The Importance of Intellectual Property Rights in the International Spread of Private Sector Agricultural Biotechnology

Carl E. Pray, Ramu Govindasamy, and Ann Courtmanche

Professor, Associate Professor, and Research Associate
Department of Agricultural, Food and Resource Economics
Cook College, 55 Dudley Road, Rutgers University,
New Brunswick, NJ 08901
Phone: (732) 932-9155, Extension 219
Fax: (732) 932-8887
Email: Pray@aesop.rutgers.edu

Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Montreal, Canada, July 27-30, 2003

The Importance of Intellectual Property Rights in the International Spread of Private Sector Agricultural Biotechnology

Abstract

The purpose of this study is to provide an overview of the current status of research and commercial use of genetically modified (GM) crops worldwide and to quantify the importance of various policies, particularly intellectual property rights, to the spread of biotechnology research and commercial products. Data collected for this paper show that most of the applied agricultural biotech research is conducted by the private sector of which a substantial portion is by multinational corporations. Econometric analysis of this data finds that plant breeders' rights and the ability to patent plants are associated with the spread of applied biotech research.

The Importance of Intellectual Property Rights in the International Spread of Private Sector Agricultural Biotechnology

Introduction

Plant breeders, biotechnology scientists, and the firms that own biotechnology inventions try to charge royalties for use of their inventions or prevent people or firms from copying their inventions so that they can sell their invention at a high enough price to profit from their investment in research and development. They control the use of their inventions by using legal means such as patents, plant breeder's rights, and trademarks. They also control their use by keeping inventions or key parts of their inventions secret, which in some countries are protected by trade secrecy law. They also protect their inventions by biological means such as putting new characteristics into hybrid cultivars or including other technical means to prevent copying (i.e. the genetic use restriction techniques (GURTs) or Terminators). In a few cases countries give one company a monopoly on the production and sales of a particular commodity.

Laws to protect new plant varieties and biotech inventions, spread rapidly in developing countries in the late 1990s. Their spread was accelerated by the intellectual property rights (IPRs) component of the World Trade Organization (WTO) agreement which required signatories to put in place some type of *sui generis* system of plant variety protection and patent protection for biotechnology inventions by 2000 (some developing countries have until 2005 to implement these IPRs). As of December 1, 2001 49 states were members of the International Union for the Protection of New Varieties of Plants (UPOV), which indicates that they have some plant variety protection. A number of countries still exclude novel plants and animals from patent coverage, although many of them do allow patenting of novel microbes as is required by WTO.

Although there is general agreement that utility patents have been an important stimulus to biotechnology research and product development in the U.S., there is no consensus about whether patents and other forms of intellectual property rights such as plant breeder's rights are an important stimulus to biotechnology research elsewhere in the world. In Europe patents on many types of biotechnologies were not allowed until the late 1990s. Despite this there has been substantial investment in biotech research by private companies in Europe although not as much as in the U.S. In developing countries there is considerable resistance to patents on biotechnology and to plant breeders rights. Countries that have joined the World Trade Organization are obligated to pass some type of plant breeder's rights and provide protection for biotechnology inventions. Many developing countries, however, have resisted actually passing such laws. People fear that both types of intellectual property rights will lead to new technology for farmers but are primarily means by which the major U.S. and European life science companies can dominate agricultural biotechnology and the seed industry in developing countries in the 21st Century.

The questions that this paper will try to answer are whether IPRs provide a stimulus to biotechnology research and technology transfer and who would benefit if a country's IPRs were strengthened. To answer these questions in the second section below, we first examine the spread of GM crops and biotechnology research. Section three of the paper discusses the econometric modeling used in this paper followed by data description from a cross section of countries. The fourth section of the paper reports the results of econometric modeling of the relationship between IPRs and biotech research. Finally, in section five we draw some conclusions for policy makers.

The Spread of GM Crops and Biotechnology Research

Commercial Use of GM Crops Worldwide

Since 1996, the year in which genetically modified (GM) crops were first commercially planted in the U.S., there has been a steady increase in worldwide acreage planted. In 2000 roughly 60 million ha. were planted in eighteen countries up from 40 million ha. in 12 countries in 1999. Table 1 provides estimated area of commercial GM crops planted in 1999 and 2000 by country. The U.S. grew the most at 40 million ha. followed by Argentina and Canada with more than 10 million ha. and 3 million ha., respectively. All of the GM crops approved for commercial use have been marketed by the private sector, except in China where a number of commercially successful public GM varieties are in use. China has been growing GM crops commercially since about 1990. In 2000, nearly 0.7 million ha. of GM crops were planted there. In addition to these four countries, 14 other countries have planted between 1,000-125,000 ha. of GM crops. These include the European and Eastern European nations such as Bulgaria, France, Germany, Portugal, Romania, Spain, and Ukraine. In addition, both the Russian Federation and former Yugoslav Republic expect to sell GM crops commercially in 2001. In South and Central America, Brazil, Chile, Mexico and Uruguay grew between 3,000 and one million ha. in 2000 (although the million ha. of GM soybean in Brazil was illegal). Finally, commercial sales have been noted in Australia (at 125,000 ha.), Japan, Israel and South Africa (at 180,000 ha.). Approximately ten different crops have been approved for commercial use worldwide.[1]

Research on GM Crops – Patterns of Research and Research Expenditure

GM crop varieties were the culmination of a research process that identified useful genes, figured out how to transfer the genes into plants, found ways to make the gene express commercially useful traits in the plants, and then tested the GM crops to find whether they could be grown without causing problems for other crops, for the environment, or for human health. Each time GM crops are moved from one country or region to another, the companies or government institutes have to test them to see whether they are adapted to local growing conditions and environments. In many cases the gene will not work effectively unless it is transferred to local varieties by genetic engineering or by backcrossing the GM crop with local varieties.

Precise estimates of plant biotech research that were required to produce the commercial biotech are not available. Byerlee and Fischer (2000) have made some preliminary estimates of biotech research expenditure. We have used their estimates to construct Table 2. About 90 percent of the biotech research expenditure is in industrialized countries. This is where both the public and private sectors conduct most of the basic research. The private sector conducts a large amount of applied research

[1] GM crops grown commercially include (in order of most-widely planted to least widely planted): herbicide tolerant (HT) soybean, Bt and some HT corn, Bt and some HT cotton, HT canola (collectively these four crops were more than 99 percent of the global GM crop area), insect resistant potato, viral resistant squash, viral resistant papaya , enhanced color and shelf-life carnation, sugar beet and HT lupin (only in Australia). Source: James (2000).

to develop new GM crop varieties. In total there is more private than public research and the private research tends to be more applied. In developing countries less money is spent and Byerlee and Fischer do not try to estimate the amount of private research that is conducted there.

Biotech research in developing countries spans the entire spectrum of research from mapping plant and pathogen genomes in Brazil, China and India to very applied research to test whether GM crop varieties that were developed in the U.S. fit into the agricultural, climatic, and market conditions found in developing countries. The field trials of GM crop varieties that are required to obtain biosafety approval in a country are the only way that we have been able to quantify the amount of the applied biotech research.

Econometric Modeling of Biotech Research Investments

The conceptual model explains the factors that influence the development of firms' decisions about whether to conduct biotech research or not and how much research they should conduct. The model is consistent with the theory that market size, technological opportunity and appropriability through IPRs or technology are important determinants of private research. The rest of this section describes the model variables and tests empirically the importance of specific variables that can influence expected market size, technological opportunities and appropriability.

Biotechnology Research

Agricultural biotechnology research and technology transfer are inseparable at present. Almost all of the key genes, which code for important economic characteristics as well as a number of key tools, which are essential to the construction of a GM crop, were developed in the U.S. or Europe. However, none of these genes can be transferred to another country without considerable testing to ensure that the genes and the crop varieties that contain them actually work effectively in the new conditions. Most genes will need to be transferred into locally adapted varieties before they can be sold commercially.

Our measure of biotech research is the number of field trials of by private firms of their GM crops by country by year. As discussed in section 2, data on research expenditure by private firms in any country is difficult to obtain and to obtain this type of data by country is impossible. The actual spread of genetically engineered crops is available for a number of countries. But it is not a good measure of companies' research since in some countries such as Brazil GM soybeans have spread despite efforts by the government and Monsanto to prevent their spread. The data on field trials of GM crops reflects the amount of research that is being conducted, although imperfectly. Field trials that are conducted of GM crop varieties from private firms can be separated from public varieties. Finally, they have been conducted in a large number of developing as well as industrialized countries, a much larger number of countries and years than actual adoption of GM crop varieties.

Expected Market Size

The first generation of biotech products are either crop protection products like Bt cotton which is protected from certain important insect pests or herbicide tolerant crop varieties that allow for better control of weeds. Both of these characteristics were embodied in the crop varieties and sold by the seed companies. The data shows that insect resistance, herbicide tolerance and disease resistance are the focus of most of the field trials in industrialized and developing countries. Thus, companies' expectations about the size of markets that will be available in a country would be based on the current size of seed market and pesticide markets. Companies make an estimate of how big these markets are and what share of these markets they could capture with their GM crop varieties that will be substitutes for conventional seeds plus pesticides.

We have estimates of the value of seed markets (Seedmkt) for a sub sample of 37 countries. Data on the size of the pesticide market in a large number of countries is not available from public sources. As an indicator of the size of the total input market relative to other countries we used the agricultural value added (AVA) as a proxy for market size.

The innovating firm's potential market size in many countries will depend on the extent of government intervention in the input markets. In many developing countries and some formerly communist countries, the government still controls a substantial share of the seed and pesticide market. Private firms may not consider the government's share as potential part of their market for innovations. In addition if the country has many restrictions on the role of private firms and markets, these firms may further discount the possibility that the country will be a good market for innovations. To capture this factor in our analysis we have included the Heritage Foundation's (ECONFREE) index of economic freedom (Holmes et al., 1995-1999).

Firms' expectations about market size and when they will be able to enter the market will also be influenced by government regulation of biotechnology, which will reflect in part consumers' attitudes. When a country first allows a GM product to be used, firms' expectations about their ability to sell more products in a market will increase. We have included a variable (COMAPPR) for the year of first utilization as another explanatory variable influencing expected market size.

Appropriability and IPRs

The share of the market that an innovating firm might capture will depend in part on the strength of the intellectual property rights laws and their enforcement as well as the technical difficulty of copying the innovation. If IPRs are stronger and it is difficult to copy the innovation, the innovating firm will expect to capture a larger share of the market. GM crop varieties can be protected with plant variety certificates (PVCs) and the genes, markers, promoters and transformation techniques can be protected with utility patents in some countries. Most countries do not allow inventors to both patent and use PVCs to protect plant varieties.

Measuring the strength of IPRs is a major problem. An ideal measure would include both the breath of legal coverage and how effectively the laws are enforced. One possibility would be to survey companies and get their perception of the strength of IPRs in different countries. However, such a survey is beyond the scope of this study. Instead we have tried a number of measures of coverage of biotechnology including membership in UPOV (the French acronym for The International Union for the Protection of New Varieties of Plants), which indicates whether they have plant breeders' rights to protect new varieties. A second variable, PNP, was included to indicate whether the country's patent law specifically excludes plants from being patented. If plants are excluded, then inventors of new GM crop varieties have weaker property rights than if they are included. We also tried the Park's index (see Ginarte and Park 1997), which is based on what is included in IPR. Finally, if a country is a signatory to the Patent Cooperation Treaty (PCTsign), an inventor in one country has a year from the time that he files during which he can file for a patent in other countries and have the original date of filing considered to be the date of filing in the other countries. We would expect that countries that have signed this treaty are also countries with the strongest patent systems.

The problem with the measures listed above is that IPRs are only useful if enforced and simply passing a law or a number of laws to protect IPRs is not sufficient to having a strong protection. Lesser (2001) has developed an index of the strength of IPRs which attempts to include the ability to enforce patents by using an index of corruption.

Unfortunately, his index covers only developing countries. We do not have any direct measure of enforcement of patents, but there are some measures of the strength of property rights in general, and we assume that stronger general property rights also will be correlated with the enforcement of IPRs. We have used the rating of property rights (PropRts) by the Heritage Foundation as a possible measure of the strength of property rights in general and also IPRs. Another way to measure the strength of IPRs would be measure how many patents are actually taken out in each country. Firms will not bother to spend the time and money to obtain a patent in a country unless there is some way to enforce it. Thus, more patents would mean that IPRs are stronger in that country. The problem with this variable (BIOPAT) is that it may be related to research, the dependent variable, for reasons other than simply the strength of the patent system. This could bias the results.

Technological Opportunity

Firms also base their research and development investment decisions on the cost to develop the new technology. If the country has similar agricultural conditions as the U.S. the research cost of introducing GM technology that was developed in the U.S. might only be the cost of the field trials for agricultural suitability and environmental impact. Therefore, we have included a dummy variable (CLIMATE), for temperate countries versus others. If more research is needed to incorporate genes into locally adapted crop varieties, then the scientific capacity of the country to do applied and more basic research may be important. As mentioned above, a few measures of private or public sector biotech research capacity are available. However, it is possible to have some idea of biotech capacity based on the output of scientific papers published in a country in the plant biology area. We have developed two variables that may measure this capacity – the number of plant biology publications in scientific journals abstracted by CAB International with authors at institutions in a specific country (CABABS1) and the number of publications published in journals that are located in the country (CABABS2). Finally, we have the data on the applications for field trials (PUBTRIALS) of GM crop varieties submitted to the government by public research institutions or universities. These reflect applied public biotechnology research. More public biotech research capacity should lead to more private biotech research.

The Econometric Model

Data were collected over multiple time periods and multiple cross sectional units. Given that the data series has both time series and cross section components, time series cross section (TSCS) regression methods were utilized to estimate the model. Out of the three popular methods, Fuller and Battese method, Parks method and Da Silva method, based on the moving average component across time series, the Da Silva method was selected for the estimation (SAS/ETS1993).

The Da Silva method can be viewed as a mixed variance-component moving average model. The TSCS model for the Da Silva method can be written as

$$Y_{i,\,t} = a_i + b_t + \beta\, X_{i,t} + \varepsilon_{i,t} \qquad (1)$$

Where,

$Y_{i,\,t}$ is the value of the dependent variable for the ith cross-section in the tth time period.

a_i is a time invariant cross-sectional unit effect

b_t is a cross-sectional unit invariant time effect

β is the slope parameter associated with the independent variable, $X_{i,t}$

$X_{i,t}$ is the value of the independent variable for the ith cross section in the tth time Period

$\varepsilon_{i,t}$ is a residual effect unaccounted for by the independent variable, the time effect, and the cross-sectional unit effect. $\varepsilon_{i,t}$ is assumed to be a finite moving average process.

The empirical model specified to test for the determinants of plant biotechnology research and development can be represented as:

$$Y_{i,\,t} = a_i + b_t + \beta_1\ SEEDMKT_{i,t} + \beta_2\ AVA_{i,t} + \beta_3\ ECONFREE_{i,t} + \beta_4\ COMAPPR_{i,t} + \beta_5\ UPOV_{i,t} + \beta_6\ PNP_{i,t} + \beta_7\ PCTSIGN_{i,t} + \beta_8\ PROPRTS_{i,t} + \beta_9\ PUBTRIALS_{i,t} + \beta_9\ CABABS1_{i,t} + \beta_{10}\ CLIMATE_{i,t} + \varepsilon_{i,t} \quad (2)$$

Where,

$Y_{i,\,t}$ is the number of applications for field trials of GM crop varieties by private firms for the ith country in the tth time period.

a_i is a time invariant cross-sectional unit effect

b_t is a cross-sectional unit invariant time effect

β_j	is the slope parameter associated with the independent variable, $X_{i,t}$, j=1,…10.
$SEEDMKT_{i,t}$	is the value of seed sales in $/year
$AVA_{i,t}$	is the value of agricultural value added products in $/year
$ECONFREE_{i,t}$	is the economic freedom index of Heritage foundation, ranges 1 through 5, 1 implies the most freedom and 5 implies the least freedom
$COMAPPR_{i,t}$	is a dummy variable which equals 1 if commercial approval of GM crop varieties exists, 0 otherwise
$UPOV_{i,t}$	is a dummy variable which equals 1 if the country is a member of The International Convention for the Protection of New Varieties of Plants, 0 otherwise
$PNP_{i,t}$	is a dummy variable which equals 1 if plants are not specifically excluded from patent laws, 0 otherwise
$PCTSIGN_{i,t}$	is a dummy variable which equals 1 if the country is a member of Patent Cooperation Treaty Signatory, 0 otherwise
$PROPRTS_{i,t}$	is the property rights index variable from the Heritage Foundation which ranges from 1 through 5, 1 implies the most protection, 5 implies the least protection
$PUBTRIALS_{i,t}$	is the number of applications for field trials of GM crop varieties by public research institutions and universities.
$CABABS1_{i,t}$	is the number of biological publications published in a country
$CLIMATE_{i,t}$	is a dummy variable which equals 1 if temperate climate, 0 otherwise
$\varepsilon_{i,t}$	is a residual effect unaccounted for by the independent variable, the time effect, and the cross-sectional unit effect. $\varepsilon_{i,t}$ is assumed to be a finite moving average process.

Description of the Data

As stated above, data on field trials of GM crops provides a measure for agricultural biotechnology near the end of the research process. The dependent variable ($Y_{i,\,t}$) is the total number of applications for field trials of GM crops that have been submitted and approved in countries worldwide for each year. Data has been collected from 1987 to 2000 and includes 58 countries including 21 industrialized countries, 24 developing countries and 13 transitional economies. Various sources such as Animal and Plant Health Protection Service (2001), Blanco (1998), Blume (2000), Artunduaga-Salas (2001), Australian Office of the Gene Technology Regulator, Biosafety Information Network Advisory Service (2001), Canada Food Inspection Agency, CONABIA, European Committee Joint Research Centre, Ghislain (2001), Hinrichsen (2000), Hungarian Agricultural Biosafety Center, James (1998), James and Krattiger (1996), Japan Ministry of Agriculture, Maoz (2001), Mexican Direccion General de Sanidad Vegetal, Moeljopawiro (1999), New Zealand Environmental Risk Management Authority, Oswaldo Cruz Foundation, Pray and Umali-Deininger (1998), Robert Koch Institute, and South African Directorate of Genetic Resources were used in collecting this data.

Membership in International Convention for the Protection of New Varieties of Plants (UPOV) and Patent Cooperation Treaty Signatory (PCTsign) were collected from World Intellectual Property Organization, 2001. Data on Plant Patent Laws (PNP) was collected from Hanellin (2000). Property Rights Index from Heritage Foundation (PropRts) and Economic Freedom Index of Heritage Foundation (ECONFREE) were collected from Holmes, Johnson, and Kirkpatrick. Data on Number of Biotech Patents approved in a country (BIOPAT) was collected from Delphion website.

Data on Seed Sales (SEEDMKT) was collected from International Seed Federation. Agricultural value-added data (AVA), Gross Domestic Product (GDP) and GDP per capita data were collected from the World Bank, World Development Indicators. Data on Commercial Approval of GM varieties (COMAPPR) was collected from James and on Climate of a Country (CLIMATE) was collected from Times Atlas of the World. Data on Biological Abstracts authored in a country (CABABS1) and Biological Publications published in a country (CABABS2) was collected from CAB International.

Results

The results of the regression analysis using the two data sets are shown in Tables 3 and 4. The R-squared is above 0.7 in both specifications. Almost all of the independent variables are significant and most have the expected signs.

In the larger data set (Table 3) the market size variables performed as expected, bigger markets lead to more research. The size of seed markets and the Agricultural Value Added variables both were positive and significant as expected. The economic freedom index, which we expected to measure the size of the public sector and governments' interference in the economy, was positive as expected (the more economic freedom the larger the expected market) but was not statistically significant. The dummy variable for countries in which at least one GM crop variety had been approved for commercial use was positive, as evidence that when at least one GM product has been approved, firms' expectations heighten that new products will also be approved.

The key IPR variables had mixed results. UPOV membership was the IPR variable that gave the most robust results – it had a consistently positive and significant impact on the number of field trials across different specifications and data sets. The variable for whether plants are not excluded from the patent act (PNP) is negative and is highly significant. This variable was expected to be positive, that is countries in which you can protect plants with patents should have a higher level of biotech research. The negative sign occurred most likely because number countries that exclude plants are European countries, which do have strong PBRs but do not allow inventors to patent and obtain PBRs on plants. Another variable that does not have the expected sign is the dummy variable for whether the country is a signatory to the patent cooperation treaty (PCTsign). The negative sign on this variable suggests that holding other things constant, signing the treaty leads to less research, which seems unlikely.

The technological opportunity variables also gave mixed results. Applied public sector biotech research does appear to be an important factor influencing private firms' decisions to do field trials. The variable (Pubtrials) was positive and significant in all of the specifications of the model. The quantity of more basic biological research conducted in a country is less important. In fact biological research as measured by publications (CABABS1) is negatively related to private biotech research. A possible explanation for the negative relationship between publications and biotech research is that companies are induced to invest in applied research in countries with strong applied biotech research programs, but many of the countries that produce a lot of publications do not do much of the applied research that is useful to industry. The temperate dummy variable (CLIMATE) is positive as expected implying that biotech research is conducted in places where the climate is similar to the U.S. and Europe but it is not statistically significant.

The second data set gives similar results but also allows us to test the biopatents variable in explaining biotech research (See Table 4). Biopatents is positive and significant and as in the previous dataset UPOV is positive, but the other IPR variables are negative. Comparing the other variables in specifications one and two indicates that adding biopatents changed the sign of one coefficient, the dummy for approval of any GM crop varieties went from positive to negative. The other change is that the climate variable is now positive as expected.

As discussed above the coefficient on biopatents variable could be biased by the fact that the number of biopatents is influenced not only by the strength of the patent system, but also by other omitted variables and by the actual amount of research expenditure by companies. Thus, we have more confidence in the specifications in Table 3, but these results do provide some support to the argument that stronger patents lead to more research as measured by field trials. The results of both data sets and specifications indicate that intellectual property rights do provide an incentive for private firms to conduct biotechnology research.

Conclusions

Plant biotechnology has had an important impact on agricultural productivity in a limited number of countries led by the U.S., Argentina, Canada, Brazil, China and South Africa.

Research on GM crops is much more widely spread and about 58 countries have reported field trials of GM crops.

Economic theory and data from other industries suggest that firms decisions to perform research are based on expected market size of the products from research, on the ability to capture some of the value that the final users of the invention obtained, and finally on the availability of useful research and information from other research organizations like public universities and public research centers. The results of the econometric analysis substantiates the hypotheses that the investments in applied biotechnology research are strongly influenced by:

- Plant variety protection and the strength of patent protection as measured by the number of patents on biotechnology products,
- Size of the seed market and the size of the agricultural sector, and
- Public sector research as measured by field trials conducted by public research organizations.

The econometric study is the first quantitative evidence that explains the relationship between IPRs and international agricultural biotechnology research. It indicates that IPRs may encourage applied biotechnology research. The findings also emphasize the limits of IPRs. If a country has a small market, no matter how strong its IPRs, firms may not invest in research and technology transfer there. If companies do not perform the research, the products of biotechnology – insect and disease resistant plants, will not be widely available to farmers.

The results suggest that the impact of GM crops in selected countries generally confirms the results found in the U.S. and Canada that GM crops have been beneficial for farmers and consumers. The results also suggest that governments in developing countries should not resist strengthening plant breeders' rights and patents on biotechnology.

References

APHIS, Animal and Plant Health Inspection Service, United States Department of Agriculture data, http://gophisb.biochem.vt.edu/cfdocs/ISBtables.cfm, September 27, 2001.

Artunduaga-Salas, Ph.D., Rodrigo, Genetic Resources and Biosafety, Colombian Agricultural Institute, Bogota, Colombia, February, 2001.

Australian Office of the Gene Technology Regulator website, http://www.health.gov.au/ogtr/gmorecord/complete.htm, September 27, 2001.

BINAS, Biosafety Information Network and Advisory Service, UNIDO, website: http://www.binas.unido.org/trials.php3, September 28, 2001.

Blanco, Gustavo, INASE, personal communication, October 6, 1998.

Blume, Yaroslav B., "Key Issues for Ukranian Acceptance of Genetically Modified Plants and Comparaison with other Central and Eastern European Countries" in Proceedings of 6th International Symposium on the Biosafety of GMPs., eds. C. Fairbrain, G. Scoles and A. McHughey University of Saskatoon, Univ. Ext. Press, pp. 15-20. Saskatoon, Canada, July 8-13, 2000.

Byerlee, D. and K. Fischer, "Accessing Modern Science: Institutional and Policy Options for Biotechnology in Developing Countries," Paper Presented at 4th International Conference, Economics of Agricultural Biotechnology, Ravello, Italy (2000).

CAB Abstracts. Wallingford, Oxon, United Kingdom: CAB International, 1991-1999.

Canadian Food Inspection Agency, Plant Health and Production Division, Plant Biosafety Office website: http://www.inspection.gc.ca/english/plaveg/pbo/triesse.shtml, September 30, 2001.

China Biosafety Committee, Pray, personal conversation with Carl E. Pray, December 4, 1999.

CONABIA, Secretaria de Agricultura, Ganderia, Pesca y Alimentacion, Argentina, website http://siiap.sagyp.mecon.ar/http-hsi/english/conabia/liuk.htm, September 27, 2001.

CTNBio, Comissao Technica Nacional de Biosseguranca, Ministerio da Ciencia e Tecnologia do Brasil, website, http://www.ctnbio.gov.br/ctnbio/Sistema/ LIBERACOESogmresp.asp, March 24, 2001.

Cuban government data website, http://www.cubagov.cu/Ingles/mapa.htm, July 2001.

Delphion website, http://www.delphion.com/cgi-bin/patsearch, 2001.

European Committee Joint Research Centre website: http://biotech.jrc.it/gmo.asp, September 28, 2001.

Evenson, Robert E. "IARC, NARC and Extension Investment, and Field Crop Productivity: An International Assessment." *Research and Productivity in Asian Agriculture.* Edited by Robert E. Evenson and Carl E. Pray with the assistance of Zafar Ahmed et al. Food Systems and Agrarian Change series, Ithaca and London: Cornell University Press, 1991, pp. 314-29.

Evenson, Robert E., and Yoav Kislev. *Agricultural Research and Productivity.* New Haven: Yale University Press, 1975.

Food and Agricultural Organization, FAOSTAT Agricultural Database, website, http://www.apps.fao.org/page/collections, 2001.

Ghislain, Marc, CGIAR, personal conversation, March 19, 2001.

Ginarte, Juan C., and Walter G. Park. “Determinants of Patent Rights: A Cross-Country Study.” *Research Policy* 26 (1997): 283-301.

Hanellin, Elizabeth, editor, Patents Throughout the World, 4th edition, West Group, New York, December, 2000.

Hinrichsen, Ph.D., Patricio, Coordinator Biotecnologia, Instituto de Investigaciones Agropecuarias (INIA), personal conversation, September 26, 2000.

Holmes, Kim R., Bryan T. Johnson and Melanie Kirkpatrick. eds. *Index of Economic Freedom.* Washington, D.C. and New York: The Heritage Foundation and Dow Jones & Company, Inc., 1995-1999.

Hungarian Agricultural Biosafety Center, http://biosafety.abc.hu/list_hun.php3?name=uid&like=%, February 27, 2001.

International Seed Federation (IFS), World Seed Statistics, website, http://www.worldseed.org/statistics.html, 1999-2000.

International Service for National Agricultural Research (ISNAR) Public sector R&D expenditure data provided by Johannes Roseboom, The Hague, Netherlands, 1998-1999.

Ismael, Youssouf, Colin Thirtle, and Lindie Beyers with Richard Bennett, Stephen Morse, Johann Kirsten, Marnus Gouse, Lin Lin, Jennifer Piesse. 2001. Smallholder Adoption and Economic Impacts of Bt Cotton in the Makhathini Flats, Republic of South Africa. A Report for DFID Natural Resources Policy Research Programme Project R7946.

James, Clive, and Anatole F. Krattiger, "Global Review of the Field Testing and Commercialization of Transgenic Plants: 1986 to 1995 The First Decade of Crop Biotechnology." *ISAAA Briefs* No. 1, International Service for the Acquisition of Agri-biotech Applications, Ithaca, New York, 1996.

James, Clive. "Global Review of Commercialized Transgenic Crops: 1998." *ISAAA Briefs* No.8 International Service for the Acquisition of Agri-biotech Applications, Ithaca, New York, 1998.

James, Clive, "Global Status of Commercialized Transgenic Crops: 1999, *ISAAA Briefs*, No. 17-2000, International Service for the Acquisition of Agri-biotech Applications, Ithaca, New York, 2000.

Japan Ministry of Agriculture, Forestry and Fisheries, website http://ss.s.affrc.go.jp/docs/sectan/eguide/edevelop.htm, January 23, 2001.

Lesser, William, unpublished International Patent Rights Index, Cornell University: Ithaca, New York, 2001.

Maoz, Dr. Arieh, Office of Chief Scientist, Israel Ministry of Agriculture, personal conversation, January 2001.

Mexican Direccion General de Sanidad Vegetal (SAGARPA), personal communication, March 7, 2001.

Moeljopawiro, Sugiono, Director of Research, Institute for Food Crop, personal conversation, January 13, 1999.

New Zealand Environmental Risk Management Authority, website http://www.ermanz.govt.nz/Search/srch_reg.htm March 10, 2001.

Oswaldo Cruz Foundation, website, http://www.fiocruz.br, 1999.

Parks, Walter, unpublished Patent Rights Index, 1990 and 1995.

Pray, Carl E., Jikun Huang, Danmeng Ma, and Fangbin Qiao “Impact of Bt Cotton in China” *World Development* Vol.29, No.5, pp.813-825, 2001.

Pray, Carl E. and David Schimmelpfennig, South Africa Trip Report – Role of Biotech in S. African Agriculture. Unpublished document. Department of Agricultural, Food and Resource Economics, Rutgers University, New Brunswick, New Jersey, 2001.

Pray, Carl E. and Dina Umali-Deininger. "Private Agricultural Research: Will It Fill the Gap?" *World Development,* Vol.26. No.6, 1998. pp. 1127-1148.

Robert Koch Institute, website, http://www.rki.de/gentec, 1999.

SAS/ETS User's Guide, Version 6, Second Edition, SAS Institute Inc., North Carolina, 1993. pp. 871-888.

South African Directorate of Genetic Resources, personal conversation, February 7, 2001.

Swiss Federal Statistical Office, website http://www.statistique.admin.ch and personal conversation, 2001.

Thailand Industrial Property Information Center, Department of Intellectual Property, website http://www.ipic.moc.go.th, August 2001.

Times Atlas of the World, Times Books, London, 1995.

U.S.Government Accounting Office. *Biotechnology: Information on Prices of Genetically Modified Seeds in the United States and Argentina*. RCED/NSIAD-00-55 Washington DC January 21, 2000.

World Bank, World Development Indicators, website www.worldbank.org/data/wdi2001/cdrom.htm, 1993-2001.

World Intellectual Property Organization, website, http://www.wipo.org, 2001.

Table 1. Estimated Area of Commercial GM Crops Planted in 1999 and 2000. (in million ha.)

Country	1999	2000
United States	28.70	40.30
Argentina	6.70	10.00
Canada	4.00	3.00
China	0.40*	0.70*
Brazil	1.00*	1.00*
Australia	0.10	0.15
South Africa	0.10	0.20
Mexico	<0.10	<0.10
Spain	<0.10	<0.10
France	<0.10	<0.10
Portugal	<0.10	0.00
Romania	<0.10	<0.10
Ukraine	<0.10	<0.10
Uruguay	0.00	<0.10

Sources: Clive James (2000) plus Pray estimates for China and Brazil noted with "*".

Table 2. Estimated Expenditure on Crop Biotechnology Research. (in U.S. $ millions)

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

Source: Byerlee and Fischer 2000.

Table 3. Factors Influencing Biotech Research: Regression Results (Dependent Variable: Field Trials of Private GM Crops in 37 Countries, 1991-1999).

	Specification 1.	Specification 2.
Intercept	-65.93	-41.44
Seed market	0.103**	0.101**
	(0.001)	(0.001)
Ag. Value Added	7.23 E-10**	7.93 E-10**
	(3.39 E-11))	(3.31 E-11)
Economic Freedom Index	9.24**	--
	(0.92)	
Commercial Approvals of GM Varieties	4.60**	4.13**
	(0.41)	(0.41)
UPOV membership	1.34**	0.95**
	(0.388)	(0.39)
Plants included in patents	-16.23**	-15.40**
	(7.54)	(7.54)
Patent Cooperation Treaty Signatory	-10.56**	-10.51**
	(0.42)	(0.43)
Property Rights	--	0.95**
		(0.34)
Public GM field trials	0.82**	0.82**
	(0.01)	(0.01)
Biological publications (CABABS1)	-0.0053**	-0.006**
	(0.0003)	(0.0003)
Climate	13.97	11.62
	(9.74)	(9.73)
R squared	.70	.70
N	333	333

Notes. Standard error in parentheses.
** Statistically significant at the 5 percent confidence level.
* Statistically significant at the 10 percent confidence level.

Table 4. Factors Influencing Biotech Research: Regression Results (Dependent Variable: Field Trials of GM Crops in 34 Countries).

	Specification 1.	Specification 2.
Intercept	-66.51	-104.49
Seed market	0.114**	0.118**
	(0.001)	(0.001)
Ag. Value Added	1.35 E-10**	4.95 E-10**
	(3.41 E-11)	(3.33 E-11)
Commercial Approval of GM Varieties	-7.86**	12.77**
	(0.48)	(0.42)
UPOV membership	1.56**	6.46**
	(0.452)	(0.441)
Plants not excluded	-52.40**	-38.12**
	(8.13)	(8.27)
No. of Patents on Plants	0.290**	--
	(0.003)	
Property Rights	4.41**	3.51**
	(0.411)	(.413)
Public field trials	0.700**	0.800**
	(0.013)	(0.013)
Biological publications (CABABS1)	-0.0027**	-0.001**
	(0.0003)	(0.0003)
Climate	21.81*	44.98**
	(12.55)	(12.80)
R squared	.80	.71
N	306	306

** Statistically significant at the 5 percent level.