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

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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. Case studies of Argentina, Brazil, China and South Africa provide evidence that the benefits from GM crops primarily go to farmers and consumers rather than multinationals. Taken together the econometric analysis and case studies suggest that if policymakers in developing countries strengthen intellectual property rights and allow the use of plant biotechnology, small farmers and consumers could increase their incomes.

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1. Introduction

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 (IPRs) such as plant breeders 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 breeders 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 IPRs are strengthened.

To answer these questions we first examine the spread of one set of technologies that may be crucial to increasing agricultural production and economic development in the rest of this century - agricultural biotechnology and agricultural biotechnology research. Thepart three of the paper reviews the types of intellectual property rights, their role in inducing research and technology transfer, , and case studies on how much protection IPRs provide in several important developing countries. The fourth part of this paper reports the results of econometric modeling of the relationship between IPRs and biotech research. Finally, we draw some conclusions for policy makers.

2. 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 (See Table 1.) were planted in eighteen countries up from 40 million ha. in 12 countries in 1999. The U.S. grew the most at 40 million ha, followed by Argentina and Canada with more than 10 million and 3 million 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 following European and Eastern European nations: 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 – Research Expenditures and Patterns of Research

GM 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 plants to find whether they could be grown without causing problems for other crops, for the environment, or for human health. Each time GM plants 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 plant with local varieties.

Information on how much biotech research is being conducted around the world is very limited. To obtain an overview of biotech research around the world, we first review the available estimates of research expenditure on agricultural biotech and then we look at data on field trials of GM plants.

Research Expenditures

Precise estimates of plant biotech research that was required to produce the commercial biotech described above 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 to develop new GM plant 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 varieties that were developed in the U.S. fit into the agricultural,

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[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% of the global transgenic crop area), insect resistant potato, viral resistant squash, viral resistant papaya (only in Hawaii, US), enhanced color and shelf-life carnation, sugar beet and HT lupin (only in Australia). Source: James (2000).

climatic, and market conditions found in developing countries. The field trials of GM varieties that are required to obtain biosafety approval are the only way that we have been able to quantify the amount of the applied biotech research on testing GM varieties.

Research Measured by Field Trials

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

For this study, field trials of GM crops were measured by the total number of applications that were approved in each country by its appropriate governmental regulatory department. In our study we have used the U.S. counting system in which one application is for one event (a gene or series of genes transplanted in one variety) no matter how many locations this event is tested in. . Our numbers include plants only, although data on animal and viral research was available. Data has been collected from 1987-2000. Data on the number of events deregulated by a government might be a better measure of the output of biotechnology research, but for use in econometric and statistical analysis, it has the disadvantage that the data does not go as far back in time and there are many fewer deregulations than field trials.

Growth by Region As of February 2001, field trials of GM crops have been conducted in at least 59 countries of which 38 are developing or transitional economies. Figure 1shows the number of field trials each year. A list of the names of the countries for which data has been collected is found in Appendix A. There were more than 1,800 applications approved for field trials of GM crops worldwide per year in 1998 and 1999. (See Figure 1.) This was a 33% increase in the more than 1,400 that were approved in 1997. The U.S. has always been the leader in the number of field trials. Other industrialized countries grew a similar pace until 1993 when the U.S. numbers accelerated more rapidly. In 1997 field trials in other industrialized countries peaked and has declined slightly since then. There was a significant reduction or plateau in GM research in Western European countries, Japan, Argentina and New Zealand The leveling trend in Western Europe was probably caused by increasing negative consumer perceptions about biotechnology and environmental pressure for increased regulation in Europe. New

Zealand slowed recently because of a voluntary moratorium on field trial applications since June 2000 while the government reviewed its biotech policy.

Developing countries (DCs) and countries in transition from socialism (mostly in Europe) have lagged behind the industrialized countries in starting to conduct field trials. In recent years, however, the numbers of field trials in those countries has increased. The number of field trials grew rapidly in part due to the increase in the number of countries conducting them. In 1999 field trials of GM crops were approved for the first time in Lithuania, Czech Republic, Moldova, Romania, Slovakia, Slovenia, Turkey and the former Yugoslav Republic. Notably, field trials of GM crops were approved for the first time in the following DCs: Colombia, India (beginning in 1998), Indonesia (beginning in 1998), Kenya (beginning in 2000), Philippines and Zambia. Field trial approvals in DCs are more erratic than developed nations. There is a 100% increase in the number of field trials approved in South Africa between 1999 and 2000 (from 55 to 110 approved applications), but others such as Argentina have banned field trials in certain years.

Growth By Country. When all the years of field trial data is combined, the United States has conducted by far the most field trials (58% of all trials). Canada has conducted the second most (11% of all field trials) followed by France (4%) and then South Africa (2.5%). Six other countries have conducted between 1.5% and 2.5% of the rest of the field trials. They include in descending order: Italy, Brazil, United Kingdom, China, Mexico and Japan. No Transitional Economies are conducting more than 1% of the field trials, but Brazil, Mexico, China and South Africa are conducting more field trial research than many developed nations. Below are case studies of several specific countries.

Crops Since 1987, when the first field trials were approved, there have been more than 11,000 field trials of 81 GM crops approved worldwide. The crop that is the most widely tested worldwide is corn (with 34 percent of the field trials), which is somewhat surprising considering that the crop with the most area of commercial planting thus far is soybean. Soybean trials rank 4th at 7 percent of approved field trials worldwide, after canola (11 percent of all field trials) and potato (10 percent of field trials). (See Figure 2.) Prior to 1998 corn dominated field trial numbers with 35 percent of all field trials, followed by canola (13 percent) and soybean (8 percent).

The number of field trials both wheat and rice has accelerated in recent years With 232 and 189 field trials approved respectively, wheat and rice became the 9th and 10th most frequently tested crop worldwide (up from 96 and 78 field trials reported for both crops by 1997). This is may mean that these crops are starting to receive some much need attention. An October 13, 2000 article in *Science*, in which scientists from the International Rice Research Institute (IRRI) in the Philippines "noted that because most rice farmers are poor, rice production has been greatly ignored by the private sector and remains relatively underdeveloped." Other GM crops that topped the list include: cotton, sugar beet, tobacco, alfalfa, melon, grasses, trees, squash and sunflower. Notably, in 2000, cassava was tested for the first time anywhere in Columbia and will be approved for testing in the U.S. in 2001. Yam, another important subsistence crop, has not yet reached the field trial test stage, but other "orphan commodities" such as bananas, sweet potato, lentils and lupins have all been approved for field testing in one or more countries. In DCs and the transitional economies of Europe, 48% of all field trials are for corn.

Field Trial By Trait. The characteristics or traits of GM crops being researched around the world vary widely. As shown in Figure 3a and 3b 29% of all field trials are for herbicide tolerance. The second most important trait tested is insect resistance (21% of all field trials). Another 5.5% of the trials are being conducted on a combination of herbicide tolerance and insect resistance, or a combination of several other traits. The next most researched trait is product quality with more than 15% of all GM field trials, followed by virus resistance with 9% of trials. Agronomic properties and disease resistance were sought in nearly 6% each of field trial research. Marker genes were implanted in more than 3% of all GM crops. Finally, other traits such as nematode resistance and antibiotic or pharmaceutical uses comprise the last 4% of field trials research.

Field TrialsBy Company or Institution. The private sector continues to heavily dominate in the research development of new GM crops.[2] Figures 4a, and 4b show the division of GM crop research by public vs. private sector. Less than 23 percent of the applications for field trials that have been approved by governments worldwide have been submitted by universities or government or international agricultural research centers. Additionally, many of those that have been submitted by the public sector have been submitted jointly with a private-sector or multinational life science partner. The transitional economies of Europe report the lowest public sector participation with only 7 percent of field trials being conducted by the public sector. The multinational firms[3] are responsible for most of the field trials in industrialized countries (70 percent), with single-country firms[4] accounting for 10 percent of all field trials Universities are conducting 12 percent of the GM crop research followed finally by the national and international agricultural research centers conducting 8 percent of all field trials in developed countries. In developing countries the only change from these statistics is that national and international agricultural research centers are conducting 16 percent of field trials with universities accounting for a mere 4 percent. This reflects the fact that most agricultural research in developing countries is conducted by the research institutes rather than universities (see Pray & Umali) Within the transitional economies of Europe 79 percent of all field trials are being conducted by multinational corporations, followed by a

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

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

[4] Single country firms are defined as companies that have conducted field trials in only one country thus far. There are 205 single-country firms.

mere 1 percent by local firms and 7 percent of the research by national agricultural research centers. None of the trials are being conducted by universities.[5]

There has been concern that the consolidation of biotech and seed companies into life science companies has reduced the competition in these markets. We do not have direct data to test this. What we can examine is whether there still are a number of companies doing research in a particular country. We find that even in the countries where there have been a number acquisitions by life science companies in the seed industry – Argentina, Brazil, and South Africa – there still are a number of companies working to develop new GM varieties as Table 3 indicates.

3. Intellectual Property Rights and Case Studies of Their Impact

Before presenting the econometric evidence on the relationship between IPRs and biotech research we review the major ways of protecting intellectual property and provide a framework for assessing the importance of IPRs relative to other factors that influence research and technology transfer investments. We then examine case studies of IPRs and whether they actually provide any protection for biotechnology inventions in South Africa, China, Argentina, and Brazil. These countries were chosen because GM varieties are planted more extensively than in other developing countries (see Table 1).

Intellectual Property Rights

Plant breeders, biotechnology scientists**,** and the firms that own biotech inventions try to charge enough royalties for use of their inventions or prevent people or firms from copying their inventions so that they can sell enough of 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 breeders rights, and trademarks (see Table 4). They also do this by keeping their 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 (the genetic use restriction techniques (GURTs) or Terminators – see FAO website). 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 component of the World Trade Organization 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

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

exclude novel plants and animals from patent coverage although many of them do allow patenting of novel microbes as it required by WTO.

Role of IPRs in Inducing Research

The expenditure on research to develop or adapt a new agricultural technology is an investment decision for private firms. They will only invest if they have a reasonable expectation that their research will provide them with a profit in the future. Our basic model of private companies' behavior is that they will be more likely to conduct research to develop and then supply GM plant varieties in those countries that:

(1) have large commercial agricultural input markets and thus a **large expected market** for new GM varieties,
(2) have good **technological opportunities** to develop well adapted GM varieties either because the country is very similar to countries in which the GM varieties were originally created or because public research has provided conditions in which it is relatively easy to develop well adapted varieties, and
(3) have institutions that enable the firm to **appropriate** a share of the benefits of the new technology through strong intellectual property rights or through technical means such as hybrids.

IPRs fall into category (3) – laws that allow firms to appropriate or capture some of the economic benefits that are generated from the use of their invention. Some way of protecting the invention from unauthorized copying is essential before firms will do research. However, firms will not invest in research and technology transfer no matter how strong the IPRs are, in the absence of large potential markets for a new product or if there is no realistic opportunity of developing an appropriate new technology in a reasonable amount of time..

These components – market size, technological opportunity, and appropriability - make up a conceptual model of the factors that influence the development of firm's decisions about whether to conduct biotech research or not and how much research they should conduct. We will look at the importance of intellectual property rights in providing appropriability in the case studies below.We will then develop these factors into the econometric models in section 4 and test the relative importance of the different factors using data from a cross section of countries. .

South Africa

South Africa has the strongest IPR protection of the four case study countries. Two systems that rate the strength of IPRs – Lesser(2001) and Park (see Ginarte and Park) – rate it the strongest of the case-study countries (see the first two columns of Table 5). Biological inventions can be protected using the patent law or plant breeders right's (PBR) law but not by both. Patents cover any novel product or process except plant varieties, animals, and discoveries of things that naturally occur in nature. Inventors have patents on genes, promoters, transformation methods, and other processes. This is a non-examination system so there are no patent examiners with expertise to decide whether the application is novel, useful and distinct. The Patent and Trademark Office can, however, reject an application if it is not in the public interest, is offensive, or is obviously a copy or is in the public domain. It is up to the readers of the patent journal to challenge in court patents that have been issued but which they think infringes on their patents. The patent system is backed up by a fairly efficient and knowledgeable court system. A weakness of the system is that it is very difficult to find out what is actually patented here. You must go to the patent office and try to figure out which category of patents the patent office may have put an application.

Plant varieties have been protected by plant breeders rights legislation since 1978. South Africa joined UPOV in 1977. In 1996 the Parliament passed new legislation to strengthen breeders rights and bring their law in line with the 1991 UPOV agreement. This law has not yet been implemented because the government would like to include some language to protect some farmers' rights.

Bt cotton which is resistant to bollworms was the first GM crop approved for commercial planting in S. Africa. It was approved for planting in 1997. Bt corn, which is resistant to stalk borer, was approved for 1998 planting. For the 2001 planting season two other GM crops have been approved for commercial use: cotton and soybeans that are resistant to the herbicide Round-up. Farmers planted about 100,000 ha. of Bt corn or less that 3 percent of the corn area in 2000. In addition cotton farmers planted about 20,000 ha. or 25 percent of their cultivated areas with Bt cotton (Pray and Schimmelpfennig 2001). Most of the farmers that have adopted Bt corn are large commercial farmers. Bt cotton has been adopted both by large commercial farmers and by small holders.

GM varieties in S. Africa are protected by plant breeders rights and the Bt and Roundup Ready® resistance genes are protected by utility patents. Enforcement of these property rights is relatively easy because technology and industry structure keeps farmers from saving their seed and because there are only small numbers of biotech and seed companies. The Bt gene for corn has been inserted in hybrids, which farmers can not replant unless they are willing to give up 20 percent of their yield which is uneconomical for most. The Bt gene in cotton was inserted in cotton varieties, which could be replanted by farmers with no major loss in genetic potential . In South Africa, however, the owners of the genes and varieties are protected because all of the cotton is ginned by a few mills that are owned by two companies, which cooperate closely with the providers of the technology. They buy the raw cotton from farmers and do not give any of the seed back to them. Farmers could hold some raw cotton back and take the seeds out by hand. However, then it would not work in the machine planters that most of them use. Thus, there is little replanting of seeds even by small farmers in S. Africa.

These conditions allow Monsanto and the seed companies to continue to capture part of the benefits from biotechnology – they charge a technology fee on each kg of seed that they sell. Large farmers are gradually increasing their area under Bt corn so they must either be making money from savings in crop management costs or they like the insurance properties of the Bt corn (they do not have to worry about stalk borer attacks). So far there is no survey of farmers to estimate the economic impact of the Bt. There is survey data on the impact of Bt cotton on small farmers (Ismael et al 2001). That survey found that small farmers in the Makhatini Flats region of Kwa-Zulu Natal increased their net income by about U.S. $31/ha (Ismael et al 2001) while the technology fee plus the increase in seed costs for small farms is about $11/ha (Pray and Schimmelpfennig 2001). Thus, at most a quarter of the total benefits per ha. from Bt cotton were captured by the seed and biotech companies and from that the companies must pay extra regulatory costs, extension expenses, and applied research that are required for GM crops. So far these companies are not making much money from GM crops because only a small area is covered with these crops, but as they expand, their profits could be substantial.

China

China's IPR system is not as strong as S. Africa's – Lesser (2001) rates it below S. Africa and Brazil and above Argentina. It is the other end of the spectrum from S. Africa. You can patent novel genes, methods of producing new genes and methods of producing new cultivars. Patents are examined for novelty, usefulness, and distinctness. A plant breeders rights law was passed in 1997 and officially went into action in 2000. China also has a trademark act similar to international trademark acts.

In November 1996 Monsanto, Delta & Pineland (DPL), and the Singapore Economic Development Board developed a joint venture with the Hebei Provincial Seed Company to produce and market Bt cotton seed through a new company called Ji Dai. After testing a number of different varieties, they decided that the DPL variety 33B carrying Monsanto's Bt gene controlled cotton bollworm, out-yielded both GM and conventional varieties, and had good fiber quality. The Chinese biosafety committee approved it for commercial use in Hebei province in 1997. In the same year the biosafety committee approved the commercial use of several Bt cotton varieties that were developed by the Chinese Academy of Agricultural Sciences (CAAS). The varieties from Monsanto and DPL and from CAAS were planted on about 700,000 ha in 2000. This entire area is planted by small farmers, who on average have farms of 1 ha (Pray et al 2001).

The Monsanto Bt gene was not protected by a patent in China and the plant breeders rights law had not been passed yet when most of the Bt cotton varieties first came on the market. Monsanto and DPL decided that they would be able to protect their variety through their joint venture with the Hebei Provincial Seed Company, which has an administrative monopoly on cotton seed sales in Hebei Province. The Provincial governmentprotected them from competitors in Hebei and allow them to incorporate a technology fee into the price of their seed there. In the following years they were able to negotiate a sdeal with Anhui Province, but they have to compete with government Bt varieties. In Shandong Province they are now allowed to sell their Bt varieties, but they have no monopoly power from the state. In Henan province, they were not able to obtain permission to sell their Bt varieties.

In Hebei and Anhui, unlike S. Africa, Monsanto and DPL have to compete with their own technology in that farmers and other seed companies are able to find gins that will give them the fuzzy cotton seed. Since farmers plant by hand fuzzy seed is not a major problem to plant. However, many farmers prefer to buy Monsanto/DPL seeds because they feel the genetic and physical quality of the seed is higher. In Shandong and Henan provinces local government seed companies, private companies and farmers reproduce 33B and sell it in competition with the Monsanto/DPL seed.

A survey of 283 farmers in Hebei and Shandong Provinces found that in Hebei where farmers paid the official price, farmers increased their net income by about $330/ha. while the seed cost including the technology fee was about $48/ha. Out of this the Monsanto/DPL/Chinese joint venture had to pay all of their costs of production, distribution, marketing, and research. Thus, the actual profit to Monsanto and DPL on a hectare of Bt cotton in China is quite low. In addition Chinese farmers and seed companies are capturing the benefits on almost all of the 33B and other Monsanto/DPL varieties that are being sold illegally. Because of the ability of farmers to save their seed they sold less seed in Hebei and Anhui than expected. Weak IPRs and the absence of administrative monopolies outside Hebei mean their earnings in Shandong were limited. Because Monsanto/DPL could not get permission from the Biosafety committee to sell Bt cotton in Henan, they earn nothing from the sale of their varieties there.

For CAAS the situation was even worse. Theyhad a patent on their Bt construct. However, the deal that they made with the government companies that distributed their seed was that the companies would pay a percent of net income from the Bt cotton seed. When it came time for CAAS to collect its money, the seed companies reported that they had not earned any net income, and so they did not owe anything to CAAS. In addition to the legitimate CAAS cotton seed, many farmers and companies are producing it with no payment to CAAS.

Argentina

The overall IPR system is not rated very highly by Lesser or Parks, but the plant breeders rights law and enforcement is thought to be one of the best in developing countries. In Argentina microbes, plants and plant parts are excluded from coverage of utility patents. Argentina has had a plant breeders rights law since 1973 and regulations to enforce it since 1978. However, it was not effective until the government passed new seed quality control regulations that made it easier for companies to track varieties and the seed industry started an institution called ARPOV in 1991 modeled after European plant royalty bureaus. This agency was able to take legal action against violators of the plant breeders rights act which individual companies were not able to do for fear of alienating some of their customers. As a result the amount of black market seed has been reduced substantially[6]

Monsanto's Round-Ready soybeans, which were introduced in 1996 in collaboration with a local seed firm Nidera, dominate the commercial plantings of GM crops in Argentina with about 6.4 million ha. in 1999 (James 2000). Bt corn and Bt cotton are grown commercially on 260,000 ha. and 10,000 ha. respectively. Monsanto supplies these Bt genes to partners and markets seed in these crops also. However, there is still competition for this market as indicated by the fact that the number of firms conducting field trials of corn is still at 10. Most farmers in Argentina are large commercial farms.

The returns to Monsanto and other multinationals on their GM seeds have probably been considerably less than expected. In Argentina, Monsanto is earning money from their licensee Nidera. However, soybeans that farmers produced can be planted again with little loss in yield. Farmers plant 25 to 35 percent of the soybean area with farmer saved seed and 25 to 50 of the area with illegal, black market seed that has not been certified (U.S. 2000) This has limited Nidera's sales and Monsanto's royalties and forced them to reduce prices of Roundup Ready soybean seeds from US $ 25 per 50 pound bag in 1997 to $9 in 1999.(U.S. 2000). Monsanto has made money on increased Roundup herbicide sales, which is their major product internationally. The available evidence indicates that like China most of the benefits from the GM seed ended up with farmers and consumers not with Nidera and Monsanto. Unfortunately, there have been no economic studies quantifying the economic benefits to farmers yet.

Brazil

Brazil has fairly strong property rights according to the two indices. It recently strengthened its patent system and passed plant breeders rights legislation. Plant breeders rights are strengthened by the existence of BRASPOV which is the equivalent of plant royalty bureaus in Europe and ARPOV in Argentina. Brazil became a member of UPOV in 1999.

[6] US GAO (2000) reports that Argentina was able to reduce the use of black-market soybean seed from 75% in 1992 to 50% in 1994.

All of the major seed and biotech companies are conducting research on GM crops in Brazil. They have been trying to get permission to sell GM crops for several years. This has been prevented by a coalition of consumer and environmental groups that have challenged Brazil's system of approving GM varieties in court. The first approvals were given for GM crops to be planted in 2001. This year (2001) farmers may be allowed to plant Round-up ready soybeans that were the result of an EMBRAPA – Monsanto joint venture unless the courts stop their use because of more lawsuits by environmental and consumer groups. Despite the fact that Roundup Ready® (RR) soybeans were not allowed by the government, RR® soybean seed came up from Argentina and has been planted extensively for several years now in southern Brazil. As Table 1 indicates there may have been a million ha of RR® soybeans planted in 2000. Monsanto is making no technology fee from the sale of these seeds although it is presumably selling more Roundup (Monsanto recently built a new Roundup production plant in Brazil). Again we have an example of the benefits from biotech going to farmers.

Summary

Early introductions of GM crops by Monsanto with collaborating companies were made in developing countries which have large well developed seed markets and strong IPRs relative to other developing countries. Argentina has one of the oldest plant breeders rights laws in a developing country and a plant royalty bureau to enforce it. In China government regulated monopolies appeared to give private companies the possibility of capturing the benefits from research. Brazil has had strong Plant Breeder's Rights since 1996. Patent protection for the Bt and Roundup Ready® gene appeared to be less important – only South Africa provided some protection for novel genes. The strength of IPRs in South Africa may have offset its relatively small market size (see Seed Markets in Table 5). In addition all four of these countries had biosafety regulations in place and had temperate climates or regions with temperate climates that allowed the direct introduction of GM varieties developed in the U.S.

Despite the fact that all of these countries appeared to have the potential for appropriability, the actual ability of inventors to the capture the gains varied considerably. The case studies indicate that IPRs in S. Africa provide the strongest protection – it is the only country in which Monsanto can collect its technology fee on nearly 100 percent of the GM crops that are grown. The reason IPRs are most effective there is that there are strong complementary institutions and technologies that allow relatively easy enforcement of the IPRs. In the cotton crop IPRs in conjunction with concentration in the ginning industry allows seed and biotech companies to collect technology fees on most of their cotton genes and seeds. IPRs and the technical difficulty of copying hybrids prevents copying of seed (seed saving) by farmers, and the small number of hybrid corn seed producers makes it easy to identify any company that might try to copy a hybrid or insert a proprietary gene. In China government provincial monopolies provide some protection of intellectual property, but so far plant variety protection and patents have provided no protection.. At most half of the farmers that are growing Bt cotton are paying a technology fee (which is embodied in the seed price). In Argentina plant variety protection with enforcement by ARPOV prevents copying by

other major companies and allows companies to make some money, but the ease of producing RR® soybeans means that Monsanto does not collect technology fees on most of the soybean seed planted in Argentina. In Brazil none of the farmers are paying technology fees on RR soybeans because they are all illegal.
The limited size of the revenue that companies capture considerably weakens companies' incentives to do biotech research in these countries. As a result the amount of money that Multinational companies invest in biotech research in these countries is limited, and it is used for very applied work such as field trials of U.S. GM varieties or trying out the genes that they have commercialized elsewhere in local plant varieties. Thus, if developing countries – even the largest developing countries – want more private investment in plant biotech research they will have to strengthen IPRs.

Will stronger IPRs hurt small farmers? Clearly in those countries where IPRs are weak stronger IPRs will force farmers to pay higher prices for GM seeds. However, stronger IPRs should lead to more technology transfer, more biotech research, and thus to higher yielding, pest resistant, and higher quality crop varieties to meet farmers' needs. The evidence from the countries and regions where IPRs are the strongest – South Africa and Hebei Province in China – is that companies are pricing their seed so that small farmers get more than 75 or 80 percent of the benefits from research (Pray et al). This suggests that strengthening IPRs would benefit farmers more than the ; biotech firms. The empirical question for policy makers is whether the loss of farmer and consumer benefits from higher priced plant biotechnology is larger or smaller than the benefits from having more biotech research in country.

4. Econometric Modeling Biotech Research Investments

These case studies are consistant with argument made above that market size, technological opportunity and appropriability through IPRs or technology are important determinants of private research. These components make up a conceptual model of 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 rest of this section fills out the model and tests empirically the importance of specific variables that can influence expected market size, technological opportunities, and appropriability.

Biotech Research

Plant 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 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 plants by country by year (the variables of the model and data sources are listed in Table 6). 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 does have most of characteristics that we want. It reflects the amount of research that is being conducted although imperfectly. Field trials that are conducted of GM 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 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 varieties that allow for better control of weeds. Both of these characteristics were embodied in plant varieties and sold by seed companies. Figures 3a and 3b show that insect, herbicide, and disease tolerance 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 seed varieties that will be substitutes for conventional seeds plus pesticides.

Table 6 shows the variables that were used in the regression analysis research project. Table 6 also shows data sources and the expected sign of the variable in the regression analysis. We have estimates of the value of seed markets (Seedmkt) for a subsample 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 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 there are many restrictions on the role of private firms and markets, these companies may further discount the possibility that the country will be a good market for innovations. To capture this factor we have included the Heritage Foundation's index of economic freedom.

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' expectation about their ability to sell more products into that market will increase. We have included a variable for the year of first utilization as another explanatory variable influencing expected market size.

Appropriabililty 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 plant 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 intellectual property rights 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 is whether the country's patent law specifically excludes plants from being patented. If plants are excluded, then inventors of new GM varieties have weaker property rights than if they are included. We also tried the Park's index (see Ginarte and Park) which is based on what is included in IPR. Finally, if a country is a signatory to the Patent Cooperation Treaty 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 intellectual property rights 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. Firms will not bother to spend the time and money to obtain a patent in a country unless there is some how that they can enforce it. Thus, more patents would mean that IPRs are stronger in that country. The problem with this variable 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 of to developing 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, which is one for temperate countries and zero for others. If more research is needed to incorporate genes into locally adapted varieties, then the scientific capacity of the country to do applied and more basic research may be important. As mentioned above 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 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 field trials of public GM varieties which reflects applied public biotech research. More public biotech research capacity should lead to more private biotech research.

The 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, 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

$$Y_{i,t} = a_i + b_t + \beta X_{i,t} + \varepsilon_{i,t}$$

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 is:

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

Where,

$Y_{i,t}$ is the number of applications for field trail of GM 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 most freedom and 5 implies least freedom

$COMAPPR_{i,t}$ is a dummy variable equals 1 if commercial approval of GM varieties exists, 0 otherwise

$UPOV_{i,t}$ is a dummy variable equals 1 if the country is a member of International Convention for the Protection of New Varieties of Plants, 0 otherwise

$PNP_{i,t}$ is a dummy variable equals 1 if plants are not specifically excluded from patent laws, 0 otherwise

$PCTSIGN_{i,t}$ is a dummy variable equals 1 if the country is a member of Patent Cooperation Treaty Signatory, 0 otherwise

$PROPRTS_{i,t}$ is the Property Rights Index from Heritage Foundation rages 1 through 5, 1 implies most protection, 5 implies least protection

$PUBTRIALS_{i,t}$ is the number of applications for field trials of GM 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 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 (fieldtr) is the total number of applications for field trials on 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. (A list of the countries with approved field trials is attached as Appendix A-2.) The data has been collected by contacting these countries individually in most cases and has been compiled into a database created specifically for this research.

After eliminating countries which had missing data, we tested a linear model which includes the variables in Table 6 for 37 countries (including 11 developing countries and 7 countries from Eastern European and Former Soviet Union). These countries all have data for the field trials and most of the independent variables for the years 1991 to 1999. We then used a smaller subset of these countries to estimate the possible impact of the independent variable which measures plant biological inventions.

Results

The results of the regression analysis using the two data sets are shown in Tables 7 and 8. The R-squared is above 0.7 in all specifications and data sets. Almost all of the independent variables are significant and most have the expected signs.

In the larger data set (Table 7) 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 variety had been approved for commercial use was positive - evidence that when at least one GM product has been approved, firms' expectations that new products will also be approved increases.

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 in across different specifications and data sets. The variable for whether plants are not excluded from the patent act is negative and is highly significant. This variable was expected to be positive – countries in which you can protect plants with patents should have higher research. It is probably is negative because a number countries that exclude plants are European countries which do have strong PBRs and 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. The negative sign on this variable suggests that holding other things constant signing the treaty leads to less research which seems unlikely unless you argue that the signatories to this treaty substitute technology transfer for local research.

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 amount of more basic biological research conducted in a country is less important. In fact biological research as measured by publications is negatively related to private biotech research. The temperate dummy variable 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. 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 do a lot of publications do not do much of the applied research that is useful to industry.

The second data set gives similar results but also allows us to test the biopatents variable in explaining biotech research (See Table 8). 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 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 7, 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 to conducting biotechnology research.

5. Conclusions

Plant biotech 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 plants is much more widely spread – 58 countries have reported field trials of GM plants.

Economic theory and data from other industries suggests that firms decisions to do 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 obtain, and last on useful research and information from other research organizations like the public universities.

The case studies of the spread of GM plants in Argentina, Brazil, China and South Africa suggest several important hypotheses:

- Some type of protection of intellectual property along with market size are two key ingredients in companies' choices of where to commercialize biotechnology.

- The expected benefits from investments in research did not immediately turn into big profits for Multinational biotech companies in any of these countries.

- To be effective IPRs need to be reinforced by other institutions or technologies as they are in South Africa, if the owners of technology are to profit from them.

- Even in South Africa, which has the strongest IPRs, at least 75 percent of the benefits from biotechnology went to small farmers or consumers not to the seed and biotech firms that invented and supplied the technology.

Our econometric analysis substantiates the hypotheses of the case studies 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.

- Public sector research as measured by field trials.

The econometric study is the first quantitative evidence that we have seen on 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 – market size counts. If you are in a country with a small market, no matter how strong your IPRs are, firms may not invest in research. If companies do not do the research, the products of biotechnology – insect and disease resistant plants, will not be widely available to farmers.

There are some important caveats about generalizing these results too far. First, the case studies are for developing countries that are just beginning to adopt GM products.. They are limited to a few large countries. However, the impact of GM crops in these countries generally confirms the results found in the U.S. and Canada – GM crops have been beneficial for farmers and consumers (Falck-Zepeda et al) . More studies are needed which assess the impact of biotech on both the small and large farmers in developing countries, but the studies presented here are important because the critics of biotech have claimed that small farmers are being hurt by biotechnology without presenting any quantitative analysis to support their claims. The second caveat is that the econometric results are not as strong as we had hoped. A number of coefficients have signs that are the opposite of what theory suggests and the signs and significance of some variables changed with different specifications or different data sets. Further analysis is needed to improve the results.

Despite these caveats the evidence from the case studies and the econometric analysis suggests that governments in DCs should not resist strengthening plant breeders rights and patents on biotechnology . The case studies suggest that LDC governments can improve the income of farmers far more than the income of multinational companies by allowing the use of GM crops in their countries. IPRs are statistically related to more biotechnology research and transfer of biotechnology, and the case studies indicated that the adoption of plant biotech leads to benefits for farmers and consumers. Hopefully, there will still be enough benefits captured by the private seed/biotech industry to provide them with continuing incentives to do biotech research.

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Tables

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

Country	1999	2000
United States	28.7	40.3
Argentina	6.7	10.0
Canada	4.0	3.0
China	0.4*	0.7*
Brazil	1.0*	1.0*
Australia	0.1	0.15
South Africa	0.1	0.2
Mexico	<0.1	<0.1
Spain	<0.1	<0.1
France	<0.1	<0.1
Portugal	<0.1	0.0
Romania	<0.1	<0.1
Ukraine	<0.1	<0.1
Uruguay	0.0	<0.1

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. Comparison of Number of Private Firms with Field Trials 1994 and 2000 in Selected Countries.

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

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

Table 4. Methods of Protecting Intellectual Property.

Intellectual Property Protection Method	Description
Patents	Temporary exclusive rights to the use of an invention that is new and useful.
Plant Variety Protection (Plant Breeders' Rights)	Temporary exclusive rights to a new plant variety that is distinct, uniform, and stable.
Trade secret	Business or technical information that a business attempts to keep secret.
Trademark	Word or mark that serves to exclusively identify the source of the product or service
Government monopoly protection	Government gives one company exclusive control of an industry in a particular region
Biological Methods Genetic Use Restriction Technologies (GURTs)	Restricts farmer duplication through a biology based mechanism which prevents them from using seed that they grew. Includes hybrids, which can be reused but with a major loss of productivity, and "terminators" which are a combination of genes which prevents germination of unauthorized saved seed

Table 5. Summary Statistics for Case Study Countries.

Countries	Lesser IP Score 1998[a]	Parks' Index, 1995[b]	PBRs (UPOV member)[c]	No. Crop Biotech Patents[d]	Market Size (Seed Sales in mil. US$)[e]	Public Sector Res. 1991[f]	No. of Crop Field Trials, 1987-2000[g]
U.S.	not avail.	4.86	1981	10,877	5,700	2023	6,439
Canada	not avail.	3.24	1991	725	550	473	1,239
France	not avail.	4.04	1971	636	1,370	456.	472
Argentina	4.90	3.2	1994	2	930	83	321
Brazil	6.70	3.05	1999	396	1,200	638	255
China[h]	5.42	not avail	1999	876	2,500	1494	180
South Africa	7.35	3.57	1977	295	180	164	281

[a] Source: Lesser (2001).
[b] Source: Parks (1995).
[c] Source: World Intellectual Property Organization (2001).
[d] Source: Hanellin (2000).
[e] Source: International Seed Federation (1999-2000).
[f] Source: ISNAR, 1998-1999.
[g] Source: APHIS, Blanco (1998), Blume (2000), Artunduaga-Salas (2001), Australian Office of the Gene Technology Regulator, BINAS, Canada Food Inspection Agency, CONABIA, European Commission, Ghislain (2001), Hinrichsen (2000), Hungarian Agricultural Biosafety Center, James (1998), James and Krattiger (1996), Japan Ministry of Agriculture, Forestry and Fisheries, Maoz (2001), Mexican Direccion General de Sanidad Vegetal, Moeljopawiro (1999), New Zealand Environmental Risk Management Authority, Oswaldo Cruz Foundation, Pray (1998), Robert Koch Institute, and South African Directorate of Genetic Resources.
[h] China's Field trial data is current through December of 1999.

Table 6. Variable List, Data, and Expected Signs.				
Variables Sought	**Variable Used (Name in parentheses)**	**Description of Variable**	**Source of Data**	**Expect-ed Sign**
Dependent Variable:				
Innovation and R&D in Agricultural Biotechnology	Applications for field trials by private firms (Nbrft)	Applications for field trials to test GM varieties by private firms approved and conducted annually 1991-1999	See Table 5 footnote g for sources.	
Independent Variables:				
Appropri-ability	Membership in International Convention for the Protection of New Varieties of Plants, 1991-1999 (UPOV)	A dummy variable to represent the importance of plant protection in a country; 1=member that year; 0=nonmember/year	World Intellectual Property Organization 2001	+
	Plant Patent Laws (PNP)	Countries specifically exclude plants from their patent laws; 0=plants not patentable; 1=plants not specifically excluded	Hanellin, (2000)	+
	Patent Cooperation Treaty Signatory (PCTsign)	A dummy variable to represent the importance of patent rights in a county; 1=signatory that year; 0=nonsignatory/year	World Intellectual Property Organization, 2001	+
	Property Rights Index from Heritage Foundation (PropRts)	The level of property rights protection in a country; a high score, between 0-5, implies less protection	Holmes K. R., Bryan T. Johnson and Melanie Kirkpatrick, 1995-1999.	**-**
	Number of Biotech. Patents Approved in a	Patents in the International Patent Category A01H (New plants or	Delphion website search of INPADOC 1991-1999.	+

	Country (BIOPAT)	processes of obtaining them)		
Expected Market Size	Sales of seed (Seedmkt)	Calculated by dividing 2000 IFS estimate of sales by area planted and then multiply this number times the area planted in each year	Sales from IFS. Area from Food and Agricultural Organization (FAOSTAT)	+
	Agricultural value-added (AVA)	Size of a country's agricultural market	World Bank, World Development Indicators, 91-99	+
	Gross Domestic Product (GDP)	Size of a country's market	World Bank, World Development Indicators, 91-99	+
	GDP per capita (GDPcap)	GDP divided by population	World Bank	+/-
	Economic Freedom Index of Heritage Foudation (ECONFREE)	A measure of the ease of entry into a country's market	Holmes K. R., Bryan T. Johnson and Melanie Kirkpatrick, 1995-1999.	-
	Commercial Approval of GM varieties (COMAPPR)	Dummy variable = 1 if any GM varieties have been approve for commercial use	James 2000	+
Technical Opportunities Available in a Country	Public field trials	Applications for field trials to test GM varieties by public research institutions approved and conducted annually 1991-1999	See Table 5 footnote g for sources.	+
	Biological Abstracts authored in a country (CABABS1)	A measure of the amount of public sector agricultural research conducted in a country	CAB International, 1991-1999	+
	Biological Publications published in a country (CABABS2)	A measure of the amount of public sector agricultural research conducted in a country	CAB International, 1991-1999	+
	Climate of a	A dummy variable	World Atlas,	+

	country (CLIMATE)	1=temperate climate; 0=tropical climate	1995	

Table 7. Factors Influencing Biotech Research: Regression Results for 37 countries 1991-1999

(Dependent Variable Field Trials of Private GM Varieties).

	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 not excluded from 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 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 8. 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
	(19.32)	(12.13)
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.

Figures

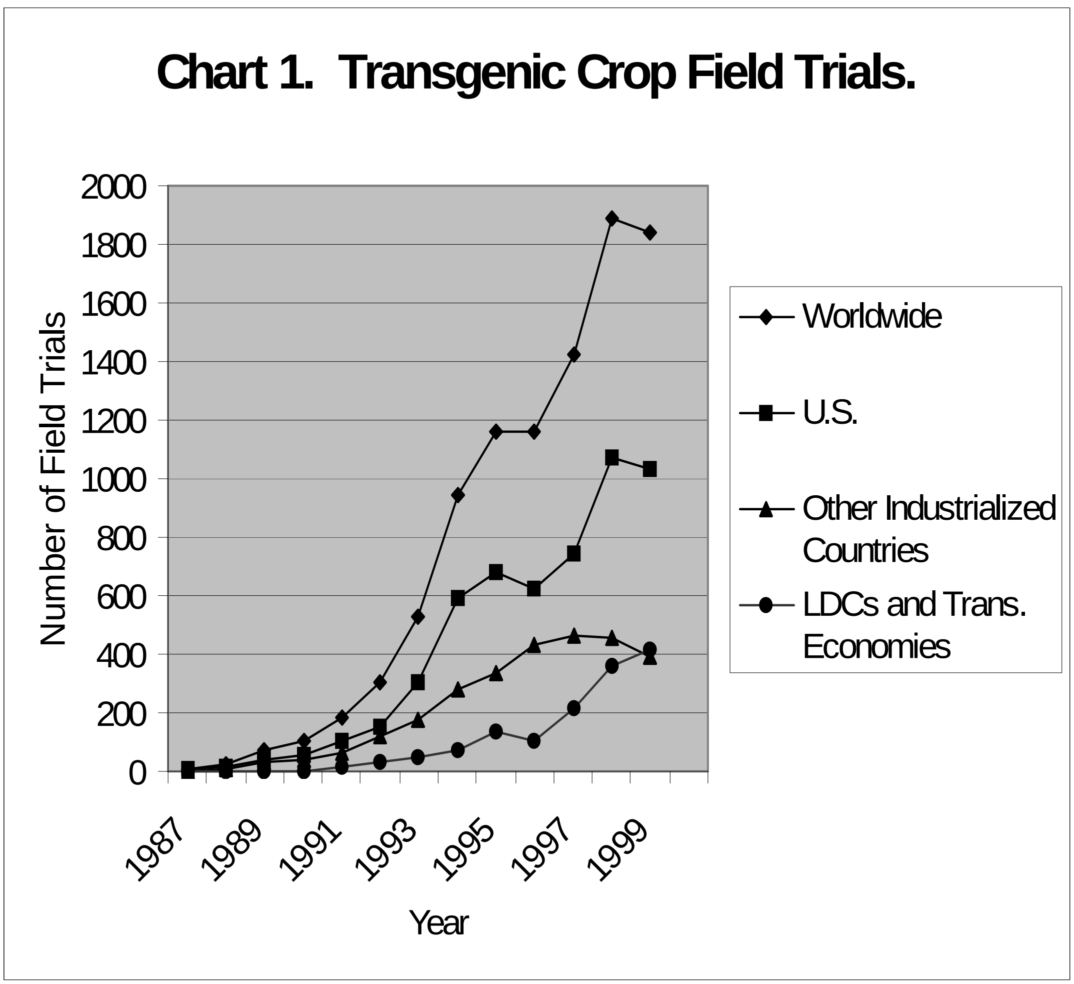


Chart 1. Transgenic Crop Field Trials.
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Number of Field Trials
1987
1989
1991
1993
1995
1997
1999
Year
Worldwide
U.S.
Other Industrialized Countries
LDCs and Trans. Economies

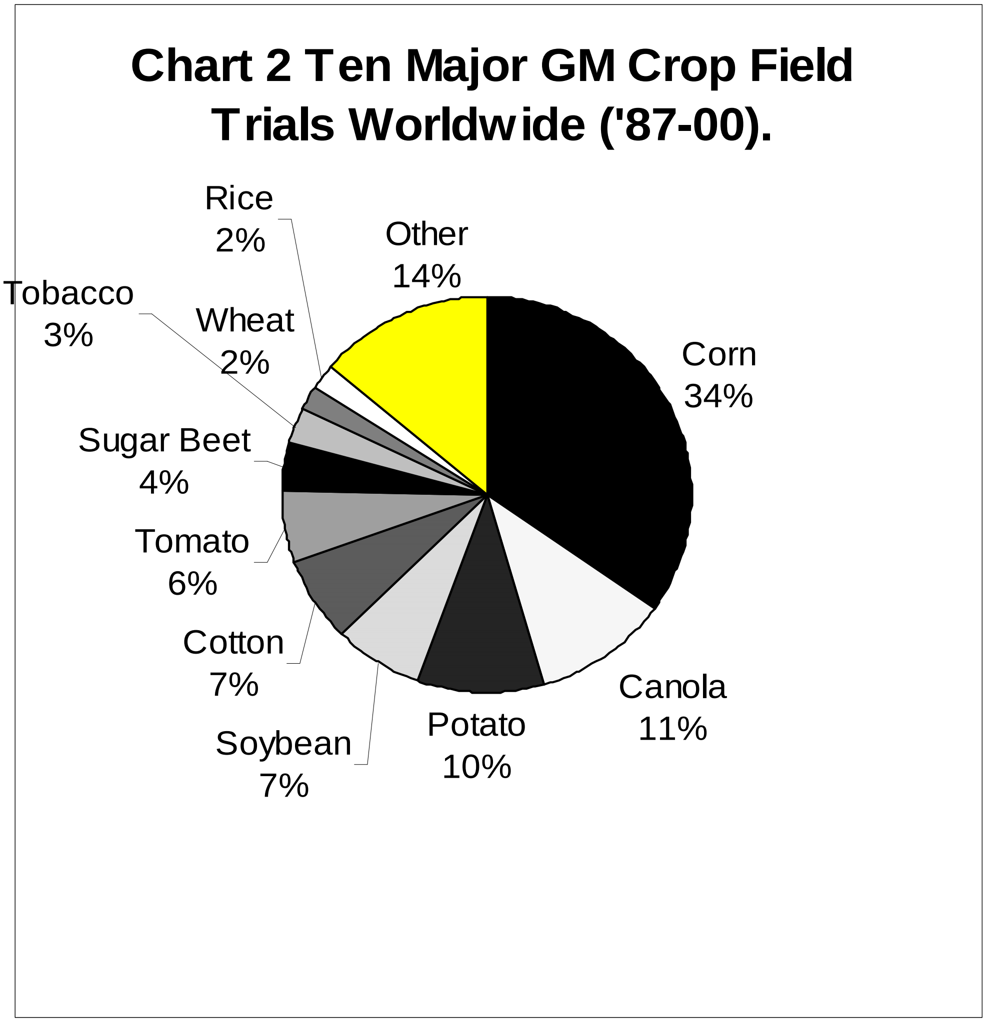


Chart 2 Ten Major GM Crop Field Trials Worldwide ('87-00).
Rice 2%
Other 14%
Tobacco 3%
Wheat 2%
Corn 34%
Sugar Beet 4%
Tomato 6%
Cotton 7%
Canola 11%
Potato 10%
Soybean 7%

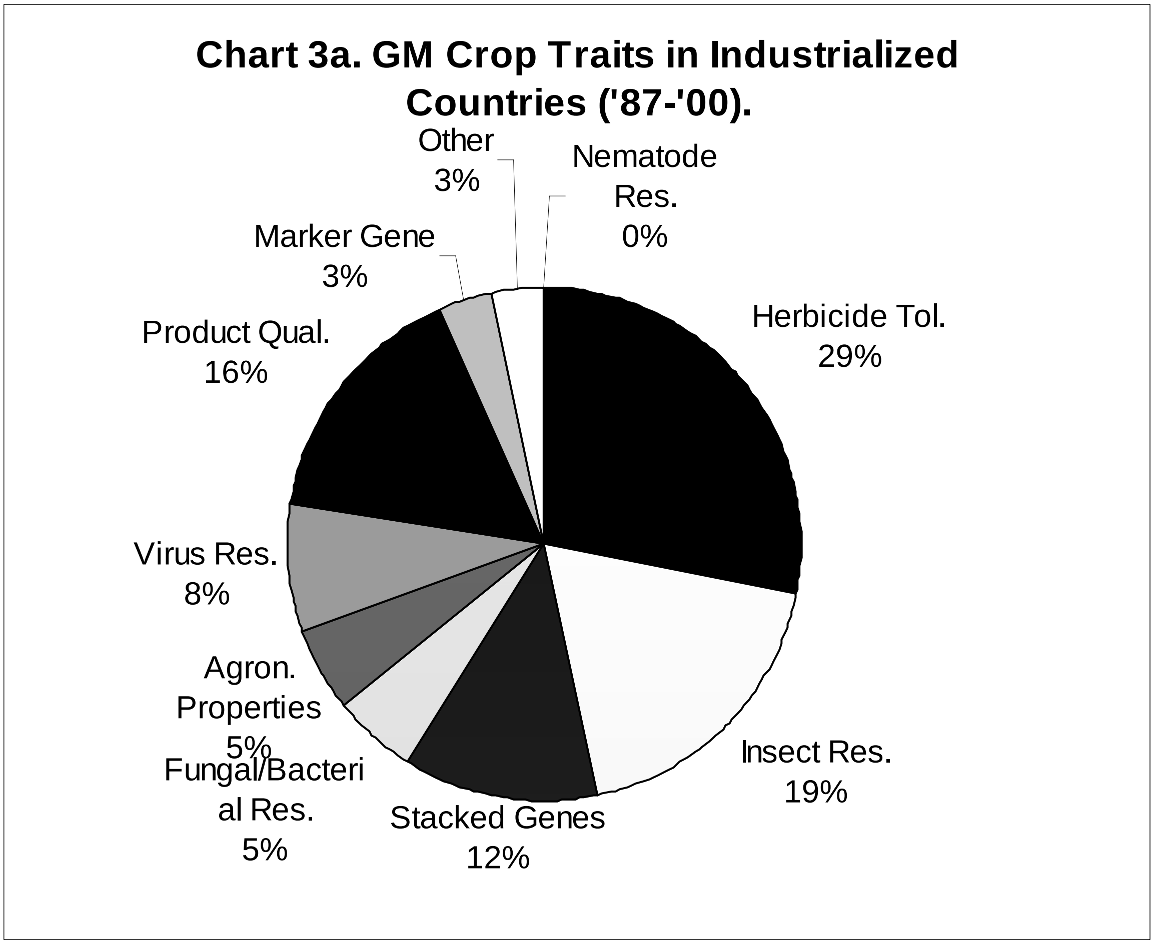


Chart 3a. GM Crop Traits in Industrialized Countries ('87-'00).

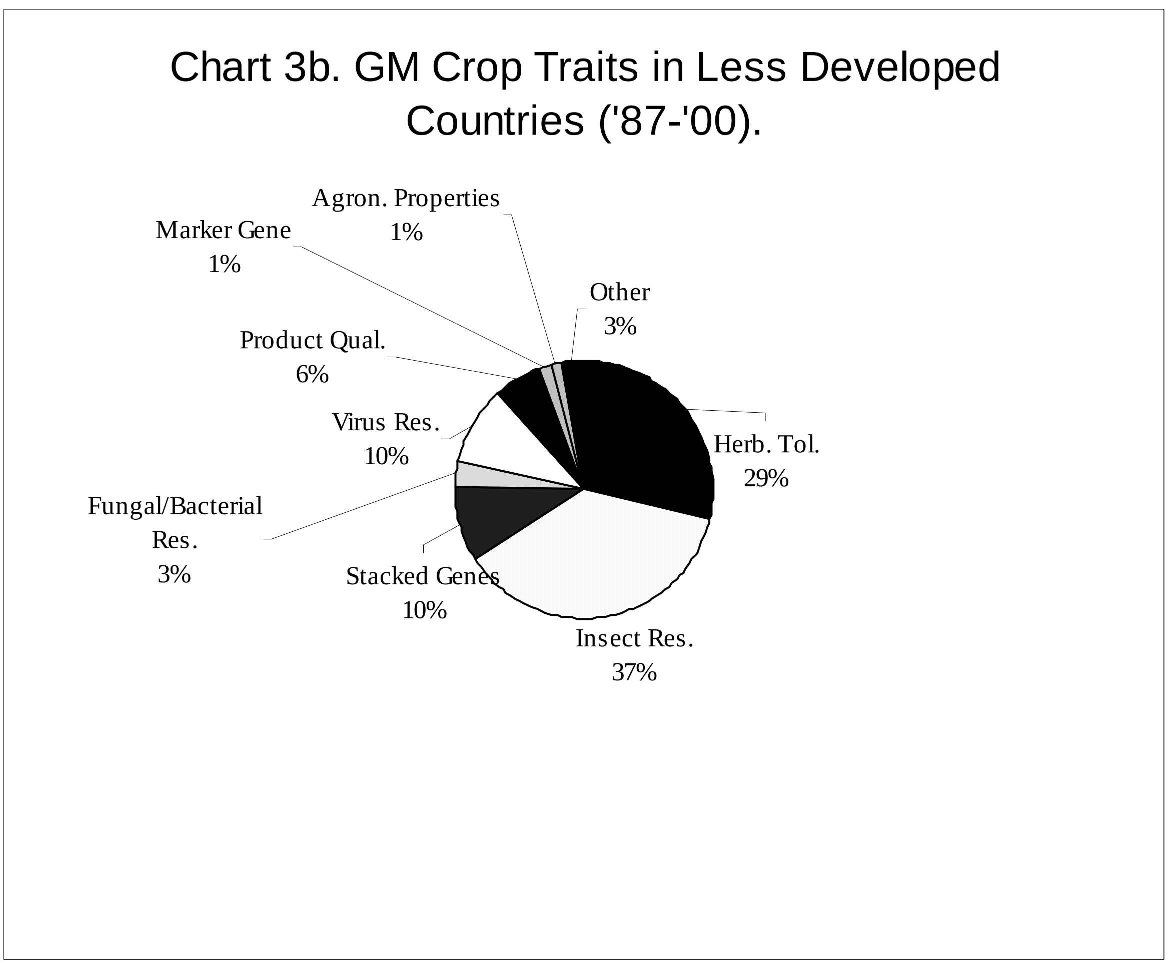


Chart 3b. GM Crop Traits in Less Developed Countries ('87-'00).

Chart 4a. Public/Private Research of GM Crops in Industrialized Countries ('87-'00).

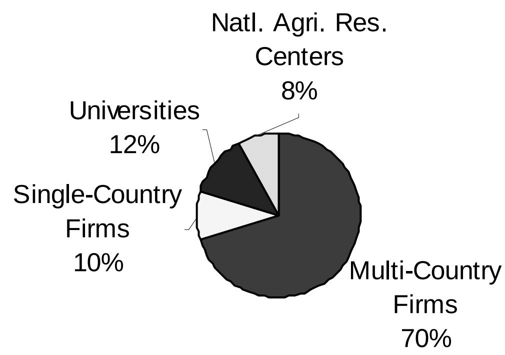
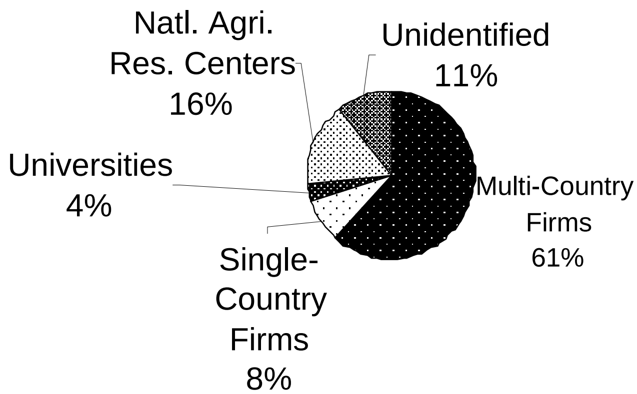


Figure 4b. Public/Private Research of GM Crops in LDCs ('87-'00)



Appendix A-1. List of Countries with Field Trials and IPR Variables.			
Countries with GM Crop Field Trials[a]	UPOV member, on or before 1999[bc]	Patent Cooperation Treaty (PCT) signatory[de] on or before 1999	Plants explicitly excluded from patent laws as of Dec. '00[f]
Argentina	yes	no	no
Australia	yes	yes	no
Austria	yes	yes	yes
Belgium	yes	yes	yes
Belize	no	no	no
Bolivia	yes, as of May 1999	no	no
Brazil	yes, as of May 1999	yes	yes
Bulgaria	yes	yes	yes
Canada	yes	yes	yes
Chile	yes	no	yes
China	yes, as of April '99	yes	yes
Costa Rica	no	yes, as of Aug. 1999	yes
Cuba	no	yes	yes
Czech Republic	yes	yes	yes
Denmark	yes	yes	yes
Egypt	no	no	no
Finland	yes	yes	yes
France	yes	yes	yes
Germany	yes	yes	yes
Greece	no	yes	yes
Guatemala	no	no	yes
Hungary	yes	yes	no
India	no	yes, as of Dec. 1998	yes
Indonesia	no	yes	yes
Irish Republic	yes	yes	yes
Israel	yes	yes	yes
Italy	yes	yes	no
Lithuania	no	yes	yes
Japan	yes	yes	no
Mexico	yes	yes	yes
Moldova, Rep. of	yes, as of Oct. 1998	yes	no
Netherlands	yes	yes	yes
New Zealand	yes	yes	yes
Peru	no	no	yes
Philippines	no	no	yes
Poland	yes	yes	yes
Portugal	yes	yes	no
Romania	no, joined Mar. 2001	yes	yes
Russian Federation	yes	yes	yes
Slovakia	yes	yes	yes
Slovenia	yes, as of July 1999	yes	no
South Africa	yes	yes, as of Mar. 1999	yes
Spain	yes	yes	yes
Sweden	yes	yes	yes
Appendix A-1 Continued.			

Countries with GM Crop Field Trials[a]	UPOV member, on or before 1999[bc]	Patent Cooperation Treaty (PCT) signatory[de] on or before 1999	Plants explicitly excluded from patent laws as of Dec. '00[f]
Switzerland	yes	yes	yes
Thailand	no	no	yes
Turkey	no	yes	no
Ukraine	yes	yes	yes
United Kingdom	yes	yes	yes
United States	yes	yes	no
Uruguay	yes	no	yes
Zimbabwe	no	yes	yes

[a] Source: APHIS, Blanco (1998), Blume (2000), Artunduaga-Salas (2001), Australian Office of the Gene Technology Regulator, BINAS, Canada Food Inspection Agency, CONABIA, European Commission, Ghislain (2001), Hinrichsen (2000), Hungarian Agricultural Biosafety Center, James and Krattiger (1996), James (1998), Japan Ministry of Agriculture, Forestry and Fisheries, Maoz (2001), Mexican Direccion General de Sanidad Vegetal, Moeljopawiro (1999), New Zealand Environmental Risk Management Authority, Oswaldo Cruz Foundation, Pray (1998), Robert Koch Institute, and South African Directorate of Genetic Resources.

[b] This list includes only those countries with GM field trials. A total of 47 countries including those listed above and Colombia, Ecuador, Estonia, Kenya, Kyrgyzstan, Panama, Paraguay, and Trinidad and Tobago were UPOV members as of February 16, 2001.[c] Source: World Intellectual Property Organization (2001).

[d] This list includes only those countries with GM field trials. A total of 108 countries were PCT members as of April 15, 2000.

[e] Source: World Intellectual Property Organization (2001).

[f]. Source: Hanellin (2000).

Appendix A –2. Countries that Have Approved Field Trials of GM Crops by Country Category (1987-2000).

Industrialized Countries	DevelopingCountries (DCs)	Transitional Economies (Europe)
Australia	Argentina	Bulgaria
Austria	Belize	Czech Republic
Belgium	Bolivia	Hungary
Canada	Brazil	Lithuania
Denmark	Chile	Moldovia
Finland	China	Poland
France	Colombia	Romania
Germany	Costa Rica	Russian Federation
Greece	Cuba	Slovak Republic
Irish Republic	Egypt	Slovenia
Italy	Guatemala	Turkey
Japan	India	Ukraine
Netherlands	Indonesia	Yugoslavia (former)
New Zealand	Israel	
Norway	Jordan	
Portugal	Kenya	
Spain	Mexico	
Sweden	Peru	
Switzerland	Philippines	
United Kingdom	South Africa	
United States	Thailand	
	Uruguay	
	Zambia	
	Zimbabwe	

Appendix B. List of GM Crops Approved in Field Trial Worldwide (1987-2001).	
Alfalfa	Melon
Apple	Monoccum
Arab. Thaliana	Mustard (brown)
Asparagus	Mustard (Ethiopian)
Banana	Mustard (Indian)
Barley	Mustard (white)
Beet	Oat
Belladonna	Olive
Broccoli	Onion
Cabbage	Orange (sweet)
Canary Seed	Papaya
Canola (oil seed rape)	Pea
Cantaloupe	Peanut
Capsicum (sweet pepper)	Pear
Carrot	Pepper
Cassava	Persimmon
Cauliflower	Pineapple
Cherry (sweet)	Plum
Chickerinchee	Potato
Chickory	Radish (wild)
Chili	Raspberry
Clover	Red Bean
Coffee	Rice
Corn (maize)	Safflower
Cotton	Soybean
Cranberry	Squash
Cucumber	Strawberry
Eggplant	Sugar Beet
Eucalyptus	Sugar Cane
Flax	Sunflower
Flowers (carnations and others)	Swede
Grape and Grapevine	Sweet Potato
Grapefruit	Tamarillo
Grasses (various)	Tomato
Legume	Tobacco
Lentils	Trees (various)
Lemon	Walnut
Lettuce	Watermelon
Lupin	Wheat
Kiwi Fruit	Yeast