

Transitions in Agbiotech: Economics of Strategy and Policy

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PART TWO: Industry Issues

**8. Impact of Industry Concentration
on Innovation in the
U.S. Plant Biotech Industry**

*Margaret F. Brennan, Carl E. Pray,
and Ann Courtmanche*

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Food Marketing Policy Center
Department of Agricultural and Resource Economics
University of Connecticut
and
Department of Resource Economics
University of Massachusetts, Amherst

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Margaret F. Brennan

Carl E. Pray

Ann Courtmanche

Department of Agricultural, Food, and Resource Economics
Rutgers University

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Chapter 8

Impact of Industry Concentration on Innovation in the U.S. Plant Biotech Industry

Margaret F. Brennan, Carl E. Pray, and Ann Courtmanche¹

Introduction

The groundswell of mergers and acquisitions in the plant biotechnology industry over the last decade has been driven by the research characteristics required to develop new biotechnology products and by the strong patent system of the United States. Many scholars and researchers are concerned that the concentration of patents, plant germplasm, and markets for biotechnology among a few firms may be causing a decline in the level of research and innovation in the industry (Barton, 1998). Persons involved with the biotech industry point to patents on enabling technology, such as transformation techniques, as well as the large number of patents on specific crops held by major companies, as reducing the incentive and ability of other companies to perform research. In addition, the cost of obtaining permission to use patented technology or genetic material may prevent some firms, particularly smaller ones, from participating in innovative research.

Several policy alternatives are available to the government for preventing excessive levels of concentration: the U.S. Patent and Trademark Office can reconsider its policies on issuing broad patents; the Federal Trade Commission (FTC) and U.S. Department of Justice can use their antitrust powers to prevent abuse; and public research institutions can develop and license technologies that prevent private firms from obtaining a monopoly at any stage of the research and development process. This paper focuses on one of these policy instruments – the antitrust activities of the FTC and Department of Justice. We examine the FTC's use of innovation market analysis to account for the impact of mergers on research and development. Then an analysis of innovation concentration based on the Herfindahl-Hirschman Index is provided using USDA field trial data for private companies as a measure of innovation activities. Pre- and post-merger concentration ratios of the field trials are also examined to illustrate the movement currently taking place towards increased levels of concentration in innovation markets.

The results of the Herfindahl-Hirschman Index and Four Firm Ratio analyses show that there is evidence of firm concentration in innovation markets. Analysis of the impacts of concentration reveal that new firm entry in the innovation market is starting to show evidence of decline, research output by firms not in the top four also appears to be falling, and gains to efficiency appear to be negatively related to firm size. Investments and research output by the larger firms both appear to be increasing. While preliminary results indicate that concentration in

innovation markets may be having negative impacts on plant biotech research activities, several more years of data will be required before any reliable conclusions can be stated. However, given what appears to be the beginning of a trend towards negative impacts on innovation and competition, the FTC should continue to monitor field trials and other measures of research activity for signs that industry concentration may be having an adverse effect on research and development activities.

Merger Activity in the Plant Biotechnology Industry

Mergers and acquisitions in the agricultural input and food industries in the U.S. and Europe have been fueled by developments such as breakthroughs in biotechnology, strengthened intellectual property rights, expansion of the stock market, and a general philosophy that bigger is better. Much of the consolidation centers around chemical and pharmaceutical multinational corporations (MNCs) with three significant trends emerging. The first is that many of the firms are selling off their chemical manufacturing divisions. The second is an increase in the number of mergers between large chemical and pharmaceutical companies. And the third is the formation of alliances of MNCs with food and feed companies.

The sale of chemical manufacturing and marketing divisions is occurring in many cases to enable the firms to increase investments in high profit products such as pharmaceuticals and biotechnology, and to acquire or negotiate strategic alliances with seed companies. One of the earliest of these decisions was by ICI (a British chemical firm) which split into ICI for traditional bulk chemicals, and Zeneca for drugs, pesticides, seeds, and agricultural biotechnology. In 1997, the U.S. firm Monsanto announced it would sell off its bulk chemicals business to concentrate on the high technology life sciences. The latest of these moves was by DuPont, which sold its oil business in 1998 and invested heavily in a joint venture with Pioneer Hi-Bred, a large U.S. seed company.

Table 1 describes some of the key purchases of biotechnology and seed firms. AgrEvo purchased Plant Genetic Systems (PGS), the largest European plant biotechnology firm, in 1996. More recently, it purchased Cargill's U.S. seed business. DuPont purchased 20 percent of Pioneer Hi-Bred in 1997 and the remainder in 1998. Monsanto has been the most active of all. It acquired three important biotechnology firms, purchasing 100 percent of Agracetus and Calgene and most of the technology assets of Ecogen. Monsanto also purchased the corn and soybean seed businesses of Asgrow, the largest soybean seed producer; Holdens Foundation Seeds, which is the largest foundation seed firm in the U.S.; DeKalb, the second largest hybrid corn firm; Delta and Pineland, the largest cotton seed producer in the U.S.; and Cargill's international seed business. In addition, a few specialized firms have captured major segments of the seed and biotech market. The Mexican conglomerate, Empresa La Moderna (ELM), has purchased a number of major vegetable seed firms and the biotech firm DNA Plant Technology, in order to create a major vegetable biotech company. In the forage and turf grass industry, AgriBiotechnology has purchased many of the major forage and turf grass firms, with 42 mergers and acquisitions since 1995.

TABLE 1 Mergers and Acquisitions in Agricultural Chemicals, Biotechnology, Seeds, and Food/Feed

	Agricultural Chemicals	Biotech	Seeds	Food/Feed
Monsanto		<p>Agracetus (1995)</p> <p>Calgene (1996)</p> <p>Ecogen (13%)</p> <p>Millenium Pharmaceutical (Joint venture for crops genes)</p>	<p>DeKalb (1996)</p> <p>Asgrow (1997) (corn and soybeans)</p> <p>Holden's Foundation Seeds (1997)</p> <p>Delta & Pineland (not yet approved)</p> <p>Cargill International Seeds, Plant Breeding Intl. (1998)</p>	<p>Cargill (1998) Joint venture feed and food</p> <p>Monsanto has brands like Nutrasweet</p>
AgrEvo (Aventis)	<p>Hoechst & Schering (1994)</p> <p>Hoechst & Rhone-Poulenc (1999) Merger to create Aventis</p>	<p>Plant Genetic Systems (1997)</p> <p>PlantTec</p>	<p>Nunhems, Vanderhave, Plant Genetic Systems, Pioneer Vegetable Genetics, Sunseeds (1997)</p> <p>Cargill U.S. Seeds (1998)</p>	
Rhone - Poulenc (Aventis)	<p>Hoechst (1999) Merger to create Aventis</p>		<p>Alliance with Limagrain which owns Nickersons, Vilmorin, Ferry Morse & others</p>	
Novartis	<p>Ciba-Geigy and Sandoz (1996) Merger</p> <p>Merck (1997) Buys pesticide business for \$910 million.</p>		<p>1996 merger brings together Northrup-King, S&G Seeds, Hilleshog, Ciba Seeds, Rogers Seed Co.</p>	<p>Gerber Foods</p>

	Agricultural Chemicals	Biotech	Seeds	Food/Feed
Dow Chemicals	(1997) Dow purchases Eli Lilly's 40% share of Dow Elanco for \$900 million.	Mycogen (1996) Ribozyme Pharmaceuticals Inc.	Mycogen buys Agrigenetics (1992) United AgriSeeds becomes part of Mycogen (1996)	
Zeneca/Astra		Mogen International N.V. (1997) Alliance with Japan Tobacco on Rice (1999)	Advanta (merger of Zeneca seed and Vanderhave)	
DuPont		Alliances with Human Genome Sciences (1996) Curagen (1997)	Pioneer (1997) (20%) Hybrinova (1999) (France) bought other 80% of Pioneer	Quality Grain (Joint venture with Pioneer), Protein Technologies (food), Cereal Innovation Centre UK
Empresas La Moderna/Seminis		DNA Plant Technology (1996)	Asgrow (1994) (Sells corn & soybeans to Monsanto in 1997) Petoseed (1994) Royal Sluis Seminis (ELM 62%)	Bionova

Another interesting trend is the increased merger activity between large chemical and pharmaceutical firms (see Table 1, Column 1). The German firms Hoechst and Schering formed a joint venture for their agricultural and environmental products called AgrEvo. The Swiss firms Ciba-Geigy and Sandoz merged in 1997 to become Novartis. Recently (December 1998), Hoechst and Rhone-Poulenc have announced their intention to merge and form a new company called Aventis.

The third trend is for "life science" firms to purchase, or develop alliances with, large food and feed companies in hopes of obtaining higher returns on biotech investments. DuPont has purchased the feed company Protein Technologies and formed a joint venture with Pioneer called Quality Grain. Monsanto and Cargill recently announced an alliance to develop and market quality food products. Novartis is involved in the food industry with Gerber and a number of other brands. ELM owns Bionova, a large fresh fruit and vegetable company.

The large numbers of mergers and acquisitions have resulted in an increase in concentration in the agricultural input industry. For instance, if the full acquisition by Monsanto of Delta and Pineland is approved, it will give Monsanto ownership of at least 80% of the U.S. cottonseed industry (Kilman and Warren, 1998). In Table 2 (p.5), estimates of the size of world markets in pesticides and seeds, and share of the U.S. market of plant biotechnology are provided. Mergers in the chemical industry enabled Novartis to jump to top position in the pesticide market, and should enable Aventis to jump ahead of Novartis this year. The purchase of seed companies by the third and fifth largest pesticide firms, Monsanto and DuPont, have placed them in first position in the world seed industry. Novartis is second in pesticides and third in seeds. Since the early stages of the plant biotechnology industry, Monsanto has dominated U.S. and world markets. In the U.S., almost 90 percent of the acreage planted with genetically engineered seed are using Monsanto products (James, 1998).

TABLE 2 World Sales of Top Ten Pesticide and Seed Firms

	Pesticides 1997	Seed 1997	Plant Biotech 1998
	\$ millions	\$ millions	% of U.S. market
Aventis Group* (Hoechst/Rhone -Poulenc)	4,554		8%
Novartis	4,199	928	4%
Monsanto	3,126	1,800	88%
Zeneca/Astra	2,674	437	-
DuPont	2,518	1,800	-
Bayer	2,254	-	-
Dow	2,200	-	-
America Home Products	2,119	-	-
BASF	1,855	-	-
Sumitomo	717	-	-
Group Limagrain	-	686	-
Agribiotech	-	425	-
Seminis/ELM	-	375	-
Sakata	-	349	-
KWS	-	329	-
Takii	-	300	-
Total	30,900	23,000	
4 Firm Concentration Ratio	47%	23%	100%

Sources: AgChem: RAFI estimate based on Agrow Inc.; Seeds: RAFI estimates; Biotech: Clive James 1998.

Investments by private firms in plant biotechnology research appear to be on the rise. In recent months, there have been a series of announcements of major new investments in basic and applied biotech research. For example, Novartis has announced that it will invest \$20 million to increase its agricultural biotechnology research in North Carolina and \$250 million in a new Novartis Agricultural Discovery Institute (NADI) which will work on plant genomics research in La Jolla, CA (Kaiser 1998). Table 3 (p. 6) shows some of the recent announcements about investments in genomics research, and the percentage of Bt and germplasm patents held by various firms.

Concentration and Drivers of Innovation

Does the increasing concentration in the plant biotechnology and agricultural input industries matter? Should we be worried, and if so, what should we do about it? There is considerable debate among scholars about the benefits and costs of firm concentration. This section reviews the academic and FTC literature on these issues.

First, consider the roles of competition and appropriability (via intellectual property rights) in fostering innovation. Competition spurs innovation as firms compete for market share and to maximize profits, and appropriability ensures that a firm will be able to benefit from its investments in research and development. There has been continued debate over which incentive leads to the greatest increases in innovation efforts, and whether broad or narrow intellectual property protection yields the greatest societal good (Scotchmer, 1991; Jorde and Teece, 1992; Lerner, 1994; Lewis and Yao, 1995; Barton, 1998).

Competition is a critical component of innovation, although there does not seem to be clear evidence that decreased competition leads to a reduction in innovation activity. Some economists feel that mergers between certain R&D competitors have the potential to remove powerful incentives for R&D competition. This is based on Arrow's finding that a monopolist, who already extracts monopoly profit, has less to gain from an innovation that would diminish its existing earnings than a firm in a competitive industry, which begins with zero economic profit (Arrow, 1962; Cohen and Levin, 1989; Greer, 1993).

Others have pointed to Schumpeter's findings that large firm size and market share may better support R&D efforts (Cohen and Levin, 1989; Pisano, 1991). It is asserted that any losses from decreased competition might be offset through the economies of scale created from combining R&D programs that would encourage even greater R&D efforts (Schumpeter, 1942). Also, the uncertainty inherent in R&D strategies and the high risk associated with being late to market typically prevent a firm's net incentive from favoring reduced R&D effort. Though there may be disagreement over the level of impacts of market structure on competition, most agree that competition does create some incentive for innovation, and that continuous innovation is critical for success in global markets (FTC, 1996).

TABLE 3 Concentration of Assets in the Research Process

Firm	Genomics Research Investments (Millions of \$)	Patents Bt (% of total as of mid 1998)	Germplasm	
			Collections	Share of Patents
Monsanto	Arqule (1997) \$12 Cerion (1998) \$200+ with Millenium Incyte St.Louis Botanical Gardens (1999) \$80 in new plant science consortium	10%	Corn – Holdens’ Seed, Dekalb, Asgrow Soybeans – DeKalb&Asgrow Cotton – Delta & Pineland Vegetables – Calgene	Corn 8% (Oct. 96) Soybeans 18% (March 97) Tomatoes 14% (June 1997)
Pioneer/ Dupont	Human Genome Sciences (1996) \$16 Kimeragen (1997); Affymetrix (1997); Curagen (1997) \$7.5 in equity, \$2.5/ year for research	N/A	Corn – Pioneer Soybeans – Pioneer	Corn 20% (Oct. 96) Soybeans 33% (March 97)
Novartis	\$250 investments in Novartis Ag. Discovery Institute, La Jolla, CA	7%	Corn – Northrup-King, Ciba Soybeans	Corn 12% (Oct. 97) Soybeans 2% (March 97)
Agrevo	Gene Logic	5%	Corn - Part of Illinois Foundation Seed	Soybeans 2% (March 97)
Dow/ Mycogen	Biosource Technologies	20%	Corn Dow Agrosiences Soybeans	Soybeans 3% (March 97)
Zeneca	\$80 for collaboration with John Innes Institute, U.K.	3%	Vegetables	Tomatoes 12% (June 97)
ELM/ Seminis	Mendal Biotechnology	N/A	Vegetables – Petoseeds	Tomatoes 4% (June 97)

Appropriability is influenced by market structure and how well the new technology can be protected through patents, trade secrets or other forms of intellectual property protection. If an input manufacturing industry is characterized by a monopoly or oligopoly structure, then the firm or firms may be able to exert market power and set the input price above its marginal cost (Nicholson, 1992). A firm may also be able to exercise market power through a patent that gives it an exclusive right to use the new technology (Greer, 1993). Another possibility is that a firm may be able to keep the technology out of its competitor's hands by keeping key elements of the new technology secret. Intellectual property in hybrid varieties can also be protected by restricting access to the patent inbred lines (Butler and Marion, 1985).

Government policies affect a firm's expectations about the benefits and costs of research and technology transfer. Strict anti-monopoly policies can reduce the size of a firm's expected market and reduce its opportunities for economies of size and scope in research, reducing expected benefits. Anti-monopoly policies can also stimulate research by increasing competition that may force firms to innovate to keep ahead of their competitors. Broad patents can increase a firm's expected benefits, but it may reduce spillovers of knowledge and technology to other firms (Barton, 1998; Scotchmer, 1991; Lerner, 1994). The primary goals of intellectual property rights and competition policies is to strike a balance between appropriability and competition, and between initial and successive innovation (FTC, 1996).

How beneficial is patent protection to biotechnology R&D efforts? In a study by Richard Levin et.al. (1987), 130 publicly traded firms in a variety of industries were examined. The study found that product patents were regarded as a "highly effective" means of appropriating returns in only five industries that included pharmaceuticals, organic chemicals, and pesticides. This confirms findings in a study by Edwin Mansfield (1986) in which 100 firms from 12 industries were examined². Mansfield found that 60% of pharmaceutical inventions and 38% of chemical inventions would not have been developed absent patent protection. In addition, at recent FTC hearings on innovation and competition, representatives of the pharmaceutical and biotechnology industries stated that patents are critical for protecting the large, up-front investments necessary to research and develop new products (FTC, 1996).

While there is conflict over whether or not market concentration reduces incentives for research in existing firms, there is also concern over the impact of concentration on the ability for new firms to enter the market. New, smaller firms may find it impossible to enter the market because "they face the assembled patent rights of the industry leaders and possibly also face contract restrictions on access to marketed materials that would once have been available for further breeding (Barton, 1998)." For newly emerging, science-based industries such as biotechnology, patents may be of particular importance for private research. Econometric studies of the U.S. biotechnology industry (Austin, 1993; Lerner, 1994) found a significant correlation between the number of patents owned by a company and its valuation in capital markets. Higher market valuation enables firms to more easily raise funds that can then be used to expand research activities.

An Innovation Market Approach to Analyzing Impacts of Mergers and Acquisitions in the Plant Biotech Industry

Conceptual Framework

As previously discussed, the explosion of mergers and acquisitions in the plant biotech industry over the last decade have resulted in a highly concentrated innovation market, with only a few companies in control over much of the patented technologies and specialized inputs to R&D. Analysis of competition impacts has begun to focus on the dimensions of innovation, such as the speed of developing, producing, and marketing improved products (FTC, 1996). To ignore the effects of a merger on innovation, in particular, would understate the importance of future competition (Scotchmer,1991). However, as one can see, the literature offers conflicting evidence about the impacts of firm concentration and strength of property rights on research activity. The purpose of this paper is to provide some insights into these issues by analyzing research output in the form of US field trials by private firms and merger activity over the last eleven years (1987-1988). The hypothesis tested is that concentration in research or "innovation" markets through ownership of important platform technology in a crop or group of crops, ownership of a concentration of patents by one firm, or concentrations of holdings of germplasm will reduce levels of research output.

Innovation Markets and FTC Considerations

Assessing impacts of mergers on the basis of innovation competition, as well as on product market competition, has been used by the FTC in recent antitrust rulings in merger cases (FTC, 1996). For example, the approval of Monsanto's purchase of DeKalb was conditional on Monsanto making their patent on agrobacterium transformation of rice, their stock of corn germplasm (obtained from an earlier purchase), and portions of their platform technology available to public and private institutions (Dept. of Justice, 1998).

The FTC's criteria for taking action under the innovation markets concept is to look at the impact on R&D activities of competitors of the merged firm, the impact of the firm's own in-house R&D, and the ability of new firms to enter the market. Along the same lines, Gilbert and Sunshine³ (1995) state that an analysis of the effects of a change in market structure on innovation involves answering the following three questions:

- 1) Does the merged firm have the ability to decrease total market investment in R&D? This is analogous to the determination of a merged firm's share of the relevant market in a horizontal product merger.
- 2) Does the new combination have the incentive to reduce innovative effort? The ability to reduce significantly the total amount of R&D does not mean that a merged firm has the incentive to reduce innovation. Ex post econometric studies of mergers and acquisitions in U.S. industry find that R&D typically declines immediately after a merger (Ravenscraft and Scherer 1987).

3) Does the merger have any consequences for the efficiency of R&D expenditure?

Analysis of the effects of a merger on innovation also requires an evaluation of efficiency considerations that might lead a merged firm to engage in greater innovative activity or in the same amount at a lower cost. Three types of quantitative evidence can provide insight into these issues, the number of new firms entering the market, the amount of merged firm and total industry research output (in this case, patents and field trials), and the ability of existing firms in the market to compete with the leaders.

Innovation can be considered a dynamic process and it requires a dynamic analysis to adequately capture the future impacts of mergers and acquisitions. The most commonly used merger models based on existing market shares result in a static analysis of competition in a particular industry (Dahgouh and Mongoven, 1996). This has raised questions over the ability of the current system of antitrust analysis to effectively evaluate the impacts on innovation that these mergers and acquisitions may be having (Jorde, 1995). However, antitrust agencies have recently begun to recognize that innovation warrants a more central role in antitrust analysis due to its crucial role in generating economic growth and in enhancing global competitiveness (Gilbert and Sunshine, 1995; Whalley; 1995).

Antitrust analysis is typically based on anti-competitive measures such as higher price or lower output. However, when there is no product in existence, the impact of business conduct on levels of innovation, as opposed to price or output, is not as easily analyzed through this methodology (FTC, 1996). The concept of “innovation markets” was developed to deal with anti-trust claims focused on R&D efforts and where the definition of a product market was not applicable (Gilbert and Sunshine, 1995; Starek, 1996). According to the FTC Intellectual Property Guidelines (1995), an innovation market “consists of the research and development directed to particular new or improved goods or processes, and the close substitutes for that research and development. The close substitutes are research and development efforts, technologies, and goods that significantly constrain the exercise of market power with respect to the relevant research and development, for example by limiting the ability and incentive of a hypothetical monopolist to retard the pace of research and development.” Innovation markets are a measure of the level of innovation competition that is occurring, and is analogous to the “product markets” that are used in antitrust analysis to measure price and other competitive variables. Innovation market analysis takes a forward-looking perspective, and recognizes the possibility that future competition can be harmed by mergers that result in a reduction in research and development activities (Dahgouh and Mongoven, 1996).

Innovation markets are delineated only when the capability to engage in relevant research and development can be associated with specialized assets or characteristics of specific firms (IP Guidelines, 1995). In addition, they are characterized by several key features: there are no products yet in existence, there are very small numbers of R&D efforts, and high entry barriers preclude reliance on easy entry to remedy a likely reduction in innovation competition (FTC, 1996). Research and development activities in the plant biotech industry provide an excellent example of the definition of innovation markets.

Antitrust guidance on how to assess possible anti-competitive reductions of innovation competition is still evolving. Congress directed in the National Cooperative Research Act of 1984 that registered ventures be reviewed for their “effects on competition in properly defined, relevant, research, development, product, process, and service markets. Competition is as important in R&D as it is in any other commercial endeavor” (NCRA, 1993). Thus far, the FTC and Dept. of Justice have provided guidelines regarding the assessment of innovation issues only with regard to licensing agreements and their treatment under the FTC and Sherman Acts (IP Guidelines, 1995; Horizontal Merger Guidelines, 1992). The 1992 Horizontal Merger Guidelines provide direction assessing whether a proposed merger is likely to create, enhance, or facilitate the exercise of market power, but no one has fully specified how those Guidelines could be used in assessing the likelihood that a merger or acquisition will reduce innovation below “competitive levels” and thereby violate Section 7 of the Clayton Act (FTC, 1996).

Data

To assess whether mergers are affecting research efforts, it is important to be able to measure whether control or power over different stages of the research process affects the amount of research that is conducted. Data on biotechnology research expenditures at various stages of the research and development process would be ideal. It would allow calculations of research concentration and the flow of research expenditures over time. Unfortunately, most firms will not reveal this data. There is no regular process of reporting biotechnology research expenditure and so other data is needed. To identify possible sources of data, an examination of the biotechnology research process is useful. The process of developing a genetically engineered commercial plant variety is shown in Figure 1.

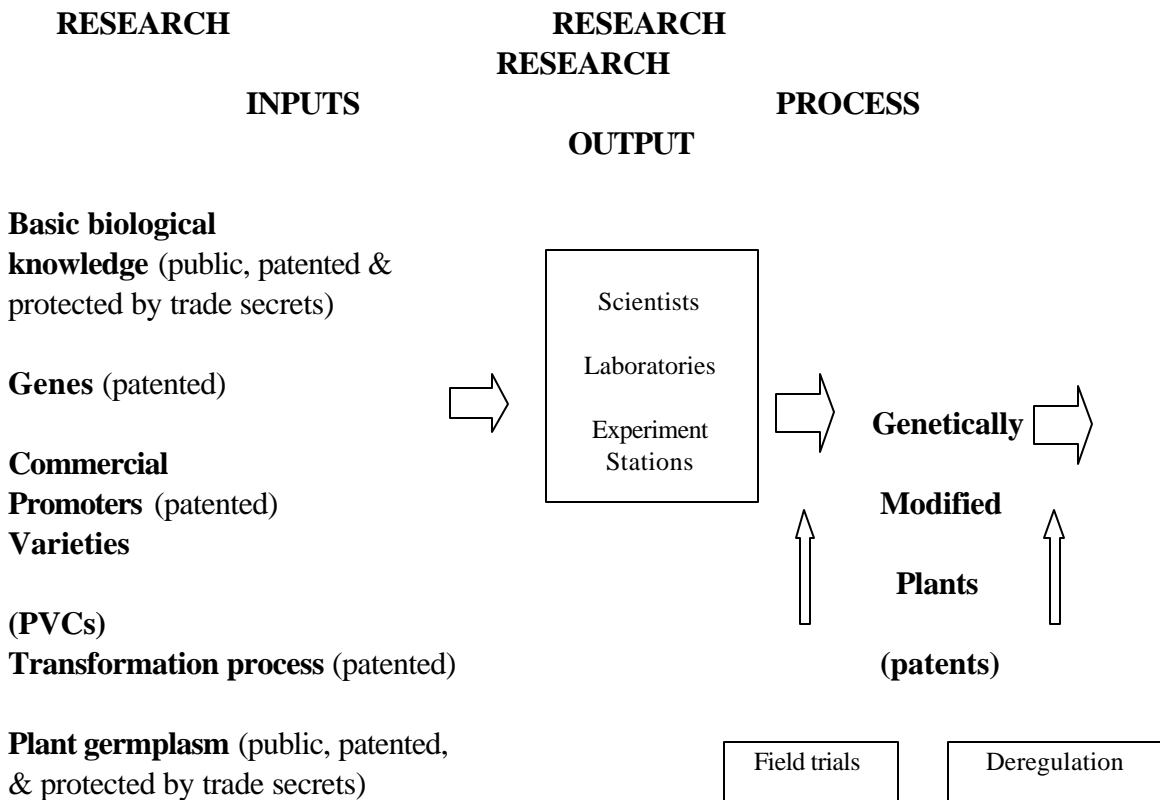
Scientists in a research program start with basic knowledge about plants, pests, the environment, and market needs. To develop genetically engineered plants, scientists insert promising genes and promoters into available plant lines using plant transformation technology. Once the plants have been transformed, 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 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 article⁴ in the United States. Companies or research institutes that are conducting research to develop GMP's must apply to APHIS for a permit or notification⁵ to do a field test (a “release into the environment”). When a GMO is ready to be grown commercially, the firm or research institute applies to APHIS have the GMO deregulated.

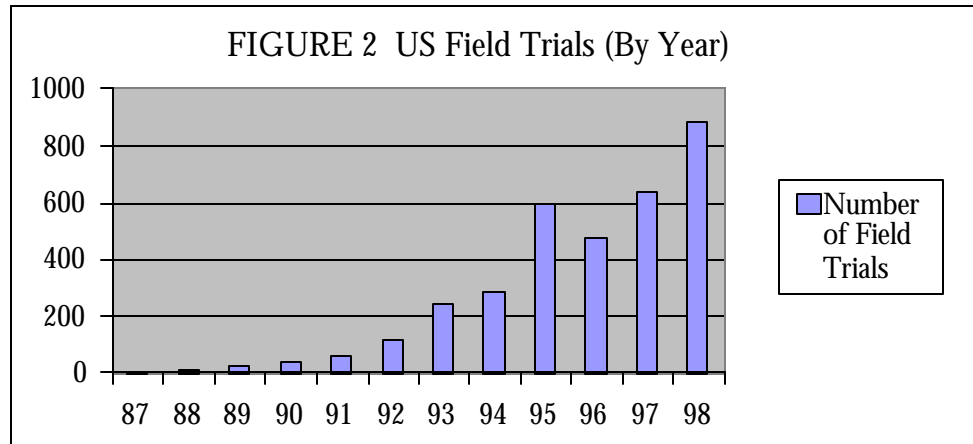
Data on field trials can be used as a measure of research activity near the end of the research process, as shown in Figure 1. It provides an indicator of biotechnology research by individual firms over time (Olinger and Pope,1995). Field trial data can be disaggregated by

crop and characteristics (e.g. insect resistance, herbicide tolerance). The first field trials for genetically engineered plants in the U.S. were held in 1987 and the first petition for deregulation was approved in 1992. The number of permits and notifications for field trials conducted by private firms in the U.S. has grown from just 5 in 1987 to 886 in 1998, indicating that innovation output over the last decade has increased at a rapid rate (Figure 2, p. 13). As of the end of May 1999, almost 5,000 field trials have taken place and 50 petitions for deregulation have been approved by APHIS in the U.S. (APHIS, 1999).

FIGURE 1 Plant Biotechnology Research Process



Research and development in the plant biotech industry requires the use of a vast array of specialized assets such as enabling technologies, plant germplasm, and gene maps. Innovation market analysis calls for “the identification of specialized assets associated with R&D so that the population of potential innovators can be defined and the evaluation of a merger’s effect on the probability of innovation can be facilitated (Gilbert and Sunshine, 1995).” APHIS field trial data for private companies is being used as a proxy for these "specialized assets". While field trials may not capture the entire innovation market in plant biotech, it does provide some measure of the output of innovation efforts that are based on specialized assets. Information on the number of mergers and the number of firms represents only those firms who conducted field trials during the time period.



Source: APHIS, 1999.

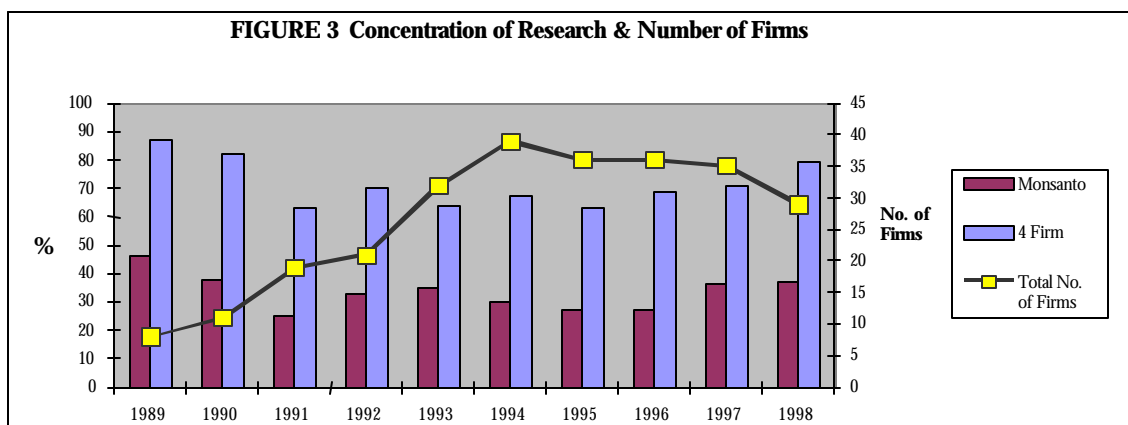
Methodology

US field trial data for private firms is used in the following section to evaluate the impacts of industry concentration on innovation in the plant biotech industry. An analysis of concentration in the industry is conducted using two standard merger models, the Herfindahl-Hirschfield Index and the Four Firm Concentration Ratio. Market power in the plant biotech industry prevails because of the collective power of just a few firms. This power may be measured by market share held by several leading firms taken together using the Four Firm concentration ratio. The Herfindahl-Hirschman Index can also be used. This index yields a better reflection of anti-competitive impacts and is more comprehensive than concentration ratios. The analysis used in this study differs from conventional techniques in that market shares of innovation output in the form of field trials is used instead of market shares based on sales. It is hoped that using this type of data will add a dynamic component to the analysis and provide some insight into the impacts of merger activity on innovation efforts. In addition, the field trial data is further evaluated to provide information that may be useful in testing the more common theories and hypotheses about the impact of concentration on ease of entry into the market; research output of merged firms, smaller firms, and the industry as a whole; and efficiencies of scale.

Results

Industry Research Output

Field Trials. The field trial data indicates a trend in concentration in innovation markets over time. Figure 3 shows that the concentration of research as measured by share of the first four firms declined as the number of firms entering the industry increased. After 1994, concentration went up and the number of firms conducting research declined.



Source : APHIS, 1999.

Patents. An analysis of patents can provide some evidence of concentration of research assets and is often used a measure of research output. Patents on key transformation technologies for grains are held by two firms, DuPont and Monsanto. DuPont controls the gene gun technology through an exclusive license. Monsanto held patents on the use of agrobacterium for transforming grain, but the FTC recently forced them to give control over some of this technology to the University of California at Berkeley. In contrast, patents on the most important genes for insect resistance, Bt, do not appear to be very concentrated. Jenkins (1998), relying on the Derwent Biotechnology Abstracts, found that the top four firms controlled 39 percent of Bt patents, and the top firm, Dow, controls 20 percent of the Bt patents. Table 4 (p. 15) shows the shares of patents held by some of the largest companies. About 70 percent of the patents on tomatoes are held by four firms. Corn and soybeans patents are less concentrated – the top four firms having 41 and 53 percent of patents respectively.

Innovation Market Concentration

The post merger Herfindahl-Hirschman indices were calculated using data on all mergers that took place in each year (Table 5, p. 16). Thus, the indices may be particularly high, since this calculation is usually conducted looking at the merger activity of just one firm. During the late 80's and early 90's innovation output in the industry was highly concentrated among a few firms, with Four-Firm ratio's exceeding 60% (in some years over 80%) and Herfindahl-Hirschman indices exceeding 1800. During the mid-90's, these indicators dropped into a moderately concentrated range. It was during that time that increases in merger and acquisition activity was accompanied by increases in new firms entering the market. Indicators for the last few years of this decade are now revealing a dramatic increase in concentration among a few firms in innovation output. Based on these results, it is felt that innovation activity is heavily concentrated among a few firms as a result of merger activity over the last decade. The impacts of this concentration are discussed in the following sections.

TABLE 4 Patents on Corn, Soybeans, Tomato, and Bt

Company	Corn (up to 1996)	Soybeans (up to 1997)	Tomato (up to June 97)	Bt (up to 1998)
Pioneer-Hi-Bred	21	27	13	
Monsanto	7 4 (DeKalb)	23	22	25
Novartis	17	2	5	36
Du-Pont	7	15		
Dow/Mycogen	3	4		98
Rhone-Poulenc-Agrochem	3	4		
AgrEvo	4 (PGS)	3		24
Zeneca		3	19	15
ELM			6	
Novo-Nordisk				25
EcoGen				22
Japan Tobacco	5			
American -Cyanamid	3			
Others	9	49	13	237
Total	138	130	78	482
% Held by Top 4 Firms	41	53	77	38

Sources: Articles in *Seedling* with numbers from Derwent Biotechnology Abstracts; Bt Patents: Jenkins, Robin. "Bt In The Hot Seat", *Seedling* Sept. 1998; Tomato Patents: GRAIN, "Tomato - Global Fame And Corporate Desire", *Seedling* October 1997; Soybean Patents: GRAIN, "Soybean, The Hidden Commodity", *Seedling*, June, 1997; Corn Patents: GRAIN, "The Biotech Battle Over The Golden Crop", *Seedling* October, 1996.

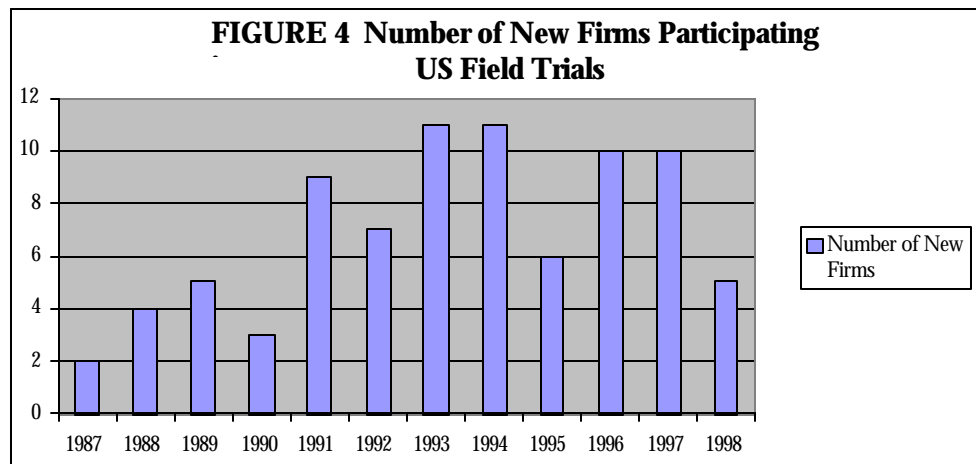
TABLE 5 Analysis of Market Concentration

Year	Four Firm Concentration Ratio (Post Merger)	Herfindahl- Hirschman Index (Pre Merger)	Herfindahl- Hirschman Index (Post Merger)	Number of Mergers	Number of Firms
1988	87%	2444	2444	0	6
1989	85%	2840	2840	1	8
1990	82%	2387	2387	1	11
1991	63%	1235	1240	0	19
1992	70%	1639	1645	0	21
1993	64%	1632	1635	0	32
1994	67%	1517	1521	2	39
1995	63%	1143	1310	3	36
1996	69%	894	1290	7	37
1997	71%	1327	1862	5	35
1998	79%	1608	2182	4	29

Source: Calculated from field trial data obtained from APHIS, 1999.

Entry by New Firms

The number of new firms receiving permits and notifications has shown some interesting patterns (Figure 4). In the late 80's and early 90's, the number of new firms conducting field trials slowly increased from two in 1987 to a peak of eleven in 1994. 1995 saw a drop to six firms followed by an increase to ten firms in the following two years. 1998 again showed a drop to five firms, the lowest level since 1990. This may be an early indicator that the increase in innovation concentration among a few firms is limiting the ability of new firms to conduct research.



Innovation Competition Among Large Firms

Table 6 shows the four firms, by year, that had the most total field trials and most trials of corn. Monsanto has the highest number of field trials from 1991 to 1998, but other large firms such as AgrEvo, which were not in the top four in 1995, are now in top positions. Looking at corn, the crop with the most trials, the picture is more fluid with AgrEvo grabbing the

Table 6. Top Four Firms in Trials of All Crops and Corn

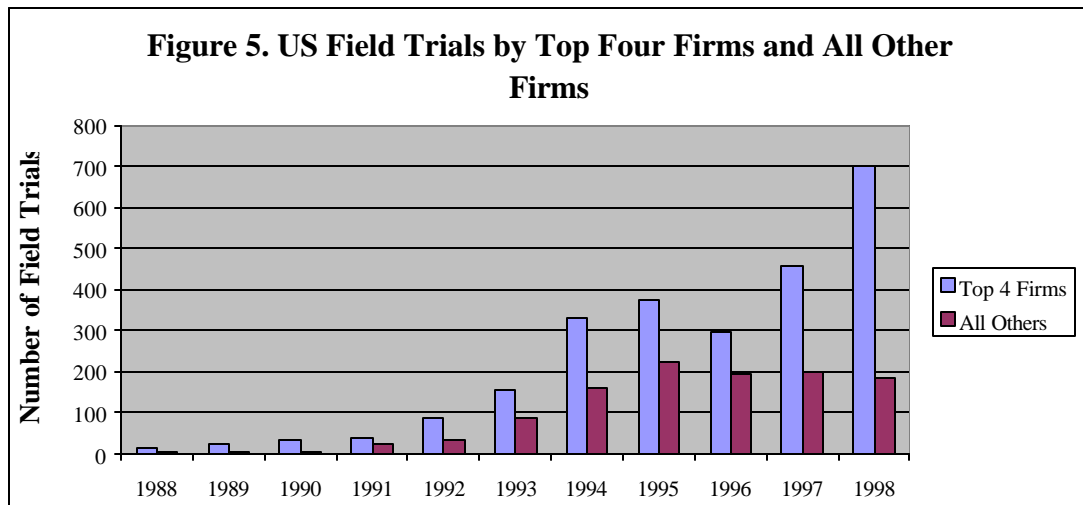
	1991	1995	1998
All Crops	Monsanto	Monsanto	Monsanto
	Calgene (Monsanto)	DuPont	Agrevo
	Pioneer (DuPont)	Pioneer (DuPont)	Pioneer(DuPont)
	Upjohn	Sandoz (Novartis)	Dupont
Corn	Pioneer (DuPont)	Monsanto	AgrEvo
	Ciba-Geigy (Novartis)	Du Pont	Monsanto/ DeKalb
	DeKalb (Monsanto)	Pioneer (DuPont)	Pioneer(DuPont)
	Upjohn	Northrup King (Novartis)	Novartis Seeds

Source: APHIS, 1999.

top spot in 1998. This suggests that although Monsanto is the major player at present, there is opportunity for other large firms to take a lead. Also, the number of field trials being conducted (see p. 13) suggest that despite industry consolidation, research by major competitors has not been greatly reduced in most parts of the biotechnology industry.

Innovation Competition Among Top Four Firms and Other Firms

A significant trend in the area of innovation competition is that research output by competitors other than the top four has been on the decline since 1995, while output by the top four has increased (Figure 5). This appears to be supporting the theory that industry concentration is causing a reduction in research and development activity in smaller firms.

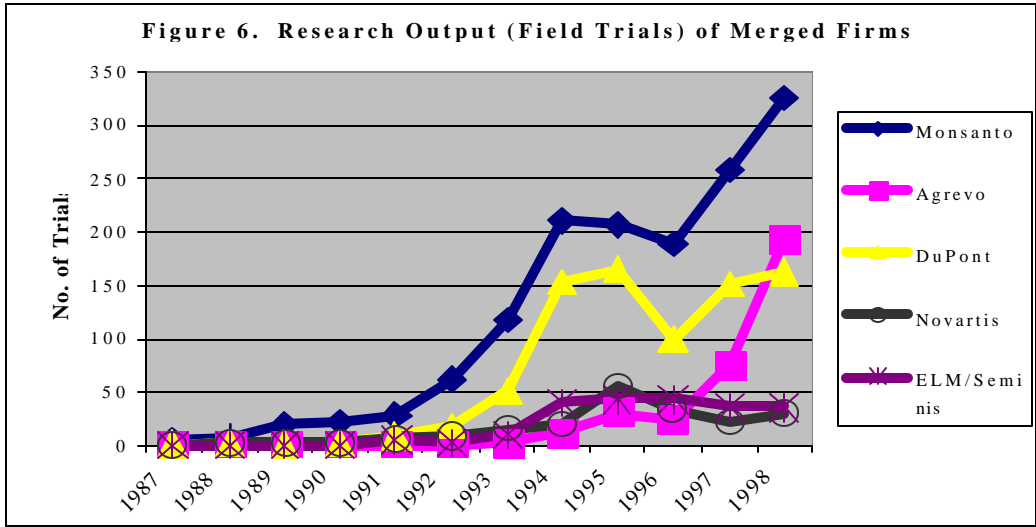


Merged Firm Research Output

To measure the impact of mergers on the research activities of merging firms, the number of field trials conducted by these firms (post merger) were examined. Figure 6 shows the number of field trials for five major firms. The majority of mergers took place from 1996 through 1998. Since 1996, two of the firms Novartis and ELM had declining numbers of field trials while Monsanto and AgrEvo had major increases since their period of mergers began. DuPont and Pioneer’s combined research grew after its purchase of 20 percent of Pioneer in 1997 but not as dramatically as Monsanto and Novartis.

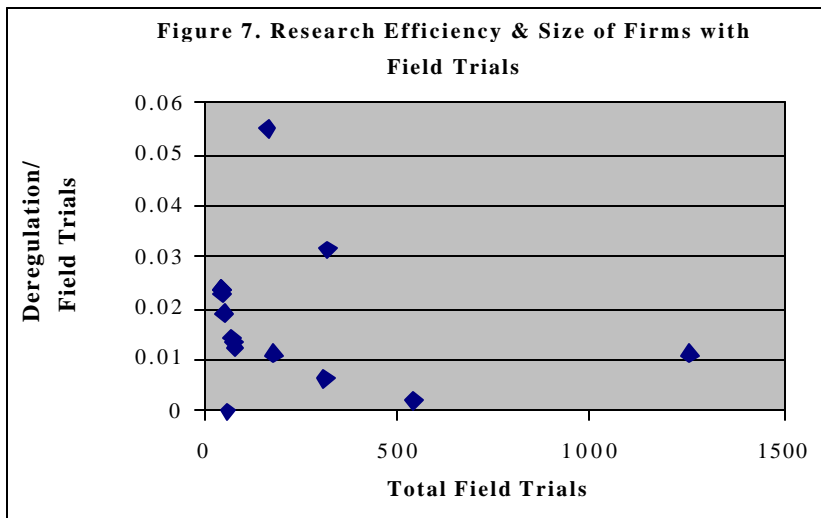
Efficiency

A key characteristic of merger analysis is the impact on efficiency in R&D activity. Some economists feel that large firm size creates efficiencies in the form of economies of



Source: APHIS, 1999.

scale, and the impact would be an increase in output per unit of input. Others feel that large firm size in a concentrated industry leads to inefficiencies in the form of reduced output. The measure used in this study to determine impacts on efficiency is the number of deregulations per field trial. The question we want to answer is, do the large firms have higher ratios? Figure 7 (p. 19) is a scatter diagram the ratio of total deregulations per total field trials and size of the company's research program. The results show that in general, size seems to be negatively related to efficiency. However, it may be too early determine whether this negative impact on efficiency is lasting, since it has been shown that R&D expenditures typically drops following a merger (Ravenscraft and Sherer, 1987).



Conclusions

The questions asked at the beginning of this paper were: How does the increase in concentration in the plant biotech industry impact research and development activities for the industry as a whole, among large and small firms, and merged firms? In addition, what are the impacts on market entry and efficiency? Table 7 summarizes some preliminary answers to these questions. Analysis of field trial data for private firms shows that concentration in the industry is growing, but there is still competition. Major firms able to compete, and they continue to increase their investments in R&D allowing them to challenge Monsanto, the industry leader.

TABLE 7 Summary of Results

Impact of Industry Concentration	Results
Total market investment	Investments are high among large firms
Total industry output of R&D	Increasing every year
Output by larger firms	Increasing every year
Output by smaller firms	Decreasing since 1995
Consequences for efficiency	Negative impact
Merged firm research activity	Ambiguous
Ability of new firms to enter market	New firm entry beginning to show signs of decline
Ability for firms to compete for top spots	Increases in investments make it possible for larger firms to climb to top spots

The total number of field trials indicate that innovation concentration by a few firms has not reduced R&D activities for the industry as a whole, but has adversely impacted the R&D activities for firms not in the top four. Mergers have negatively impacted R&D activity in two of the five major plant biotech firms (ELM and Novartis), has had a positive effect on Monsanto and AgrEvo, and some initial positive impact on DuPont, although the growth rate does not currently appear to be increasing. Entry by new firms into the market also appears to have been reduced. Large firm size resulting from merger activity is showing signs of reduced research efficiency. Econometric analysis would provide more detailed and reliable information on the drivers of innovation. These results are only preliminary, and further analysis based on several more years of data is required before any conclusive statements can be made about the impacts of merger activity on research and development activities in the plant biotech industry.

Endnotes

¹Rutgers University, Dept. of Agricultural, Food, and Resource Economics.

²Firms with annual sales below \$25 million were excluded from the study.

³Deputy Assistant Attorney General for Economics and Deputy Assistant Attorney General for Mergers, respectively, in the Antitrust Division, US Dept. of Justice, at the time article was written.

⁴Regulated 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 genetically modified organisms (GMO's) that may pose a plant pest risk, and includes almost all GMP's.

⁵Firms 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.

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