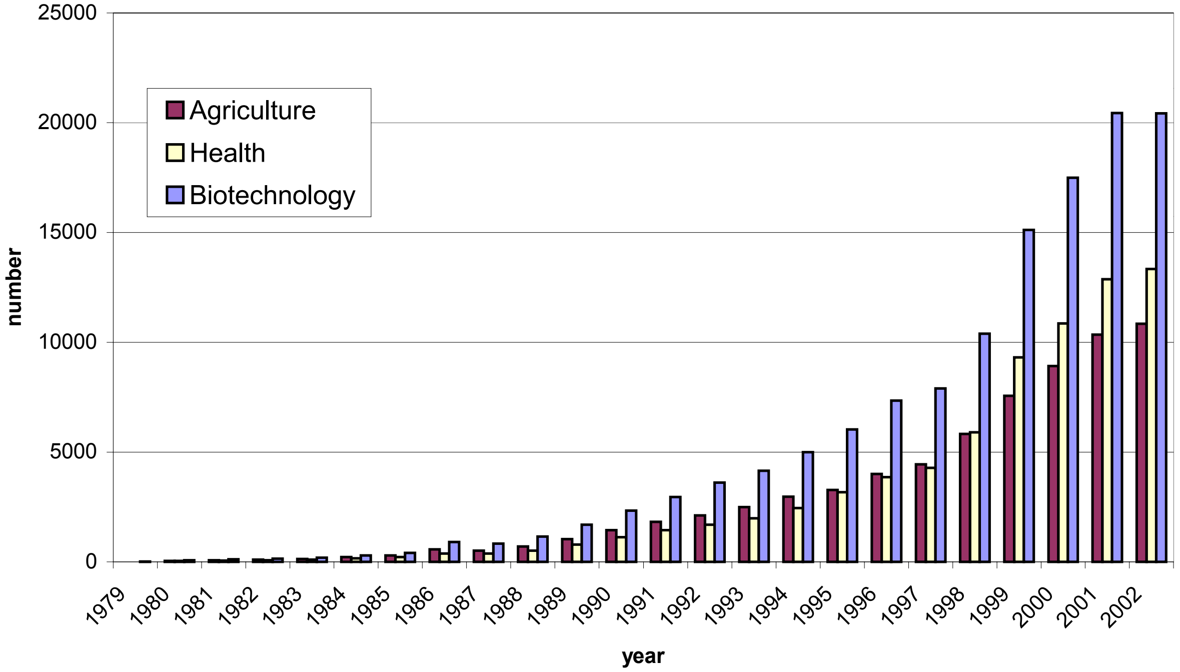
Species	1996	1997	1998	1999	2000	2001	2002	Total
Number of Applications				(*counts*)				
Agricultural crops	365	343	404	407	406	440	415	4,104
Vegetable crops	123	148	214	181	244	181	177	1,833
Ornamental plants	834	953	1,100	1,194	1,266	1,415	1,504	10,636
Fruits	61	77	104	95	95	117	125	973
Others	2	9	13	4	2	5	1	44
Total	*1,385*	*1,530*	*1,835*	*1,881*	*2,013*	*2,158*	*2,222*	*17,590*
Share of Total				(*percentage*)				
Agricultural crops	26	22	22	22	20	20	19	23
Vegetable crops	9	10	12	10	12	8	8	10
Ornamental plants	60	62	60	63	63	66	68	60
Fruits	4	5	6	5	5	5	6	6
Others	0	1	1	0	0	0	0	0
Total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

Source: CPVO (2002).

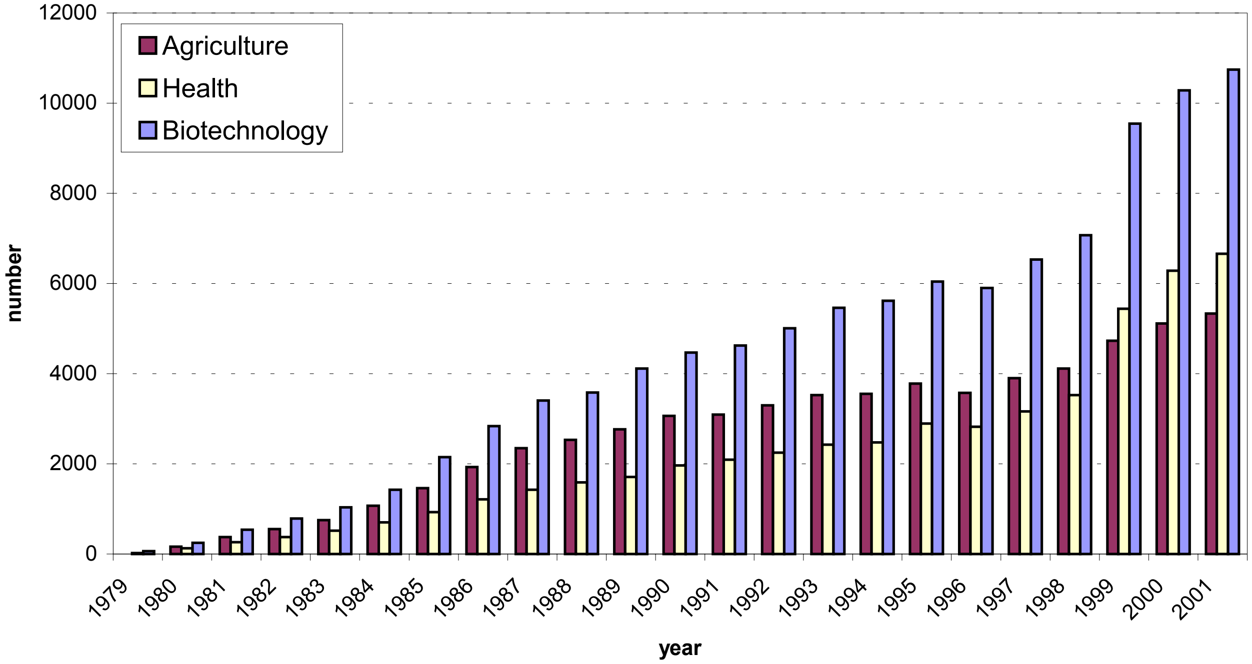
Note: Totals in right hand column include applications lodged in 1995-2002.

Figure 1: *Biotechnology Patents*

Panel (a) PCT Applications



Panel (b) EP-B Grants



Source: Compiled by authors from CAMBIA-IP Resource database

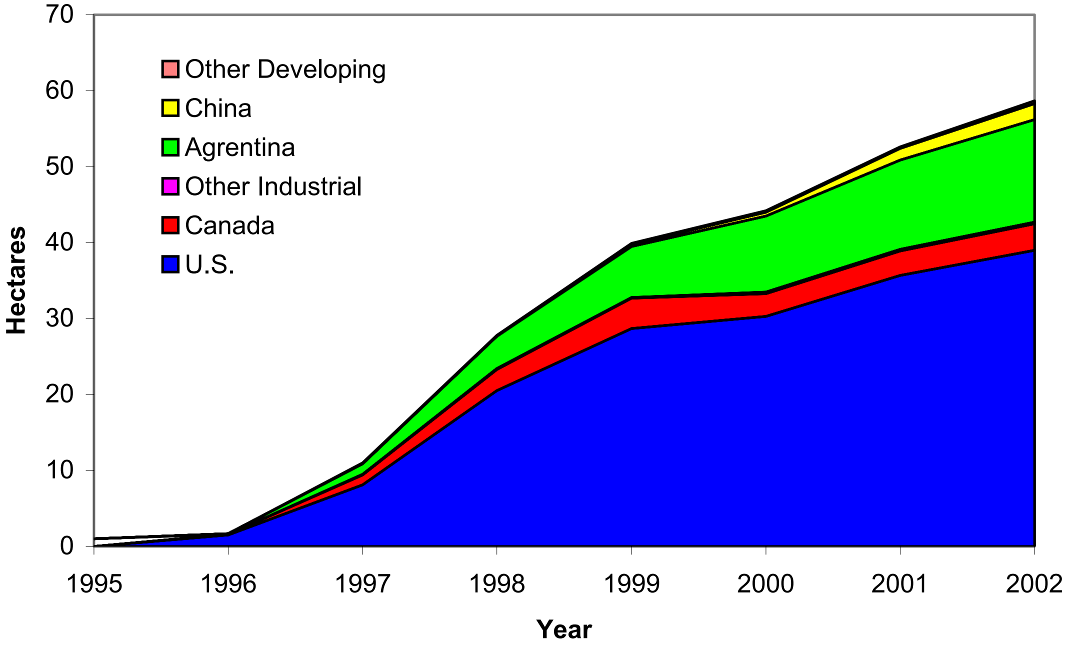
Table 9*: Share of Area Planted to Modern Varieties of Rice, Wheat, and Maize*

	Rice			Wheat				Maize	
Regions	1970	1983	1991	1970	1977	1990	1997	1992	1996
				(*percentage of area planted*)					
Sub-Saharan Africa	4	5	n.a.	5	22	52	66	37	46
West Asia/North Africa	0	11	n.a.	5	18	42	66	26	n.a.
Asia (excluding China)	12	48	67	42	69	88	93	42	64
China	77	95	100	n.a.	n.a.	70	79	97	99
Latin America	4	28	58	11	24	82	90	49	45
All Developing Countries	30	59	74	20	41	70	81	58	62

Source: For rice and wheat, Runge et al. (2003) based on data from Byerlee and Moya (1993), Byerlee (1996), Heisey, Lantican, and Dubin (1999). For maize, Morris (1998), and Morris (2002).

Note: n.a. indicates not available. Modern varieties of rice and wheat refer mainly to semi-dwarf varieties; for maize it includes hybrid and improved open pollinated varieties.

Figure 2: *Area Sown to Bioengineered Crops Worldwide*



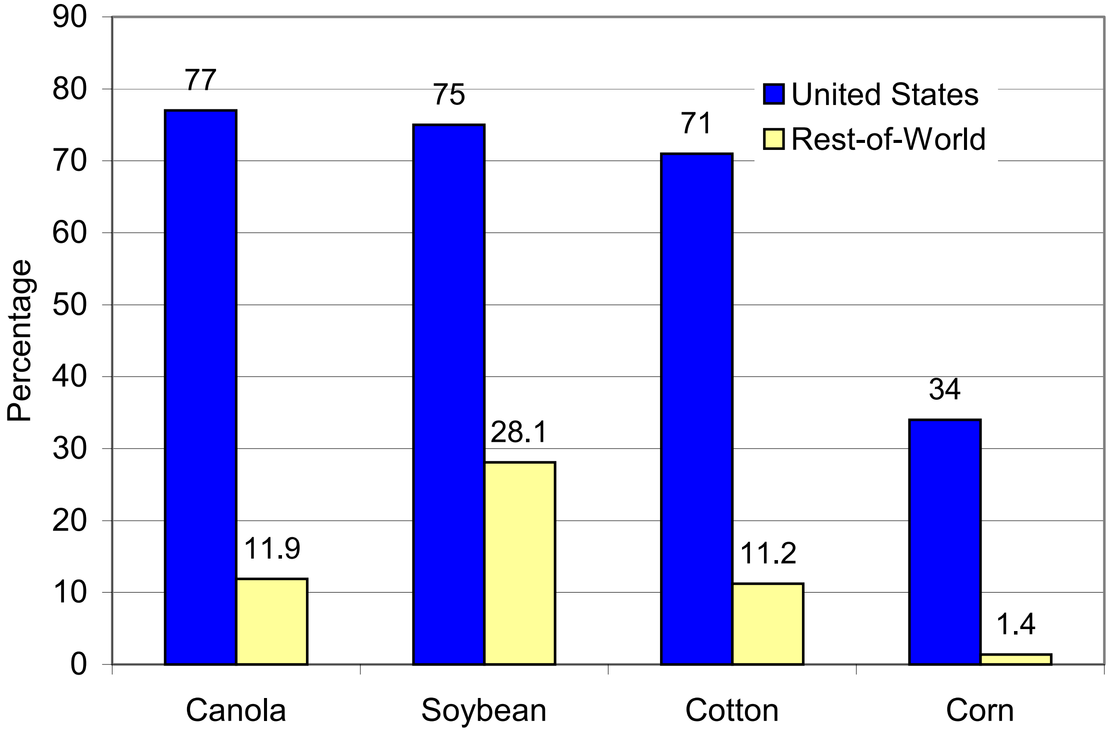
Source: Authors based on data from James (various years).

Table 10: *Bioengineered Cropping Patterns in the United States*

	1996	1997	1998	1999	2000	2001	2002	2003
				(thousands of acres)				
Bioengineered acres								
Corn	3,536	9,547	22,704	26,249	19,895	19,696	26,878	31,626
Bt corn	1,125	6,097	15,432	20,055	14,324	13,635	17,392	19,767
Herbicide-tolerant	2,411	3,450	7,272	6,194	4,775	5,303	7,115	8,697
Stacked	-	-	-	-	796	758	1,581	3,163
Soybean								
Herbicide-tolerant	4,728	12,045	32,142	41,169	40,231	50,391	55,319	59,659
Cotton	2,413	3,521	5,561	11,066	9,487	10,880	9,909	10,165
Bt cotton	2,097	2,071	2,173	4,804	2,333	2,050	1,814	1,949
Herbicide-tolerant	316	1,450	3,388	6,262	4,044	4,888	5,025	4,456
Stacked	-	-	-	-	3,110	3,784	3,071	3,759
				(percentages)				
Bioengineered share								
Corn	4.4	11.9	28.1	33.9	25	26	34	40
Bt corn	1.4	7.6	19.1	25.9	18	18	22	25
Herbicide-tolerant	3	4.3	9	8	6	7	9	11
Stacked	0	0	0	0	1	1	2	4
Soybean								
Herbicide-tolerant	7.4	17	44.2	55.8	54	68	75	81
Cotton	16.8	25.5	43	74.4	61	69	71	73
Bt cotton	14.6	15	16.8	32.3	15	13	13	14
Herbicide-tolerant	2.2	10.5	26.2	42.1	26	31	36	32
Stacked	0	0	0	0	20	24	22	27

Source: Fernandez-Cornejo and McBride (2002) for years prior to 2000. All other years from USDA, NASS (2003).

Figure 3: *Bioengineered Cropping Intensities—United States vs Rest-of-the-World, 2002*



Source: Authors based on data from USDA, NASS (2003) and James (2002).

Note: Data represent share of respective crop acreage in each region sown to bioengineered varieties.