AgBioForum, 8(2&3): 52-63. ©2005 AgBioForum.

Innovation and Dynamic Efficiency in Plant Biotechnology: An Introduction to the Researchable Issues

Carl Pray
Department of Agricultural, Food, and Resource Economics, Rutgers University

James F. Oehmke
Department of Agricultural Economics, Michigan State University

Anwar Naseem
International Food Policy Research Institute

The agricultural biotechnology industry is characterized by heavy investment in research and development, dynamic technical change, and increasing concentration in both the output market and the ownership of intellectual properties that support ongoing innovation. This raises questions about the industry's ability to continue to deliver path-breaking innovations. This paper lays out these questions, describes the relevant data (including the newly available agricultural biotechnology intellectual property database), and provides a conceptual framework for addressing the questions. The empirical discussion and conceptual framework in this paper constitute a structure upon which the remaining articles in this issue build to address the overall question of how best we can maintain socially desirable rates of innovation and dynamic efficiency in plant biotechnology.

Key words: agriculture, agricultural biotechnology, concentration, industry structure, intellectual property, mergers and acquisitions, patents, patent policy, research and development.

The unprecedented consolidation of the agricultural plant biotechnology and seed industries in the late 1990s raised concerns about the development and control of agricultural biotechnologies for farmers. Patent applications increased exponentially, and their concentration in the hands of a few corporations was ominously dubbed "the problem of the anticommons" (Heller & Eisenberg, 1998). The 1990s witnessed legal challenges to many key patents, complaints by scientists and industry that they could not commercialize products that relied on intellectual properties patented by private firms, record numbers of mergers and acquisitions to integrate the biotechnology and seed industries, and complex thickets of interwoven patents that prevented even the most skilled negotiators from obtaining rights to disseminate innovative technologies. Industry responded by aggressively consolidating, so that enabling intellectual properties were owned by the same company, which could then move forward with the commercialization of new agricultural technologies.

This introductory paper has two objectives: (a) to describe the data available for analysis of the plant biotechnology industry, including the introduction and application of a new agricultural biotechnology patent dataset, and (b) to provide a conceptual and empirical background on topics relevant to plant biotechnology that are covered in this issue. We begin this paper with a description of the available data, because the data condition our presentation of empirical background on topics relevant to plant biotechnology.

Background on Available Data

The Research Process

Plant biotechnology research is not a single activity but a sequence of activities that covers the continuum from generating ideas to testing these ideas, developing them into commercial products, and marketing the products. The process of producing a transgenic variety uses public knowledge, proprietary knowledge, and technology protected by intellectual property, money, and other inputs (Figure 1). These inputs are used to hire scientists, build laboratories, purchase equipment, and so on, which are in turn inputs to later stages of the research process. The research produces genetically modified (GM) plants, possibly along with patents on improved research protocols such as new genetic sequences, transformation techniques, or new promoters. These intermediate products are then inputs into a commercialized variety.

Expenditure Data

Data on biotechnology research expenditures at various stages of the research and development process would be ideal for many purposes—especially for benefit-cost applications. It would allow calculations of research concentration and the flow of research expenditures

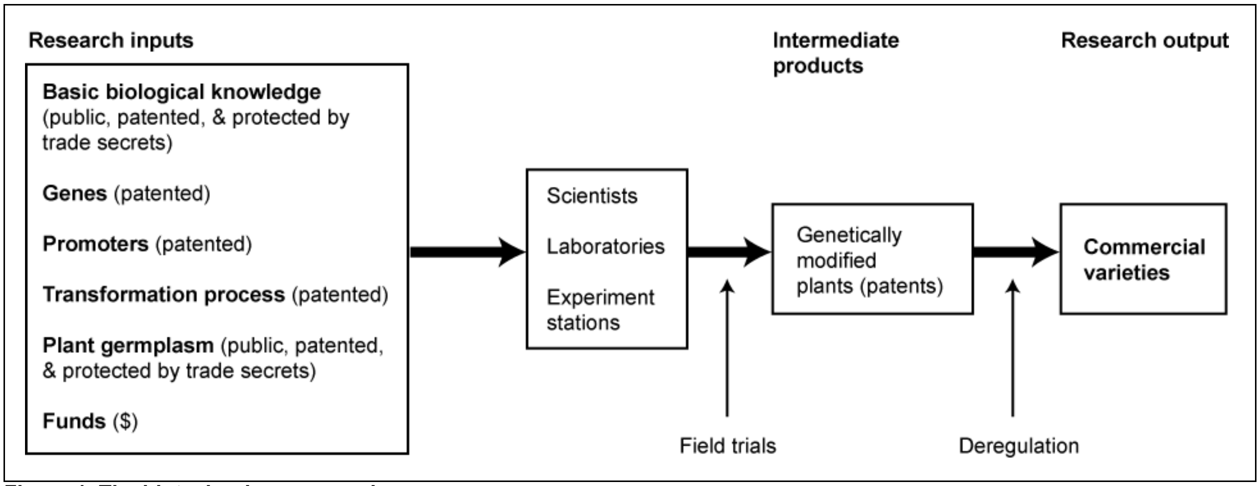

Figure 1. The biotechnology research process.

over time. However, there is no regular process of reporting biotechnology research expenditure. Nor are research budgets an ideal measure: Money is an input into the research process and hence not a perfect measure of research activity. Moreover, dollars are fungible. Therefore, it is sometimes difficult to associate expenditures with particular aspects of the research process. Finally, most private-sector firms will not reveal research expenditure data in any detail, and so other data are needed to measure research activity.

Field Trial Data

Scientists in a research program start with basic knowledge about plants, pests, the environment, and market needs. To develop GM plants, scientists insert promising genes and promoters into available plant lines using plant transformation technology. Once the plants have been transformed, they are first tested in greenhouses. The varieties that survive this round of testing are then tested outdoors in fields.

Before firms can conduct field trials, they must obtain permission from the Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture (USDA). Under the authority of the Federal Plant Pest Act, APHIS regulations provide procedures for obtaining a permit or for providing notification prior to introducing a regulated article[1] in the United States. Companies or research institutes that are conducting research to develop genetically modified organisms (GMOs) must apply to APHIS for a permit or notification[2] to do a field test (a "release into the environment").

Field trial data, available at http://www.nbiap.vt.edu/cfdocs/fieldtests1.cfm (Information Systems for Biotechnology [ISB], 2005b), can be used as a measure of research activity near the end of the research process, as shown in Figure 1. These data provide an indicator of biotechnology research by individual firms over time (Ollinger & Pope, 1995). Field trial data can be disaggregated by firm, crop, gene (e.g., *Cry1Ac* or *Cry2A*) phenotype characteristics (e.g., insect resistance or herbicide tolerance), and several other variables. Importantly, the APHIS data set is a census of all field trials conducted in the United States, so that the researcher does not have to worry about sample selection or if the sample is representative.

Previous applications of field trial data to understand the structure of the biotechnology industry include Brennan, Pray, and Courtmanche (2000), Oehmke (2001), Fulton and Giannakis (2001), Oehmke and Wolf (2003), and Oehmke, Wolf, and Raper (2005), each of which uses the data to help describe the structure of the industry.

1. *Regulated articles are considered to be organisms and products altered or produced through genetic engineering. The act of introducing includes any movement into (import) or through (interstate) the United States, or release into the environment outside an area of physical confinement. APHIS regulates GMOs that may pose a plant pest risk, including almost all genetically modified plants.*
2. *Firms can either apply to conduct a field test or for a notification, which is a simplified procedure. If a field trial is requested, APHIS reviews the permit application and prepares an environmental assessment of the potential environmental impact of the release. A field test that involves tomato, corn, tobacco, soybean, cotton, or potato and meets other criteria can be granted a notification, which does not involve an environmental assessment.*

Data on Deregulation

Once the firm has completed field trials and selected a genetically improved plant(s), the firm then moves to developing a variety based on that plant and commercializing that variety. A standard practice is to then produce a sufficient number of clones to introduce the new gene into traditional breeding programs. To obtain legal approval to use the new gene in breeding programs, the firm applies to the USDA for deregulated status; if the USDA grants the application, the new plant is no longer a regulated article and can be treated as a non-GM plant for commercialization purposes. Deregulation marks the end of the GM research process.[3]

APHIS maintains a publicly available database of deregulated crops at http://www.nbiap.vt.edu/cfdocs/biopetitions1.cfm (ISB, 2005a). As with the field trial data, this database contains information on petitioning firm and crop characteristics (including genetic modification) and constitutes a complete census of all deregulated crops.

Utility Patent Data

The US Supreme Court decision in *Diamond v. Chakrabarty* (1980) allowed patenting of living tissue or components thereof. Ensuing case law has allowed patenting of genetic sequences, and *ex parte Hibberd* (1985) extended patent protection to new plant varieties. These decisions have led the agricultural biotechnology industry to rely heavily on utility patents for intellectual property (IP) protection.

Although a perfect measure of innovation has yet to be found, historically patent statistics have proven adequate to that end (Acs & Audretsch, 1989; Griliches, 1990). Patents as a measure of innovative activity have a long history in the economics literature, with seminal contributions by Griliches, Pakes, and Hall (1986), and Hausman, Hall, and Griliches (1984). Griliches (1990) wrote that patents are appropriate for measuring innovation output as they "are available, they are by definition related to inventiveness, and they are based on what appears to be an objective and slowly changing standard." The emphasis of much of the previous work has been to examine the relationship between research dollars spent on inventive activity and innovation. Griliches et al. (1986), for example, found a strong relationship between the number of patents granted and R&D expenditures in a firm-level cross-sectional data analysis, leading to the conclusion that patents are a good indicator of differences of inventive activity. In agricultural biotechnology, patents (at least of genetic constructs and transformation tools) tend to indicate activity at the earlier stages of the research process (Figure 1). Utility patents of novel plants would indicate activity at a late stage of the research process.

Using patent data is difficult. The US Patent and Trademark Office (USPTO) makes available the text of all patent applications that are granted. From 1976 to 2000, about two million applications are in this database. Although the USPTO classifies patents by category, agricultural biotechnology patents can appear in at least eight extant and one defunct category. The complexity of patent applications creates further difficulties. For example, a word search of patent applications for the phrase *bacillus thuringiensis* (Bt) reveals more than 3,100 patents, including several hundred patents seemingly related to the development and application of Bt sprays with no apparent connection to biotechnology or genetically modified plants. Until recently, the number of patent applications and the complexity of the USPTO database made it extremely difficult to use patent data for agricultural biotechnology.

This issue of *AgBioForum* introduces a new agricultural biotechnology patent dataset to the literature. A consortium of University and USDA researchers has filtered the USPTO database to create a database of agricultural biotechnology patents (details are available at http://www.ers.usda.gov/data/AgBiotechIP/filtering.htm). The first step in this filtering was to use the USPTO classification system to eliminate patents in categories that were clearly unrelated to agricultural biotechnology. This reduced the number of possibly relevant patent applications to about 130,000. Using new linguistic software, these applications were then parsed to determine if they were indeed agricultural biotechnology patents. A total of 11,740 agricultural biotechnology patents were identified. These patents were then classified into seven main technology headings and 58 subtechnologies that are designed to be research friendly. (A detailed description of the classification scheme is available at http://www.ers.usda.gov/data/AgBiotechIP/classification.htm.) This database is searchable by entity (organization), entity type, technol-

3. *One could consider development of a variety as the last step in the research process, and variety data is certainly important when examining the adoption and impact of biotechnology research. However, because deregulation allows the genetic modification to be crossed into a number of varieties using traditional breeding techniques, even transgenic variety data carry limited information about biotechnology research activity.*

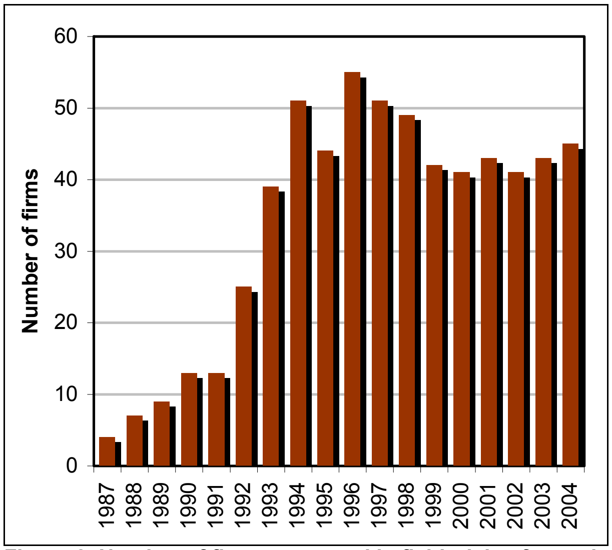

Figure 2. Number of firms enganged in field trials of genetically modified crops, 1987–2004.
Note. Data from ISB (2005b).

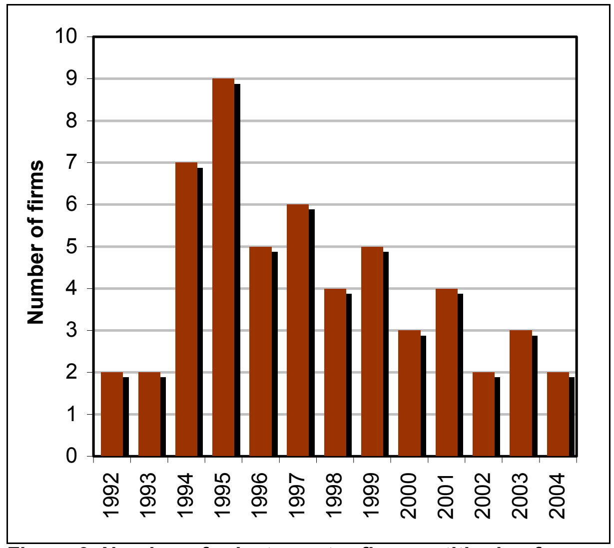

Figure 3. Number of private-sector firms petitioning for deregulation of a genetically modified crop, 1992–2004.
Note. Data from ISB (2005a).

ogy heading, and technology subheading. The database is publicly available at http://www.ers.usda.gov/data/AgBiotechIP (USDA Economic Research Service [USDA ERS], 2004).

The papers in this issue, for the most part, rely to some degree on this new database to address issues of industry evolution, intellectual property rights, the level and productivity of inventive activity, the role of the public sector, and public policy in the agricultural biotechnology industry.

Conceptual and Empirical Background on Topics Covered in This Issue

Industry Evolution and Structure

The first measure used to quantify the evolution of an industry is how the number of firms in the industry changes over time. Because in a typical year less than half of the patent applications show the assignee, it is difficult to get an accurate count on the number of firms who are engaged in agricultural biotechnology research that leads to patented outcomes. Consequently, to identify the firms in the agricultural biotechnology research industry, we need field trial and deregulation data, which give accurate counts at the later stages of the research process, although they may not be representative of firm numbers at earlier stages of the process.

Figure 2 shows the number of firms engaged in field trials from 1987 to 2004. This number climbed rapidly between 1987, when the first transgenic field trial was conducted, and 1994, when 51 firms conducted field trials. The number of firms peaked in 1996 at 55, then declined slightly, and for the past six years has been hovering in the low to middle 40s.

Figure 3 shows the number of firms petitioning for deregulation from 1992 to 2004. In 1992 Calgene filed the first petition for deregulation, of a genetically modified tomato. The number of firms that petitioned for deregulation peaked in 1995 (nine firms), and declined through 2004 when only two firms filed petitions.

The second important measure of industry evolution is the level of R&D activity in the industry. Figure 4 shows the level of agricultural biotechnology patenting activity by year from 1976 through 2000. The data represent the total number of patents granted, with the year representing the date of application. The number of agricultural biotechnology patents has grown exponentially over the sample period. The proportion of agricultural biotechnology patents increased from about 1% of all US patents in 1976 to over 10% in 2000.

The number of field trials represents the level of inventive activity at a later stage in the research process. Figure 5 shows that the number of field trials increased steadily until 1998, then fluctuated somewhat, and finally declined in the past two years.

Industry Structure

Two important measures of industry structure are concentration and merger-and-acquisition activity. Concentration brings to the foreground the underlying

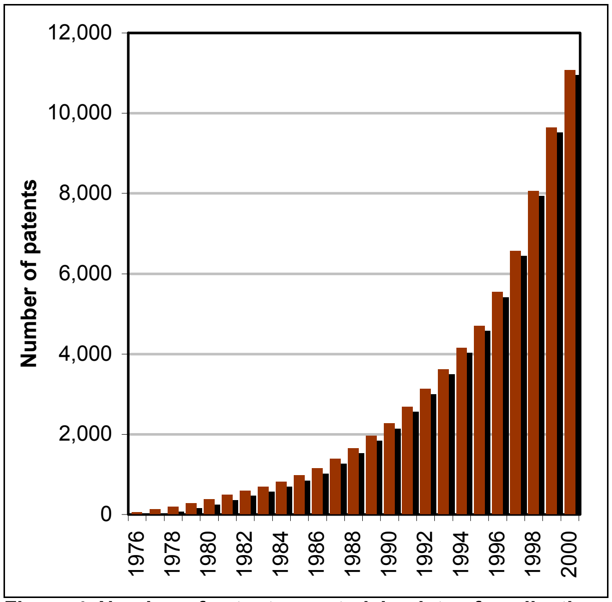

Figure 4. Number of patents granted, by date of application (public and private).
Note. Data from USDA-ERS (2004).

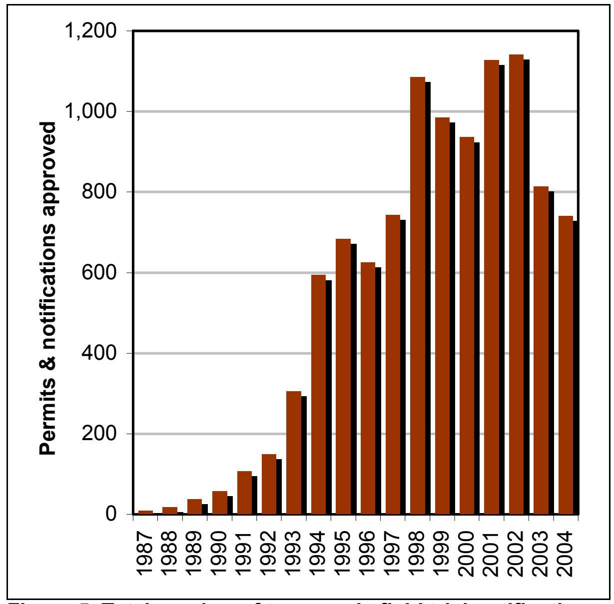

Figure 5. Total number of transgenic field trial notifications and permits approved, by year of application.
Note. Data from ISB (2005b).

economic tradeoff between static efficiency and dynamic efficiency that is inherent in any R&D-based industry. Static efficiency—the maximization of social welfare in the market (for agricultural biotechnology products such as seeds) at a specified point in time—occurs when the market structure is competitive and no firm has market power. However, the absence of market power prevents firms from recovering investments necessary to enter the market, such as the R&D investment necessary to enter the transgenic seed market. That is, if Monsanto's Roundup Ready technology were available free of charge to all comers, then Monsanto would not be able to recoup its R&D costs and/or have funds available for further research. Thus, some degree of market power and monopoly rents—and hence a degree of concentration in the industry—appears to be necessary in order to provide corporations with the profit incentives to invest in R&D. It is less clear whether market power is necessary in the innovation market, that is, in the market for the insertion techniques, promoters, and other intermediate research products.

During the late 1990s, there was growing concentration in the ownership of agricultural biotechnology patents. Scientists became concerned that private firms would not allow their competitors or the public sector permission or licenses to use the research tools and/or to commercialize their research products. The high transaction cost of tracking down and licensing the multiple patents required to be able to commercialize the products was also a concern. There is anecdotal evidence that some universities and private-sector companies have abandoned patenting, commercialization, or even research programs due to this problem (see Pray & Naseem in this issue). This problem is described as "the problem of the anticommons" (Heller & Eisenberg, 1998) or as "patent thickets" (Shapiro, 2001).

Consolidation in the biotech industry has increased the concentration of ownership in intellectual property rights. Because the largest firms in the industry have the largest R&D budgets, it is not surprising that they possess the greatest number of patents. However, mergers and acquisitions (M&As) by larger firms have increased the concentration of patent ownership much more than R&D alone. Table 1 shows the growth in agricultural biotechnology patenting and the effect of M&A activity. Column 2 in Table 1 shows the number of patents that can be matched with the firms that own the patents (assignees). Columns 3 and 4 show the number and the share of all biotech patents held by the companies with the ten greatest numbers of patents. Column 5 and 6 show the number and share of biotech patents after accounting for mergers and acquisitions. Column 6 shows that the top ten firms increased their control of biotech patents to over 50% in 2000. This could be a response to the anticommons/thicket problem: instead of negotiating for the rights to a competitor's technology, it might be simpler, cheaper, or more advantageous to acquire the competitor outright. It is possible that this

Table 1. Concentration of US agricultural biotechnology patent awards among top 10 patent holders, 1976–2000, including adjustment for mergers and acquisitions, 1988–2000.

			Excluding patent ownership of subsidiary organizations		Including patent ownership of subsidiary organizations (1988–2000)	
Year	Cumulative ag biotech patents	Cumulative ag biotech patents matched to assignees	Cumulative matched ag biotech patents, top 10 assignees	CR-10 ratio of matched patents	Cumulative matched ag biotech patents, top 10 assignees	CR-10 ratio of matched patents
1976	54	15	13	0.87	—	—
1977	129	42	35	0.83	—	—
1978	201	76	65	0.86	—	—
1979	277	107	89	0.83	—	—
1980	376	142	113	0.80	—	—
1981	483	178	136	0.76	—	—
1982	594	221	159	0.72	—	—
1983	694	259	176	0.68	—	—
1984	818	309	205	0.66	—	—
1985	974	377	238	0.63	—	—
1986	1,143	446	267	0.60	—	—
1987	1,385	541	303	0.56	—	—
1988	1,649	643	345	0.54	374	0.58
1989	1,965	768	398	0.52	398	0.52
1990	2,270	906	467	0.52	467	0.52
1991	2,689	1,059	514	0.49	514	0.49
1992	3,132	1,189	544	0.46	548	0.46
1993	3,625	1,348	591	0.44	595	0.44
1994	4,157	1,543	644	0.42	648	0.42
1995	4,701	1,733	701	0.40	705	0.41
1996	5,541	2,050	812	0.40	850	0.41
1997	6,569	2,387	896	0.38	998	0.42
1998	8,060	2,987	1,068	0.36	1,314	0.44
1999	9,641	3,596	1,239	0.34	1,733	0.48
2000	11,076	4,085	1,432	0.35	2,080	0.51

Note. — = not available. Data from USDA ERS (2004).

concentration also imposes barriers to entry by elevating the level of complexity necessary to compete effectively.

As the technology has developed, patenting has become increasingly widespread in every major area of agricultural biotechnology. Every successive five-year period has seen more patented innovation than the last period—in every technology. It is unclear whether this supports the anticommons/patent thicket concern.

It is worth noting that the area with the greatest intensity and a rapid increase is genetic transformation (see Figure 6). This is one of the key research tools and thus potentially an area of great concern. Other areas with a strong likelihood of containing research tools—DNA-scale metabolic pathways and genomics—have fewer patents but perhaps a greater rate of increase.

Private companies own the largest share of patents, but other entities are also performing R&D and obtaining patents in significant amounts (Figure 7). Universities and national research centers have been active in this area. Although the public and university patenting that occurred is smaller in size, it has increased at a similar rate of growth. This activity may be effective in combating patent thicket issues if public research is targeted towards research tools, enabling technologies, or areas conducive to the creation of startup firms.

Growth in research on plant breeding and plant biotechnology by private firms has followed a path consis-

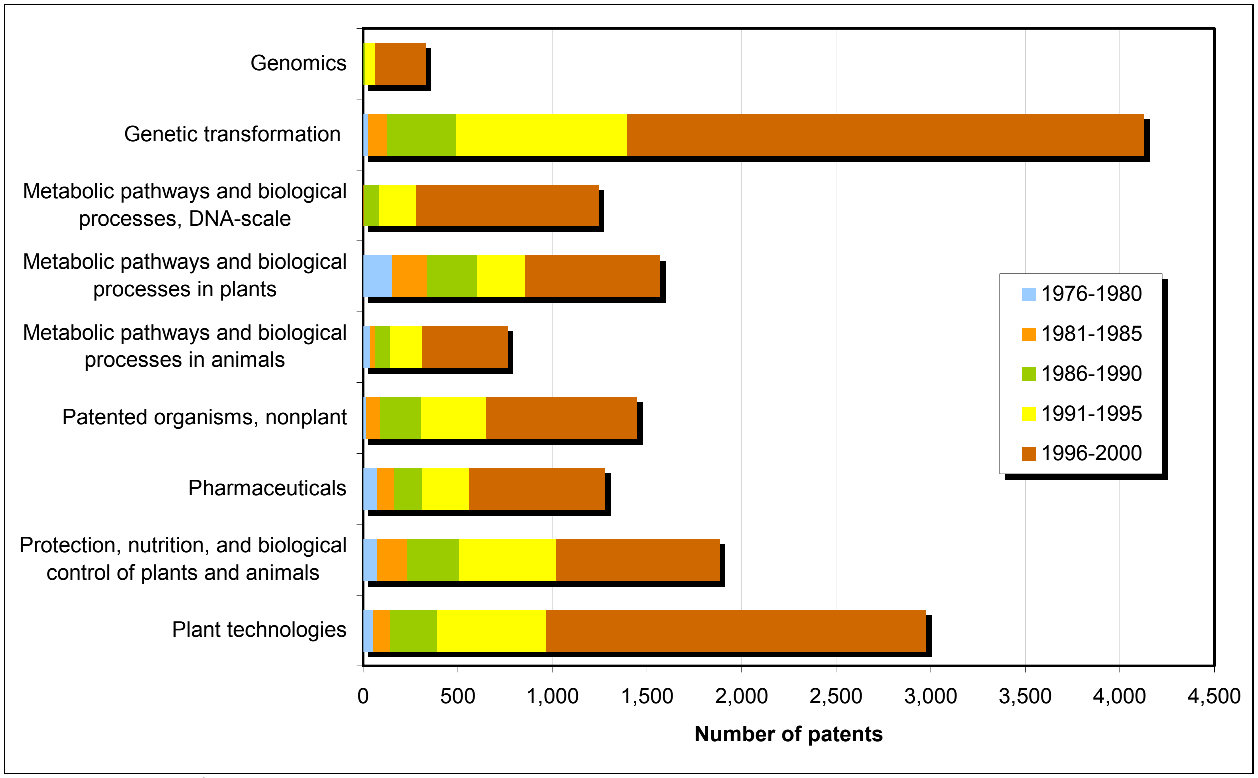

Figure 6. Number of plant biotechnology patents by technology category, 1976–2000.
Note. Data from USDA ERS (2004).

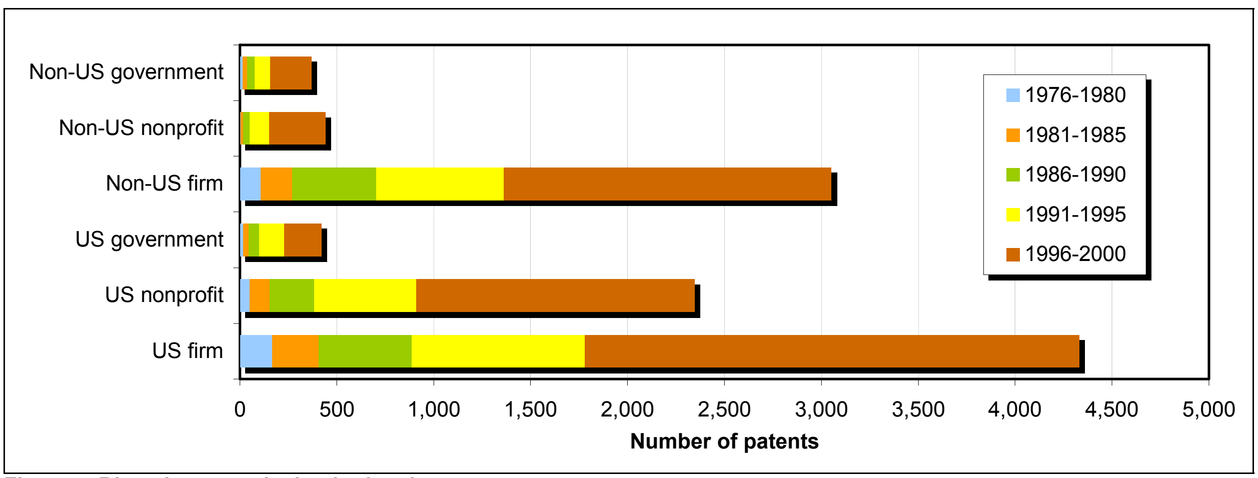

Figure 7. Biotech patents by institutional type.
Note. Data from USDA-ERS (2004).

tent with the argument that in the early years patents induced research, but later too many patents and too much concentration slowed down research. Agricultural biotechnology research increased very rapidly in the late 1980s and 1990s in response to the technological opportunities offered by the breakthroughs of cellular and molecular biology and stronger IP rights. Some of this change was due to companies shifting research resources from chemical research to biological research. Since the late 1990s, however, several of the largest firms have reduced their agricultural biotechnology research, and in the aggregate agricultural biotechnology research expenditures probably stagnated. Monsanto reduced its research expenditure, which is about

85% agricultural biotechnology and plant breeding, from $588 million in 2000 to $510 million in 2003 before increasing it 6% this year (Monsanto, 2005). Syngenta's total agricultural research, of which about 21% is biotech and 15% plant breeding, declined from $745 million to $727 million from 2000 to 2003 (Syngenta, 2005). In 2003 they closed their Torrey Mesa Research Institute in California. Dow Agrosciences reduced its research expenditure, although we do not know how much that budget is.

In contrast, Pioneer's research budget declined about a year after the 1998 merger with DuPont, when DuPont's plant biotechnology and Pioneer's agricultural biotechnology units were unified and rationalized. However, since then the seed and agricultural biotechnology research budget of DuPont has increased steadily, according to former Pioneer scientist Anthony Cavalieri (personal communication, October 14, 2004). Two unknowns are the trends in Bayer and BASF. Bayer's seed and biotech research budget now compares with the research budgets of Bayer (which did almost no biotech research) and Aventis, which they bought. BASF bought American Cyanamid, which may have increased its agricultural biotechnology research temporarily, but these research expenditures declined from $285 million in 2002 to $239 million in 2003 (BASF, 2005).

There were also concerns that patents were leading to concentration in the agricultural biotechnology and seed industry. Large chemical companies were thought to be buying up agricultural biotechnology companies in part to acquire research tools and traits such as Bt genes for insect resistance and in part to get control of the most productive plant germplasm, which could be the varieties that would carry the transgenic characteristics to the market. The concern about the concentration of the industry in a few hands was that this would reduce the amount and the productivity of research and as a result it would slow the development of new technology for farmers and consumers. This problem could work through several pathways. First, the merger of two large firms almost always leads to the consolidation in R&D expenditures in the name of rationalization or efficiency. Whether consolidation results in greater efficiency is an empirical question. Second, if existing firms in a concentrated industry use their market power to create barriers to new firms entering the industry, creative startup firms with intellectual roots in the universities or spinoffs from major firms could be substantially reduced. This could reduce the effort of some of the most creative and potentially valuable research in the seed and biotech industry.

A final concern about concentration is that it would allow the large biotech firms to capture most benefits from agricultural biotechnology rather than passing on some of these benefits to farmers and consumers. For this to happen, there would have to be substantial monopoly power in the seed/biotech industry and few substitutes for the concentrated products of the biotech industry.

Mergers and Acquisitons

The plant biotechnology R&D industry now consists of six large firms, a varying number of smaller firms, and public-sector research organizations such as land-grant universities. Consolidation in the seed industry has been ongoing since at least 1970, but even in the early 1980s there were more than two hundred different seed companies (Butler & Marion, 1985), many agricultural chemical companies, and few companies that had both seeds and agricultural chemicals. In the early 1990s, the industry had a vision of the integrated life-sciences company, which sold high-value products ranging from pharmaceuticals to pesticides to transgenic seeds. This vision led to a consolidation and then reorganization within the agricultural industry.

At first, pharmaceutical and chemical companies sold off their bulk chemicals businesses and bought up or merged with other pesticide and pharmaceutical companies. The major life-sciences companies each purchased smaller biotechnology companies that had promising new genes and seed companies that owned efficient seed distribution networks and/or traditional varieties into which novel genes could be inserted (Table 2). Monsanto, for example, transformed itself into a company driven almost exclusively by the promise of genetically modified crops, herbicides, food products, and pharmaceutical products.

The integrated life sciences companies proved unwieldy, and when the European Union shunned genetically modified crops, much of the luster rubbed off. This led to a sequence of divestitures and rearrangements, such as Aventis's sales of its Crop Science Unit to Bayer in 2001 and Monsanto's 2000 merger with Pharmacia only to separate the agricultural and nonagricultural businesses in 2002 (Table 2).

The effect of these mergers on innovation market structure can be seen by an examination of M&A activity among firms who are conducting transgenic field trials in the major crops. In Figure 8 the line represents the aggregate number of M&A events in the five major US transgenic crops (corn, cotton, potato, soybean, and

Table 2. Selected mergers and acquisitions in the US and European agricultural chemicals, biotechnology, seeds, and food/feed industries.

	Agricultural chemicals	Biotech	Seeds	Food/feed/industry
Monsanto (merged with Pharmacia in March 2000; spun off entirely in August 2002)		Agracetus (1995) Calgene (1996) Ecogen (13%) Millenium Pharmaceutical (joint venture for crops genes) Paradigm (2000; $50 million contract)	DeKalb (1996) Asgrow (1997; corn and soybeans) Holden's Foundation Seeds (1997) Cargill International Seeds, Plant Breeding Intl. (1998) Delta & Pineland (1994; alliance, not purchase) Seminis (2004) Emergent Genetics (2005)	Renassen (a joint venture for feed and food with Cargill; 1998) Monsanto sold brands like Nutrasweet in 2000
Bayer (bought Aventis Crop Sciences in 2001)	Hoechst & Schering create Agrevo (1994) Hoechst (Agrevo) & Rhone-Poulenc merge to create Aventis (1999) Bayer buys Aventis Crop Sciences in August 2001 for $6.6 billion	Plant Genetic Systems (1996) PlanTec (1999) Lion Biosciences (11.3%; 1999)	Nunhems, Vanderhave, Plant Genetic Systems, Pioneer Vegetable Genetics, Sunseeds (1997) Nunza (vegetables) Proagro (India) & 2 Brazilian seed companies (1999) Fibermax (joint venture with Cotton Seed Inc. of Australia; 2000?)	Solavista & Novance (alliances for starch & nonfood oils)
Syngenta (Novartis+ Astra-Zeneca Ag., 1999)	Formed by merger of Novartis agriculture division & AstraZeneca's Ag. Chemicals, December 1999 Novartis buys Merck's pesticide business for $910 million (1997) Novartis formed by Ciba-Geigy and Sandoz merger (1996)	Zeneca Ag. bought Mogen International N.V. (1997) Alliance with Japan Tobacco on Rice (1999) Alliance with Diversa (2002) Zeneca buys PSA Genetics (via Garst subsidiary; 1999)	1996 merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co Golden Harvest (2004) ICI splits into Zeneca (including ICI seeds) and ICI PLC (1993) Garst reborn as a Zeneca company (1996) Zeneca via Garst buys Agripro Seeds (1998), Gutwein Seeds (2000)	
Dow Chemicals	Dow purchases Eli Lilly's 40% share of Dow Elanco for $900 million (1997) Rohm and Haas Ag.Chem (2001)	Mycogen (1996–98) Ribozyme Pharmaceuticals Inc. Proteome Systems Limited (1999 contract)	Mycogen buys Agrigenetics (1992) United AgriSeeds becomes part of Mycogen (1996) Phytogen (joint venture with Mycogen for cotton seed with Boswell; 1998) Danisco Seeds (joint venture; 1999) Illinois Foundation Seed (agreement; 1999) Cargill Hybrid Seeds U.S. (2000)	Agreement with Cargill on plastics from corn
DuPont		Alliances with Human Genome Sciences (1996) Curagen (1997) Purchased Verdia from Maxygen for $64 million (2004)	Pioneer (1997; 20%) Hybrinova (France; 1999) Bought other 80% of Pioneer in 1999	Quality Grain (1998; joint venture with Pioneer), Protein Technologies (food), Cereal Innovation Centre UK Joint venture with General Mills on soy protein Working on fiber from starch Joint venture with Bunge on soy products (2003)
BASF	Bought Sandoz N. American Herbicide business (1996) American Cyanamid from AHP for $3.8 billion (2000)	SunGene (joint venture with Institute of Plant Genetics & Crop Plant Research) Metanomics (joint venture with Max Planck Institute)	Bought 40% of Svalöf Weibull (1999)	

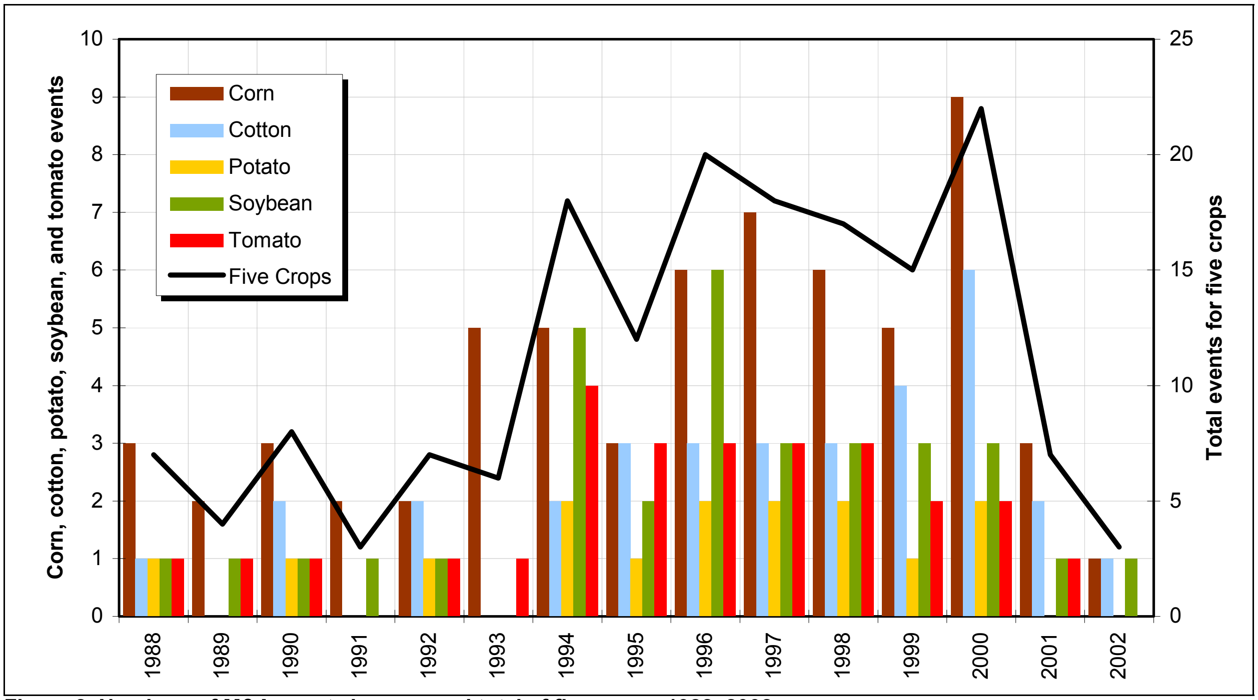

Figure 8. Numbers of M&A events by crop and total of five crops, 1988–2002.

tomato). The industry was most actively in M&A events from 1994 through 2000, with a peak of 22 in 2000 and a notable decline thereafter. This aggregate pattern is largely determined by M&A activity where at least one firm had conducted transgenic corn or cotton field trials. For M&A events involving at least one firm that had conducted transgenic corn field trials, peak activity occurred in 2000 with nine events. Cotton M&A activity also peaked in 2000 with six events. Soybean activity peaked in 1996 with six events, contributing to a secondary peak in aggregate M&A from 1994 to 1998 relative to other years. There were never more than two potato M&A events in any year, although M&As involving at least one firm that had conducted transgenic potato field trials were most common from 1994 through 2000.

The picture painted by the M&A data is one of an industry that went through a period of significant consolidation from 1994 through 2000 with minor adjustments to company organization in 2001 and 2002. This picture is consistent with the evidence on increasing concentration since 1995.

Public Policy

The role of public policy is to generate the socially optimal industry structure and level of research. The government has a selection of interventions at its disposal, from tools for controlling the structure of the output market to tools for controlling the structure of the market for intermediate R&D products (the innovation market) to sponsoring or even conducting research.

Patent Policy

The first set of policy tools are patent policies. Patent laws themselves can be changed, but that is a monumental task. The USPTO policy guidelines on what it takes to patent something can be changed, but perhaps more important is that the courts' interpretation of the patent law might be changed by well-argued academic and legal papers. Finally, private firms themselves can be encouraged to conduct their research, publishing, patenting, and licensing policies in such a way to make the knowledge and research tools that they develop more accessible to the public sector and small private firms.

Antitrust Policy

Antitrust policy can be used to ensure that none of the agricultural input firms has too much market power in the product market. Less frequently, antitrust power is used to prevent too much concentration of patents on important research tools in the hands of one firm. There are two primary roles for antitrust policy: to prevent mergers or acquisitions that would create a noncompetitive market structure, and to prevent or punish the use of monopoly power. (For a review see Kovacic & Shapiro, 2000.)

The Role of Public-Sector Research

The third type of policy tool is public research institutes' research, patenting, and licensing policies. Universities and governments can develop technologies that provide alternatives to the tools controlled by the large firms. There are a number of reasons why universities may wish to patent or otherwise protect their intellectual property, not all of which are incompatible with making this property available for society (Maredia et al., 1999). The patenting and licensing policies of universities can also be influenced by the government agencies that provide money for research. For example, these agencies could require that universities provide nonexclusive licenses on research tools developed with government funding to ensure that scientists in the public and private sector get access to them.

To a large extent, the existing agricultural biotechnology R&D industry structure has been influenced by public policies regarding intellectual property. The most notable influences have been the *Chakrabarty* decision and ensuing case law that allowed utility patenting of genetic material and novel plants, the Bayh-Dole Act that encouraged universities to patent intellectual property developed with federal monies, and the university mandate of making such intellectual property available the private sector even if on an exclusive basis. Few if any of these public policies were designed with agricultural biotechnology in mind. Coupled with rapid advances in biotechnology, this has generated an intricate and dynamic set of relationships among firms and organizations in the agricultural biotechnology industry.

Conclusions

The plant biotechnology industry has a complex and changing structure that raises a variety of interesting research issues. Among the most important researchable questions are: Who is doing what in the industry, and how does that affect industry structure? What are the effects of industry structure (including intellectual property rights) on both the level of innovation and on the output (seed) market structure? Where is plant biotechnology research going in the future? The remainder of this issue addresses these questions.

References

Acs, Z.J., & Audretsch, D.B. (1989). Patents innovative activity. *Eastern Economic Journal*, *15*(4), 373-376.

BASF Corporation. (2005). *BASF group: Corporate publications*. Ludwigshafen: BASF Aktiengesellschaf. Available on the World Wide Web: http://berichte.basf.de/en/2005/.

Brennan, M., Pray, C.E., & Courtmanche, A. (2000). Impact of industry concentration on innovation in the US plant biotech industry. In W.H. Lesser (Ed.), *Transitions in agbiotech: Economics of strategy and policy.* Storrs, CT: University of Connecticut Food Marketing Policy Center.

Butler, L.J., & Marion, B. (1985). *The impacts of patent protection on the US seed industry and public plant breeding* (North Carolina Regional Research Publication 304, North Central Project 117, Monograph No.16). Madison, WI: University of Wisconsin College of Agricultural and Life Sciences.

Diamond v. Chakrabarty, 447 US 303 (1980).

ex parte Hibberd, 227 USPQ 443 (1985).

Fulton, M., & Giannakas, K. (2001). Agricultural biotechnology and industry structure. *AgBioForum*, *4*(2), 137-151. Available on the World Wide Web: http://www.agbioforum.org.

Griliches, Z. (1990). Patent statistics as economic indicators: A survey. *Journal of Economic Literature*, *28*(4), 1661-1707.

Griliches, Z., Pakes, A., & Hall, B.H. (1986). *The value of patents as indicators of inventive activity* (NBER Working Paper No. 2083). Cambridge, MA: National Bureau of Economic Research.

Hausman, J., Hall, B., & Griliches, Z. (1984). Econometric models for count data with an application to the patent-R&D relationship. *Econometrica*, *52*(4), 909-938.

Heller, M.A., & Eisenberg, R.S. (1998). Can patents deter innovation? The anticommons in biomedical research. *Science*, *280*(5364), 698-701.

Information Systems for Biotechnology. (2005a). *Crops no longer regulated by USDA* [database]. Blacksburg, VA: Author. Available on the World Wide Web: http://www.nbiap.vt.edu/cfdocs/biopetitions1.cfm.

Information Systems for Biotechnology. (2005b). *Field test releases in the U.S.* [database]. Blacksburg, VA: Author. Available on the World Wide Web: http://www.nbiap.vt.edu/cfdocs/fieldtests1.cfm.

Kovacic, W.E., & Shapiro, C. (2000). Antitrust policy: A century of legal and economic thinking. *Journal of Economic Perspectives*, *14*(1), 43-60.

Maredia, M., Erbisch, F., Naseem, A., Hightower, A., Oehmke, J., Weatherspoon, D., & Wolf, C. (1999). Public agricultural research and the protection of intellectual property: Issues and options. *AgBioForum*, *2*(3&4), 247-252. Available on the World Wide Web: http://www.agbioforum.org.

Monsanto Company. (2005). *Investor information*. St. Louis, MO: Author. Available on the World Wide Web: http://www.monsanto.com/monsanto/layout/investor/.

Oehmke, J. (2001). Biotechnology R&D races, industry structure, and public and private sector research orientation. *AgBioFo-*

rum, *4*(2), 105-114. Available on the World Wide Web: http://www.agbioforum.org.

Oehmke, J.F., & Wolf, C.A. (2003). Measuring concentration in the biotechnology R&D industry: Adjusting for interfirm transfer of genetic materials. *AgBioForum*, *6*(3), 134-140. Available on the World Wide Web: http://www.agbioforum.org.

Oehmke, J.F., Wolf, C.A., & Raper, K.C. (2005). On cyclical industry evolution in agricultural biotechnology R&D. *Journal of Agricultural & Food Industrial Organization*, 3(2). Available on the World Wide Web: http://www.bepress.com/jafio/vol3/iss2/art1.

Ollinger, M., & Pope, L. (1995). Strategic research interests, organizational behavior, and the emerging market for the products of plant biotechnology. *Technological Forecasting and Social Change*, *50*(1), 55-68.

Pray, C.E. & Naseem, A. (in press). Intellectual property rights on research tools: Incentives or barriers to innovation? Case studies of rice genomics and plant transformation technologies. *AgBioForum*.

Shapiro, C. (2001). Navigating the patent thicket: Cross licenses, patent pools and standard setting, in innovation policy and the economy. In A. Jaffe, J. Lerner, & S. Stern (Eds.), *Innovation Policy and the Economy* (v.1). Cambridge, MA: National Bureau of Economic Research.

Syngenta Corporation. (2005). *Syngenta investor relations*. Basel: Author. Available on the World Wide Web: http://www.syngenta.com/en/investor/.

United States Department of Agriculture Economic Research Service. (2004). *Data: Agricultural biotechnology intellectual property* [database]. Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/data/AgBiotechIP/.