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Examining Industry Concentration In The Plant Biotechnology Sector

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Examining Industry Concentration in the Plant Biotechnology Sector

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BY

Heather Renee Williams

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Examining Industry Concentration in the Plant Biotechnology Sector

Heather Williams

Eastern Illinois University

Abstract

The core focus of this research is to recognize industry concentration in the plant biotechnology sector. The literature review examines institutional dynamics affecting the industry - discussing the importance of innovation, and how the government can influence the industry to remain competitive. An examination of a few key firms' history and evolution helps explain the structure of the plant biotech industry. The research also provides examples of what crops are being altered using biotechnology, and why companies are willing to spend money to gain the rights to this research. This article compiles plant biotechnology US field trial data from 2000 – 2009. The data was organized to find the extent of industry concentration within field trial research. Concentration was measured by the percent of shares held by the top four firms and the *Herfindahl-Hirshfield Index* which measures relative size and distribution of the firms. The study examined U.S. field trials only and showed high levels of concentration in the industry.

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Introduction

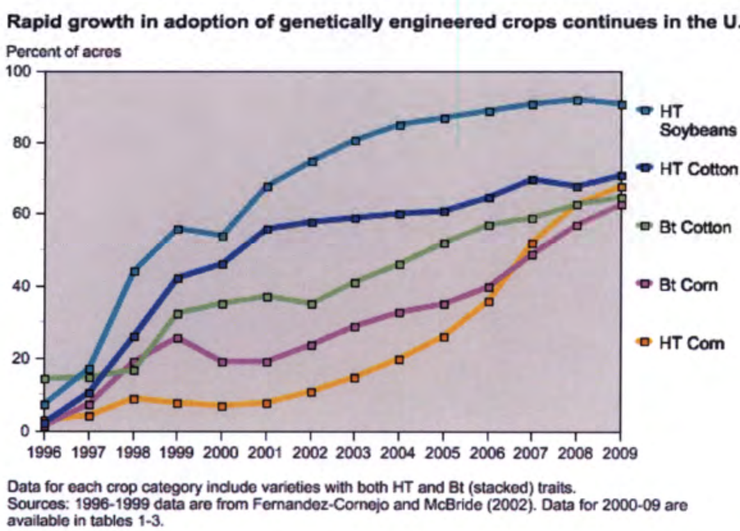
This paper will discuss the institutions that create and own plant biotechnology products, the institutional structures, a review of relevant mergers and acquisitions of plant biotechnology companies, examination of industry concentration of field trial research, and a brief review of relevant government policy. Current economic literature does not provide a clear consensus on whether merger activity and concentration have positive or negative impacts on innovation. This study is imperative given the nature of the subject; plants provide items such as food, textile material, medical compounds, biofuels, etc. Plants are essential to human survival; therefore, understanding the structure of plant biotechnology is very important. At the present, the developed world's food supply is being mass-produced by relatively large farms and firms. By 2006, large farms dominated the market; 44.7 percent of US agricultural production was by family farms with more than $500,000 in sales per year. In the 1970s and 1980s the census of agriculture documented shifts of production from small to larger farms. Family-operated agricultural farms account for 86 percent of the farms in the US, leaving 14 percent as nonfamily farms (Economic, 2006).

Traditional plant breeding is a process of artificial selection that has been applied by humans for thousands of years. Plants with desirable traits are selectively bred together to produce sought-after characteristics. In the 1980s and 1990s, advances in genetic engineering allowed scientists to alter plants on the genetic level and create useful products, which directly or indirectly increase

agricultural output. The genetic modification process is complex, but basically consists of inserting information in the form of DNA into a plant. A DNA sequence is taken from an organism with a desired trait and inserted into the genome of a plant where the new trait can express itself. New varieties of crops are developed by altering cells then regenerating the plant from those modified cells.

Plant biotechnology is ever increasing; worldwide in 2006, three-fifths of soy plants, one quarter of cotton plants, one-fifth of canola plants, and one-sixth of corn plants were genetically modified. In 2007, the worldwide land dedicated to plant biotechnology rose to 125 million hectares. The USDA has information on the United States' acceptance of genetically modified crops as a percent of the total amount of the crop being produced. The most common genetic modification in crops in US is herbicide resistant (HT) crops and insect resistant (IR) crops. The most common type of IR crops are know as "Bt" crops, containing a gene from *Bacillus thuringiensis*. Figure 1. depicts this time trend (Adoption, 2009).

Figure 1.



There are many reasons why scientists are manipulating these food products such as: nutrition, resistance to insect pests and weeds, aesthetics and increased product lifespan. First consider golden rice, which was bioengineered with vitamin A. Scientists saw the plight of millions of people in less developed who were not able to consume enough vitamin A, which lead to malnutrition, diarrhea, blindness and can even cause death; this is what drove the research and production of golden rice. Another genetically modified food product to hit the market was the ice-minus strawberry. A regular strawberry would be coated with a bioengineered foliar spray developed to protect strawberries from frost damage. Bioengineered crops can also contain herbicide resistance DNA. Monsanto developed a line of Roundup Ready seeds, which are resistant to their brand of herbicide. The farmers can spray Roundup herbicide directly onto their herbicide resistant crops and there will be no damage to the primary crop. Other types of genetically modified crops are insect resistant. The prevailing advantage of insect resistance is that fewer chemical pesticides need to be applied to the crops. The most common traits in the U.S are the stacked trait varieties, which contain both herbicide tolerance (HT) and insect resistance (IR); stacked trait seeds contain more than one biotechnological characteristic.

Literature Review

The Plant biotechnology industry refers to the institutions that create and produce genetically altered seeds. Plant biotechnology is a dynamic industry, with substantial investments in research and development, where firms attempt to

differentiate and improve products. Increases in innovation lead to a rise in total factor production in an industry, which increases social welfare. Therefore, a static analysis of the industry would not be appropriate or accurate. Antitrust analysis is imperative because investment in research is what drives future economic growth. The economic literature is very clear in stating that innovation and technological advances contribute substantially to economic advancement. Investment in research is propelled by competition and patent rights. "Competition is a critical component of innovation, although there does not seem to be clear evidence that decreased competition leads to a reduction in innovative activity" (Brennan, 2000, p. 158). There is evidence that the proportion of the firms conducting research and development increase as the size of the firm increase up to a threshold point. Furthermore, the dynamics of technological advances stimulate competition; if a firm neglects to adopt technological opportunities, the firm will fail and be replaced by new entrants (Brozen, 1982).

The U.S. Patent Trademark Office, the Federal Trade Commission and the U.S. Department of Justice can all impose limitations on antitrust actions to prevent misuse. The government's goal is to prevent excessive levels of concentration in all industries, including innovation industries. Firms engage in joint ventures, strategic alliances, and cross-licensing agreements to increase their corporate welfare. Innovation markets deserve a distinctive antitrust analysis because their labors are consumed internally rather than on the open market (Dahdouh, 1995). Depending on the price elasticity of demand, firms can charge enough to earn well above what

it costs to research and develop new products. The potential profits provide incentive for investing in new technologies. If a firm can capture monopolistic rents, the firm can produce at the most profitable level of output (O'Sullivan and Sheffrin, 2001).

A historical examination of relevant laws and the role of different government authorities provide insights into the regulation of this industry. Before 1930, patents of living organisms were strictly prohibited. In 1930, the Plant Patent Act allowed the patenting of asexually-propagated plants only. It was not until 1970 that sexually-propagated plants could be patented via the Plant Variety Protection Act. Plant breeders felt that they were granted less protection under these acts compared to the protection given by regular, or utility, patent laws. On September 18, 1985, the U.S. Patent and Trademark Office appeals decision, *Ex parte Hibberd,* allowed open-pollinated seeds to be patentable under the Patent Act (35 U.S.C. sec. 101) (Lesser, 1987). This decision stood, because in 1980 the Supreme Court decided that patents would protect "... anything under the sun which is made by man" (Lesser 1987, p. 37). The *Ex parte Hibberd* decision provided a pivotal role because seeds became patentable with utility status protection. This decision provided much broader protection for the plant breeder and bioengineered seed industry. Patent protection is used as a tool over a variety of economic sectors to increase private investment in research and development.

There are some differences in protection provided by utility patents and the protection that is available for seed patents. For an inventor to gain a patent for

their product, three conditions must be satisfied: novelty, utility, and non-obviousness. The invention must be new and not exist in that form in nature, the invention must have a specific function, and the invention must be substantially different from previous inventions (Lesser, 1987).

While patent laws are directed toward protecting producers, antitrust laws aim to protect consumers and the nation's welfare as a whole. The U.S. Congress passed the Sherman Antitrust Act in 1890 to prohibit trusts. Trusts were formed when several companies transferred their shares to a single trustee and jointly managed the company, increasing the shareholders earnings and destroying competition (Sherman, 1890). The Clayton Act of 1914 was another measure taken by the government to prevent anti-competitive practices. Section 7 of the Clayton Act prohibits any person or firm from acquiring stock or assets of another corporation in which the effects of the acquisition reduces competition or creates monopoly power (Becker, 2004). Current anti-trust laws can be violated in three main ways: by conspiring to suppress competition, through predatory behavior intended to maintain monopoly power, or by mergers that significantly reduce competition (Milligan, 2003).

In 1984 Congress imposed the National Cooperative Research Act (NCRA). This act forced registered ventures to be assessed for their effects on competition, specifically: research and development, available products, and service provided to customers (Brennan, 2005). The Federal Trade Commission addresses the impacts of merger activity on research and development by looking at levels of individual

firm's research and development as well as examining how difficult it is for new firms to enter the market (Brennan, 2000).

Staff attorneys from the Bureau of Competition's Office of Policy and Evaluation at the Federal Trade Commission, Dahdouh and Mongoven (1995), explain how the Federal Trade Commission addressed the merger analysis process. Merger analysis has a future-oriented outlook which attempts to forecast the post-merger environment including the ease of market entry, whether a company could generate monopolistic power to raise price or reduce quality, if there is a reduction in (or corporate incentive to reduce) research and development efforts, or if the merger leads to anti-competitive actions such as collusion.

In 1992, the Horizontal Merger Guidelines emphasized examining merger and acquisition transactions, and recognizing externalities that affect non-price attributes, such as product quality, service, or innovation (Dahdouh 1995). Horizontal integration occurs when two firms in the same industry merge operations, which typically results in increased industry concentration (Weston, 1981). Vertical integration occurs when two firms from different stages of production merge. Vertical mergers generally occur when a firm merges with a firm it purchases an input from or a firm that it supplies output to (Clarkson, 1982). A conglomerate is a type of merger between businesses that make unrelated products; conglomerates are generally not known to decrease competition (O'Sullivan and Sheffrin, 2001).

The Federal Trade Commission incorporates long-run forecasts into their decisions, knowing that without immediate anti-competitive results, long-run innovation and competition can be harmed. The assessment of individual firm market power provides information on individual firm's ability to control price and total market output. Analysis of the ease of market entry is important because if one firm gains the power to derive monopolistic profit, it is important to know if other firms can enter the market and generate competition. The Federal Trade Commission also takes into consideration all efficiencies gained from any merger and weighs those benefits against the costs (Dahdouh, 1995).

In 1995, the Federal Trade Commission and the Department of Justice jointly released Intellectual Property Guidelines. These Guidelines are yet another attempt to stabilize industry competition by incorporating the products of the industry, the assessment of market participants, the research and development abilities of competing firms, and the availability of substitutes on the market (Dahdouh, 1995).

In March 2002, the Federal Trade Commission and the Department of Justice formed an agreement that assigned antitrust law responsibility of Agricultural and the related Agro Biotechnology field to the Department of Justice. Anti-trust laws are not violated simply because the industry has high concentration or because firms price similarly. Government intervention only occurs when a law has been broken, which can be difficult to prove in court. Anti-competitive measurements (even units) are not definite and are difficult to precisely calculate quantitatively or qualitatively (Milligan, 2003).

A common tool that the Department of Justice uses to sustain competition is by requiring the merging firms to divest particular assets or information (Milligan, 2003). For example, the Department of Justice only allowed Monsanto to purchase DeKalb on the conditions that they would make public their patented agrobacterium transformation technology. Agrobacterium transformation technology is one important method used in genetic engineering to insert foreign DNA into a host genome of a seed. Monsanto was required to enter into binding commitments to license its Holden's corn germplasm to other firms that introduce new traits into corn. The Department of Justice's goal was to encourage competitive biotechnology developments in corn (DOJ, 1998).

While Monsanto was in the process of acquiring Delta & Pine Land Company, the Department of Justice required that Monsanto divest Stoneville Pedigreed Seed Company, Delta & Pine Land released 20 cottonseed lines, Monsanto released other cottonseed lines, and alter trait licenses so that other cottonseed companies could stack Monsanto and non-Monsanto traits and sell them. Without these requirements, Monsanto would have controlled nearly 95 percent of all cottonseed sales in the highest value cotton growing regions of the US. In 2007, the Department of Justice directly stated that the divestures and other requirements were necessary to "[p]reserve the current competition to sell traited cottonseed; prevent any significant delay in bringing cottonseed with non-Monsanto traits to the marketplace; and ensure the continued presence in the market of a firm independent of Monsanto with traited cottonseed development capabilities

sufficient to serve as a platform for future trait development and commercialization" (DOJ, 2007).

The government is not the only entity that can bring anti-trust claims against a corporation. In March 2000, DuPont filed an anti-trust lawsuit against Monsanto which claimed that Monsanto incorporated tying agreements which restricted farmers from using any other herbicide than Monsanto's Roundup brand. Prior to April 2002, Monsanto and DuPont had 11 pending lawsuits against each other. The two firms agreed to drop all lawsuits and cross-license their patented assets to one another. This type of collusion potentially encourages "non-merger monopolies" which generally accomplishes the effects of a merger without undergoing the regulatory analysis necessary for merger approval (Milligan, 2003). Furthermore, strategic alliances in the plant biotechnology industry can generate a cartel like environment where output is restricted and prices are high.

Some important aspects to consider when examining industrial organizations are basic economic conditions, market structure, conduct, and performance. Relevant economic conditions include the state of technology, the price elasticity of supply and demand, cross-price elasticities, location, and seasonal and cyclical characteristics. The term "market structure" refers to the forces that influence the nature of competition. "Market structure thus includes size and size distribution of firms, barriers and conditions of entry, and product differentiation, as well as firm cost structure and the degree of government regulation" (Clarkson, 1982, p. 5).

Market structure is the influential force behind individual firm conduct. Conduct refers to how the firm allocates its resources and what products the firm chooses to produce. Conduct includes advertising, research and development, pricing strategy, collusion, product choice, internal organization, and merger activity. A firm's performance is generally characterized by efficiency, growth, equity, and technological change. Although mergers and acquisitions are the main focus of this research, it is essential to know that mergers and acquisitions are not the only conduct that explain changes in performance or even indicate how competitive the industry is (Clarkson, 1982). For example, economies of large-scale production also influence industrial concentration.

Economies of large-scale can be attributed to large mandatory upfront investment, while the volume of output is not necessarily large. When firms experience economies of scale, the average cost decreases for each additional unit produced. The average-total-cost curve usually plots in the shape of a quadratic, or is u-shaped, with a minimum turning point. But when the firm experiences economies of scale the average-total-cost curve slopes downward and plots as a rectangular hyperbola (Chiang, 1984). This allows large firms to offer lower prices and gain market shares. Moreover, the cost of raising capital is less to larger firms and more for smaller firms. If the flotation cost of issuing a new security decreases, more capital is made available to the firm by investors. Larger firms can offer low-risk to investors, raise more money and economize on flotation costs (Brozen, 1982).

Even if the market was originally competitive with many sellers of the same size, concentration can arise out of competition. For example, competition encourages firms to expand and drive down price until only low-cost firms can survive which eliminates all but a few firms, creating an oligopolistic or concentrated market structure (Brozen, 1982).

The costs associated with innovation in creating new products can be risky; firms cannot control the consumer's preferences of which products will fail and which will succeed. Alternatively, large firms can better support a wider array of research and development and recoup any losses due to failed products. If a firm sells products with a complex design and large overhead costs, small firms may be uneconomical (Weston, 1981). Large firms benefit society by increasing employment and total national income through the multiplier effect. A neoclassical economist would incorporate benefits of increased productivity, increased real wages leading to a larger national income (Brozen, 1982).

The plant biotechnology sector possesses characteristics found in models of oligopoly. The term oligopoly implies that the number of firms in the industry is in the range between two and a dozen or more firms. The plant biotechnology industry that had between 10 and 20 firms involved in field trial research from 2000 through 2009 (Brozen, 1982). Oligopolistic models are the first to introduce a reaction function.

The reaction function is the way one firm reacts to another firm's actions. Firms recognize the interdependence amongst one another and make pricing and

output decisions based on inaccurate information about competitors reactions. Firms believe that their prices affect the prices set by rivals, and wish to set price or quantity to optimize profits. Generally speaking, the interaction amongst oligopolies is of a rivalry nature, but some firms also mimic or act to collude.

Another oligopolistic model assumption in this industry that has held true is the assumption of differentiated products. Oligopolistic assumptions that have not held true consist of each firm having identical marginal costs and perfect information about market demand, and that the institutions have identical interests. Under oligopoly output is less than under perfect competition however, output is greater in oligopoly than in a pure monopoly.

The plant biotechnology industry does not sell homogeneous products; the industry sells differentiated products. The concept of differentiated products came from Chamberlin in 1933. His simple example of apples, which appear to be homogeneous products, have a variety of tastes, sizes, texture etc. hence, some consumers prefer one firm's apples over another. Furthermore, if the customer is impartial to the physical differences in the apples, they will usually choose the less expensive apple (Friedman, 1983). Therefore, each firm has a monopoly on the production and sale of their unique product, while the other firms in the industry are producing close substitutes. The products are differentiated by: design, quality, brand, trademarks, and company name. Each firm has an interval of prices at which it is willing to sell. A large number of firms may cause this interval to be small, but the plant biotechnology industry has a relatively small number of firms, which

implies that noticeable differences should arise in individual firms pricing (Friedman, 1983).

The oligopolistic assumption that all firms have identical marginal costs does not necessarily hold true in this industry. The plant biotechnology industry is composed of other institutions besides firms. Universities and government research institutions have very different sources of income. Public universities are, in general, nonprofit organizations in the business of increasing social welfare. A nonprofit organization is an institution that functions like a business, but profits are not the foremost goal. Institutions vary in their goals, strategies, investments, and financial contributors; therefore these institutions could not have the same marginal cost. Marginal costs are different amongst firms in this industry depending on firm size and wage differences in the industry. This oligopolistic industry is comprised of a variety of firm size. The array of firm sizes is thought to be beneficial to the industry because the large firms have the resources to conduct large-scale research and development while the small firms can specialize in research areas (Brozen, 1982).

The Stigler Oligopoly Model of Implicit Collusion hypothesizes that oligopolists collude to maximize joint profits (Clarkson, 1982). If firms in the industry acted together, then the optimal price and output could be set to maximize total profits in the industry. If the entire industry colluded, monopoly profits would be earned. One of the problems that colluders face is that collusions are expensive to undertake and difficult to control. Firms may face the incentive to cheat with the

promise of higher profits. It is not in the interest of all firms to collude even if the firms as a whole would benefit. Explicit collusion is difficult to initiate and firms often cannot reach agreements; therefore tacit collusion is near impossible (Brozen, 1982).

Stigler's Oligopoly Model is the base for the open oligopoly model. The open oligopoly model hypothesizes that existing firms would not price to deter market entry (Clarkson, 1982, p. 150). The firms will price to maximize their present value of profits. The profit rate over time is downward sloping; first convex, then concave. The firm receives high profits in the beginning due to high prices, with diminishing profits over time due to the entry of new firm. A downward sloping profit rate implies a high discount rate, where the present value of profits is smaller in the future.

In 1956, the economist Bjarke Fog, proposed that an upward sloping profit rate over time is due to a low discount rate, where future profits have a higher value. Fog suggested long-time horizons for firms, which suggests stability in a number of firms and/or concentration, whereas Stigler's model suggests an increase in firms and/or a reduction in concentration (Clarkson, 1982).

The plant biotechnology industry has possessed characteristics of Stigler's model over the past ten years. Stigler explains, competition is more dependent on the number of potential rivals than with the number of actual rivals (Brozen, 1982).

Enabling technologies encompass the knowledge and the techniques that allow the desired traits to be transplanted into the desired plant. Enabling

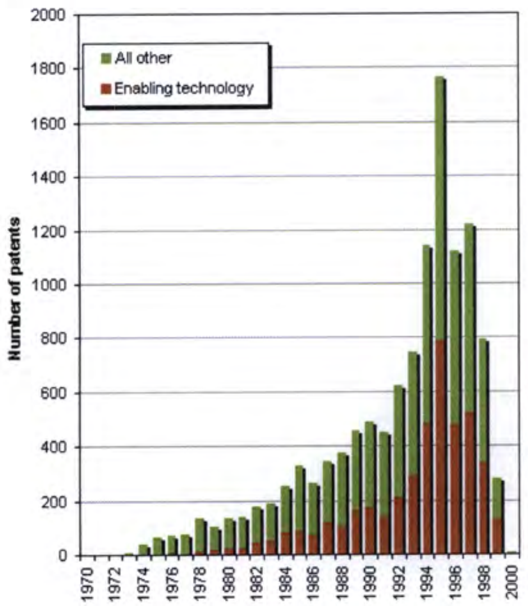
technologies are few in numbers and most are patented. Knowledge of transforming processes is mandatory in this type of research and development. The use of patented transforming technologies requires firms to pay expensive licensing royalties. The cost is high for smaller companies to obtain permission to use patented technologies which will most certainly enhance barriers to entry in the industry. The lack of any companies' abilities to obtain information necessary for advancement in research may result in a negative social impact on research participation. Popular enabling technologies include the use bacteria such as *Agrobacterium tumefaciens* and *A-rhizogenes*, along with physical and chemical systems such as microinjection, recombinant DNA electroporation, chemical poration and microprojectile bombardment (i.e. gene gun) (Jouanin, 1993).

If the plant is resistant to the common process of recombinant DNA, as many grains are, then scientists use microprojectile bombardment. The gene gun shoots DNA-laden golden bullets into the cells. The gene gun technology belongs to DuPont. DuPont allows access to this technology through exclusive licensing (Brennan, 2005). Monsanto and Syngenta control patents for the use of *Agrobacterium*, a key organism used for transforming crops. Monsanto also controls the 35S promoter, derived from a common plant virus, which is a necessity for some transformations such as herbicide resistance. (Brennan, 2005; Milligan, 2003).

From 1990 to 1995, there was a steady increase in patent applications for enabling technologies, which peaked in 1995, and then gradually declined. All other agricultural biotechnology patent applications have the same peak and downward

trend after 1995. It is difficult to determine why this decrease occurred. Perhaps the decline was due to firms' inabilities to access needed enabling technologies. Figure 2 provides the number of patents granted in the biotechnology sector (Brennan, 2005).

Figure 2.



Total and enabling-technology agricultural biotechnology patents, 1970-2000.
Source. Data from USDA ERS (2004).

The significant work of Brennan (2005) measured the impacts of mergers by comparing the number of patents held by the top four firms in the plant biotechnology industry to the number that would be held by the top four firms if no merger or acquisitions took place. There has been a rise in the number of patents held by merged firms since 1997. This type of analysis is called the four-firm concentration ratio (CR4). Traditionally, the CR4 measured the top four firm's concentration of total sales. In a competitive industry the concentration is more evenly distributed, and in a more monopolistic industry the concentration is among

a few firms (Maddala, 1989). For the intent of this study, the CR4 has been applied to patents, field trials, and phenotypes.

An assumption of the CR4 is that market power is related to market share. A high CR4 measurement implies that a few firms control a large portion of the market. The top four firms could potentially place influential pressure on the other firms in the industry (Weston, 1981). "This relationship in turn has been linked to the notion that both the incentive and the opportunity exists to collude or otherwise engage in cartel policies that increase revenues to the industry" (Clarkson 1982, p. 63). The nature of the CR4 leads to some inadequacies in the measurement because it does not reveal firm turnover, the number of firms in the industry, nor does it provide individual information about the relative size and position of the top four firms. Another relevant type of analysis is the Herfindahl-Hirshfield Index (HHI).

The HHI is a commonly used measure of market concentration. The HHI is calculated by squaring the market share of every firm in the market and adding the resulting numbers together. The HHI incorporates the relative size and distribution of the firms involved, an HHI of 10,000 implies only one firm in the industry controlling the entire market. The HHI decreases when the number of firms in the market increases or when the sizes of the market shares of the existing firms decreases. The U.S. Department of Justice considers industries to be moderately concentrated if the HHI is between 1000 and 1800 points. Industries in which the HHI is above 1800 points are considered to be concentrated. If a merger or acquisition increases the HHI by 100 points or more, concerns of antitrust arise due

to the Horizontal Merger Guidelines issued by the U.S. Department of Justice and the Federal Trade Commission (DOJ). The equation to find any HHI is:

$$HHI = \sum_{i=1}^{N} s_i^2$$

Where S_i is the market share of the i^{th} firm, and N is the number of firms in the industry. A complete monopoly occurs when the HHI reaches the maximum (HHI = 100^2 = 10,000) and one firm has 100 percent of the market share.

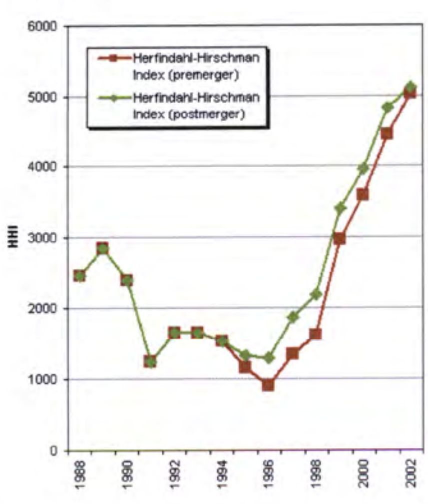
The HHI is dependent on the number of firms in the industry and the variance of the market. Higher HHI levels indicate few firms or exceptionally unequal market shares. High HHI generally implies monopoly power; monopoly power is the ability of a firm to alter the products price through an adjustment in output (Maddala, 1989). Firms in the plant biotechnological industry can create monopoly power by designing, testing, and marketing unique crops.

Once the agricultural biotechnology firm has inserted foreign DNA into a plant and reproduces seeds for that plant, the firm must test the seed to determine if the desired traits will be expressed. The inventing firm conducts field trials in ordinance with the United States Department of Agricultural Animal Plant and Health Inspection Service (APHIS) guidelines. If the inventing firm wants to commercialize the product, the firm must apply for deregulation from APHIS. If deregulation is granted, the firm is free to commercialize the product without any

further regulation with respect to its transgenic properties. The firm can then acquire a utility patent for the new plant (Oehmke, 2003).

Brennan (2005) used the number of field trials as a proxy for market share for her analysis. The HHI between 1998 and 2002, taking into account pre-merger and post-merger HHI points are shown in Figure 3. Concentration was moderate from 1991 to 1997, but after 1997 the HHI rose dramatically. The HHI reached its highest level, with a total of 4,828 points (Brennan, 2005). Unfortunately, some bias may be lying within the data. For instance, if a firm is applying to APHIS for deregulation, they might increase the number of field trials to prove that the transgenic crop is the same as the non-transgenic crop considering the large number of environments in which the plant could be grown. Furthermore, the stage of the biotechnological development (near the end and requesting deregulation) can influence the number of field trial requests (Oehmke, 2003).

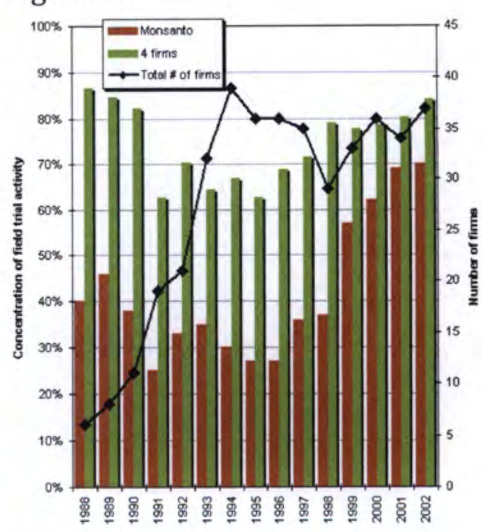
Figure 3.



Pre- and postmerger HHI for field trials, 1989-2002.

Source. Data from USDA APHIS (2002).

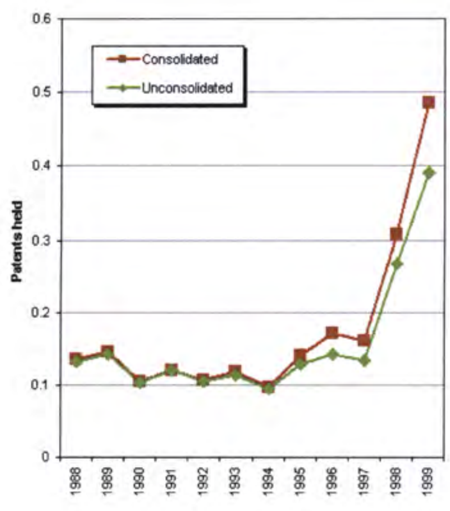
Figure 4.



Concentration of field trial activity and number of firms, 1988-2002.
Source. Data from USDA APHIS (2002).

Between 1994 and 1996, concentration ratios in this industry rose and the number of firms conducting research declined. After 1996, the top four firms had an even greater percentage of research concentration. It is noteworthy to mention that during this time period the number of firms conducting research slightly increased (refer to Figure 4). Until 1997, the top four firms (Monsanto, Pioneer, Novartis, and DuPont) controlled less than 20 percent of the industry's patents, and by 1999 the top four firms held nearly 49 percent of the agricultural biotech patents. Brennan's results determined that without the mergers and acquisitions taking place, the top four companies would have continued to gain patent concentrations. What is not evident is whether or not any firms were deterred from research and patenting (see Figure 5).

Figure 5.



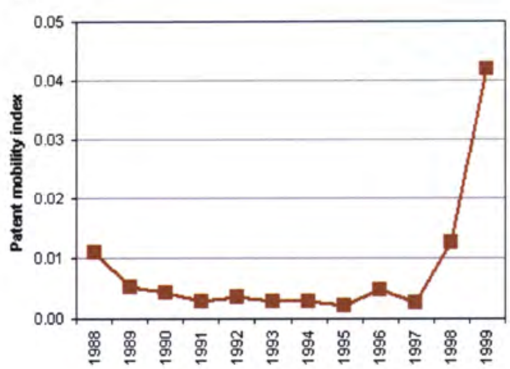
Agricultural biotechnology patents held by the top four firms, 1988-1999.
Source. Data from USDA ERS (2004).

Another tool that Brennan (2005) used to measure the impacts of mergers was examining which firms were market-share leaders, as well as looking at the

ability of one firm to acquire market shares from another over time. This process requires the examination of a mobility index. Note that an analysis of the top four firms would not necessarily expose changes in market leadership. The mobility index examines market share over time. Let $m_{i,t}$ represent the share of firm i at time period t. The mobility index is defined as $M_t = \Sigma_i (m_{i,t} - m_{i,t-1})^2$. The mobility index ranges from 0 to 2; it is zero when there is no change in market share and two when one monopoly replaces another (Brennan, 2005). Some economists believe that large firm size carries advantages and the ability to establish and hold on to the market-share leader position (Brozen, 1982).

Brennan applies the mobility index to patent data and her results show an increase in the mobility index suggesting a change in firm's shares, yet the increase is relatively small which does not indicate any significant level of mobility, the results are shown in Figure 6 (Brennan, 2005). By combining the information of reduced patent applications and relatively consistent leaders, questions arise about the rate of innovation in this industry.

Figure 6



Mobility index for plant agricultural biotechnology industry, patent data, 1988-1999.
Source. Data from USDA ERS (2004).

Oehmke and Wolf (2003) suggest that previous research, such as Brennan's work, could become more robust if strategic alliances were taken into account. Brennan (2005) treats the agricultural biotechnology firms as independent entities conducting independent research. The previous analysis did not take into account alliances, which do occur in the real world. Therefore, "plant varieties invented by one firm but tested by another company have not been counted toward the share of R&D activity of the inventing company" (Oehmke, 2003, p 134). The alliances come in the form of license agreements and subcontracts, which allows one firm to utilize another firm's intellectual property. Including alliances into ones analysis can provide more meaningful results when examining the structure of innovative activity.

The pace of innovation in this industry is affected by the structure of innovation, whether or not the innovation is dependent on previous innovations or is independent of other innovations. "In cases of trait stacking, each succeeding innovation most likely relies on a patent(s) held by the previous innovator(s)... there could be an issue of access to the intellectual property, which in turn could act as a barrier to [research and development] and innovation" (Oehmke, 2003, p 135). The size of a firm's market share can also impact innovation. To elaborate, if the firm is small and has to compete with large firms that have well-known products (such as the herbicide resistant trait and Monsanto's Roundup Ready herbicide) the small firm has to put forth substantial effort to deter customers from purchasing well-known, trusted brands and convince them to purchase their lesser-known

products instead. Depending on cost-benefit analysis, the small firm might not develop the herbicide resistant trait if it would be a poor (in the economic sense) substitute for Roundup. This leads to less ability for small firms to innovate, while the incentive still exists. The development of new technologies for the firm's production can cut fixed costs, which could have a greater positive impact on smaller firms (O'Sullivan and Sheffrin, 2001).

Oehmke and Wolf (2003) provide strong evidence of this process. "There are 98 different types of Bt holotype toxins..., but only six different Bt types in crops that the USDA has deregulated for commercialization: four in crops commercialized by Monsanto, one by Dow, and one by Aventis" (Oehmke, 2003, p 135). This is a shame from a social perspective because the different Bt proteins affect a variety of insect orders and species and therefore, the Bt proteins are not perfect substitutes for one another.

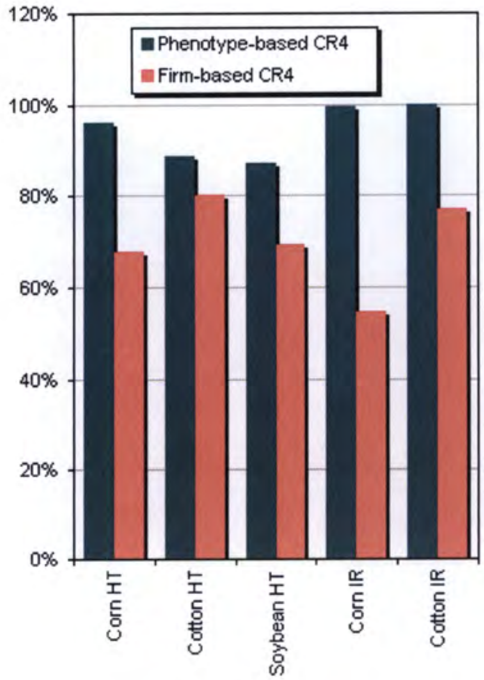
If there are large numbers of gene constructs being developed by numerous independent firms, the innovation market will be moderately competitive. However, "[a] small number of gene constructs-no matter how many firms are testing them-could lead to excessive concentration and limited innovative activity" (Oehmke, 2003, p 136). Oehmke and Wolf (2003) propose a new type of analysis to measure the use of gene constructs, which will provide information on the structure of the research and development industry. The complaint with previous research is that it fails to capture the intellectual property issue of access to previous innovations.

Oehmke and Wolf (2003) propose a measure similar to the CR4. The new measure differs from the traditional CR4 in that institution or industry concentration is not used instead, the numbers of trials of each type of gene construct containing a specific trait is measured. The GR4 measures, of all of the known phenotypes, how many field trials are being done on the top four phenotypes. The GR4 is taken for individual crops and traits –such as Corn insect resistant. (Oehmke, 2003). The concentration ratio is found by dividing the denominator into the numerator, which gives a percent from 0 to 100. A concentration ratio of 100 percent implies a pure monopoly. Similarly, a low percent implies high competition. This new measurement is called GR4, which stands for gene related concentration of the top four characteristics.

APHIS collects data on every firm's gene construct when the company applies for field trials. Unfortunately, the APHIS dataset does not publicly disclose that information; the information is confidential. However, one could substitute gene-construct information for similar data that is publicly available, phenotype data. A phenotype can be generalized as an observable trait. "The corn phenotype of glyphosate tolerance can be readily associated with one of two gene constructs conveying this tolerance in standard farming environments" (Oehmke, 2003, p 137). Oehmke and Wolf (2003) took the proportion of field trials from the four most prevalent phenotype categories through the end of 2000 to create the GR4 measurement. The authors found that for this industry, the GR4 provides more concentrated results than the CR4 results.

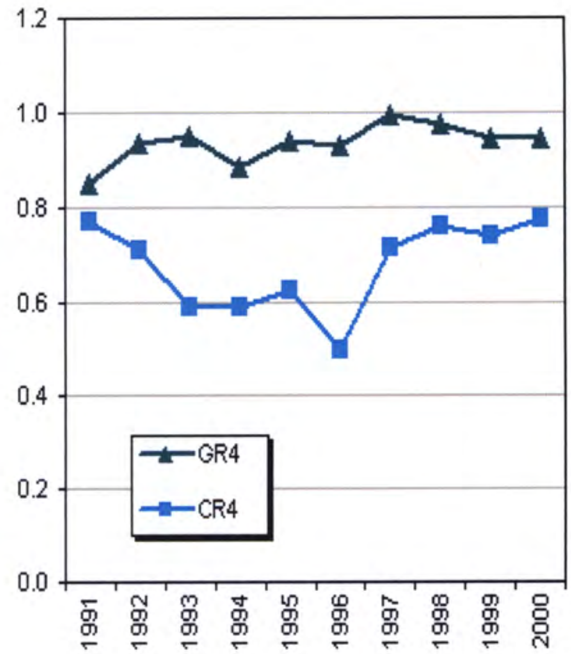
Through the end of 2000, the GR4 measures showed uniformly high concentration in the industry (figures 7 and 8 show the results). Their conclusion emphasizes that GR4 analysis can provide insights for expectations of market competition. If many firms conduct research on one single gene construct, then the owner of that gene construct can collect monopoly-type profits from all sales made in the output market. If many firms conduct research on many gene constructs, there will be higher competition and less concentration (Oehmke, 2003).

Figure 7.



Phenotype- and firm-based concentration ratios.
Source. Data from USDA APHIS (2003).

Figure 8.



Concentration measures for herbicide tolerance R&D, 1990-2000.

Source. Data from USDA APHIS (2003).

Firms in the agricultural biotechnology industry are willing to invest millions of dollars in research and development in order to possess exclusive rights to the

newest technology or products. Patents provide incentives for firms to take part in research and development because the firm's unique intellectual property will be protected. Intellectual property is defined as "property that results from original creative thought, as patents, copyright material, and trademarks" (Random, 2009). Without intellectual property rights, firms would be less enticed to invest money in research because they would not profit from the labor. A general understanding of intellectual property rights is required for understanding firms' behaviors. Free-flowing technology enhances innovation at a cost, but without intellectual property protection, there would be little incentive driving innovative investment.

Historically, property rights were given to inventors of tangible or physical goods. More recently, focus has been placed on intellectual property. Intellectual property refers to the process or ideas for putting something together. These ideas are referred to in the literature as disembodied ideas. The disembodied ideas "can often be transferred between individuals at virtually no cost" (Phillips, 1999, p. 3). Therefore, the marginal cost of one additional unit of the new idea is roughly zero, producing a relatively flat supply curve after the first unit. Therefore, if the information could be freely mobile, it would not be economically efficient for any firm to invest in innovative research. It is now known why intellectual property rights is so important to the industry, but the question of what the agricultural biotechnology industry looks like has yet to be answered. This naturally leads to the topic of industrial activity.

There has been a plethora of mergers and acquisitions over the past two decades within the plant biotechnology industry. Brennan (2005) believes that this activity "has been driven by the research assets required to develop new biotechnology products and by the strong patent system of the United States" (Brennan, 2005, p. 89). These mergers have generated some anti-competitive concerns due to the concentration of patents, the increase of market shares held by the top firms and any external impacts on research and development in the industry. The new industrial environment is one of a small number of firms possessing influential market power over the direction of biotechnology innovation and products. This is important because a change in industry concentration can alter levels of research and innovation.

Some major mergers that have taken place in the past twenty years are illustrated Table 1 located in the appendix (Information, 2009). A significant trend of the plant biotechnology industry in the 1990s was for many firms to sell their chemical manufacturing division, increase mergers with seed companies, and form alliances with multinational corporations (Brennan, 2000). Several of these firms sold their chemical manufacturing companies, redirecting resources, in order to increase investment in biotechnology and negotiate with or acquire seed companies. To understand how these companies are composed and thrive, one must examine the company's history and financial information. Some top firms in the plant biotechnology industry are Monsanto, Syngenta, Dow AgeroSciences, Pioneer Hi-Bred International, Inc., and Bayer Cropscience.

Background Information

Monsanto is the leading U.S. company driving research and development in bioengineered crops. Prior to September 1997, the Monsanto Company produced a much more diverse array of products. The original Monsanto Company operated an agricultural products business, a pharmaceuticals and nutrition business, and a chemical products business (Relationships, 2009). On September 1997, Monsanto Company entered into an agreement with Pharmacia whereby Monsanto Company divested its pharmaceutical business to Pharmacia, and its chemical products business to Solutia. Today, these three companies are separate entities engaged in ongoing service and supply agreements.

In 2008, Monsanto's fiscal year sales were made up of 44 percent agricultural products (non-seed based products i.e. herbicide and turf products) and 56 percent seeds and genomics. The seed products are comprised of corn, cotton, canola, wheat, and other vegetable seeds. Monsanto allocates 9 percent to 10 percent of sales toward their research and development budget. In 2008 and 2009, net sales were over 11 billion dollars (Monsanto Annual, 2009). Monsanto focuses most of its research and development efforts on "new biotech traits, elite germplasm, breeding, new variety and hybrid development, and genomics research" (Investors, 2009). From 2005 to 2009 Monsanto spent 4.8 billion dollars on acquisitions of other companies.

In 1996, the original Monsanto purchased Agraceyus, a research and development facility that specialized in transformation technology and molecular

biology. In 1997, the original Monsanto acquired Calgene and purchased Asgrow agronomics seed business. In 1998, Monsanto purchased DeKalb Genetics Corp for $2.3 billion. In 2004, Monsanto formed American Seed Inc., a holding company which specialized in corn and soybean. The central purpose of American Seed Inc. was to provide support to regional seed businesses that needed assistance with capital, genetics, and technological investments. Within 2004, American Seed Inc. acquired three seed brands: Crows Hybrid Corn, Midwest Seed Genetics and Wilson Seeds (Monsanto Who, 2009).

In 2005, Monsanto acquired the American company Seminis, Inc., a global vegetable and fruit seed leader. Monsanto's American Seed Inc. subsidiary acquired four companies that are the shareowners of the CORE Group, and Specialty Hybrids, (Monsanto Who, 2009). Monsanto also finalized the sale of their Enviro-Chem Systems Inc. to a new company, MECS, Inc.

In 2006, Monsanto's American Seed Inc. subsidiary acquired several regional seed companies, one of which was Fielder's Choice for $50 million (Monsanto Annual, 2009). "Monsanto and Dow AgroSciences LLC signed a global agreement cross-licensing intellectual property, product licenses in corn and soybeans, cotton technologies, and enabling technologies" (Monsanto Who, 2009).

In 2007, Monsanto sold their swine genetics business, Choice Genetics, Inc., to Newsham Genetics, LLC. "Monsanto and Dow AgroSciences announce a cross-licensing agreement aimed at launching SmartStax™, the industry's first-ever eight-gene stacked combination in corn" (Monsanto Who, 2009). Monsanto and BASF

collaborated on a long-term research and development program as well as commercialization of plant biotechnology that focuses on higher yielding crops, which can withstand adverse weather conditions. Monsanto's American Seed Inc., acquired nine separate U.S. seed companies for an aggregate cost of $37 million (Monsanto Annual, 2009). Monsanto and Bayer CropScience AG announced several long-term business and licensing agreements. Monsanto acquired Delta and Pine Land Company, the largest cottonseed producer in the world for $1.5 billion; the entire company was acquired except Stoneville and NexGen cotton businesses, because Monsanto had already acquired them in 2005 (DOJ, 2007).

In December 2008, Monsanto acquired the Brazilian company Aly Participacoes Ltda., whose focus was on sugarcane and breeding technologies. Monsanto bought Aly Participacoes Ltda. for R$616 million (Brazilian reais) or $264 million. That year, Monsanto also acquired Semillas Cristiani Burkard, a Guatemalan company. Monsanto spent $135 million on Semillas Cristiani Burkard. Monsanto also acquired De Ruiter Seeds one of the top breeding companies in the world for $756 million. In 2008 Monsanto sold its POSILAC® bovine somatotropin (a dairy bovine growth hormone) brand and related business to Eli Lilly and Company. By 2009, Monsanto acquired the assets of WestBred LLC, wheat germplasm specialists, for $49 million (Monsanto Annual, 2009). Over the years Monsanto has undergone a significant transformation, mainly acquiring companies and technologies, but also divesting certain assets. Monsanto has become a key firm conducting high percentages of U.S. research and development.

Another significant plant biotechnology firm is Syngenta. Although Syngenta is a relatively young company (it officially became a firm on November 13th 2000), the corporate heritage trail is interesting and dates back over 250 years. Geigy was founded in 1758. In 1935, Geigy produced pesticides, and in 1956 Geigy introduced herbicide for the first time, which no other company had done. Sandoz was founded in 1872, and in 1975 acquired Rogers Seed Company. This was the first time the company got involved in the seed market. Ciba was established in 1884, and merged with Geigy in 1970 to form Ciba-Geigy. In 1978, Ciba-Geigy introduced the systematic fungicide Ridomil. In 1996, Sandoz and Ciba merged to form Novartis, which was one of the largest corporate mergers in history. Novartis acquired the crop protection division of Merck & Co., gaining access to insecticide market shares (Syngenta, 2009).

In 1926, Imperial Chemical Industries (ICI), a British chemical firm, was formed by the merger of four companies. Zeneca was formed in 1994 after ICI vertically disintegrated three of its specialized businesses: pharmaceuticals, agrochemicals, and specialties. In 1997, Zeneca acquired Mogen, a plant biotechnology company, and rights to a fungicide owned by ISK. In 1999, Astra AB of Sweden and Zeneca Group PCL of UK merge, becoming AstraZeneca (Syngenta, 2009). Table 2 depicts Syngenta's corporate history.

On November 13th, 2000, Novartis and AstraZeneca merged their agribusinesses creating Syngenta, a global firm focused explicitly on agribusiness. In 2002, Syngenta released their rice genome map. Also in 2002, Syngenta and

Diversa entered into an agreement to share biotechnology research. Syngenta was active in 2004, acquiring Dia-Engie and Golden Harvest. Syngenta went on to form a partnership agreement with Tanimura & Antle, and Syngenta became involved in a long-term agreement to develop cotton biotechnology products with Delta & Pine Land Company. In 2005, Syngenta and Sumitomo created an herbicide license agreement. Syngenta also formed a strategic alliance with COMPO for consumer lawn and garden products.

Syngenta acquired Emergent Genetics Vegetable A/S in 2006 for $3 million. One of Syngenta's subsidiaries merged with Conrad Fafard, Inc., allowing Syngenta full control of Farfard and all of its subsidiaries. This acquisition cost Syngenta $43 million. Syngenta also settled $14 million worth of Fafard's financial debt. In 2006, Syngenta purchased the remaining shares (50 percent) of Longreach Plant Breeders. Net cash outflow for acquisitions in 2006 was $143 million (Syngenta, 2008).

In 2007, Syngenta joined a partnership to explore bio-fuel potential with Diversa, and also increased its shareholding in Syngenta India Ltd. from 84 percent to 95 percent at the cost of $66 million. In 2007, Syngenta acquired Fischer, a European flower company, and by the end of 2008 that acquisition had contributed $24 million to seed sales growth. Incorporating Syngenta's direct acquisition costs, assets purchased, and share purchases, net cash outflow for 2007 acquisitions was $108 million.

In 2008, AgroFresh and Syngenta formed a strategic alliance, which allowed Syngenta to distribute a sprayable formulation of 1-methylcyclopropene, a plant

growth regulator that allows plants to withstand high temperatures and extended drought (Syngenta, 2008, p. 9). Syngenta also made agreements with DuPont for access to general insect control technologies in corn. Syngenta acquired a 49 percent share in Sanbei Seeds Co. Ltd., a Chinese seed company. Syngenta purchased SPS Argentina SA, a soybean, corn and sunflower business, and acquired Goldsmith Seeds, Inc. which specialized in pot and bedding products and flowers.

Today, Syngenta is a thriving company operating all around the world, with sales over $11.6 billion in 2008. Syngenta produces a magnitude of products which include but are not limited to herbicides, fungicides, insecticides, professional lawn products, seed care products, and diverse field crops with an emphasis on corn, soybean, vegetables, and flowers (Syngenta Product, 2009). Syngenta's has major manufacturing plants located in Switzerland, the United Kingdom, the United States of America, India, and China (Syngenta, 2008).

Another prominent plant biotechnology firm is Dow AgroSciences, who's mission is to grow through ambitious innovation programs. Dow AgroSciences' roots date back to 1950; in 1998 the DowElanco joint venture was created. "DowElanco acquired majority ownership in Mycogen Seeds in 1996; in 1997, The Dow Chemical Company acquired 100 percent of DowElanco and the company was renamed Dow AgroSciences. Other significant acquisitions include Acetochlor Herbicide, Cargill Hybrid Seeds, several Brazilian seed companies and the agricultural chemicals business of Rohm and Haas" (Dow Who, 2009).

Dow AgroSciences is a wholly owned subsidiary of The Dow Chemical Company.

Therefore, Dow AgroSciences' financial information is not available, except as part of The Dow Chemical Company's aggregate financial information (Dow Financial, 2009).

Moving on to another leader in plant biotechnology, Pioneer Hi-Bred International, Inc., a DuPont business, is headquartered in Johnston, Iowa. Pioneer Hi-Bred was originally Hi-Bred Corn Company founded in 1926 by Henry A. Wallace. Hi-Bred Corn Company continued to grow and flourish, and in 1993 "Pioneer" was added to the name. In 1995, it entered into a collaboration with Mycogen, which went on to become Dow AgroSciences LLC. In 1999, Pioneer Hi-Bred merged with DuPont (Pioneer History, 2009).

The main seeds Pioneer Hi-Bred provides are corn, soybean, sorghum, sunflower, canola, wheat, and forages such as alfalfa. Pioneer Hi-Bred is now reported to be the world's largest seed company, which offers a multitude of seeds with diverse genetic modifications that are stacked with the leading traits. These traits help farmers manage tough weeds, enable built-in pest resistance, and maximize crop rotation flexibility, all while delivering uncompromised crop to human safety (Pioneer Technology, 2009).

Another notable plant biotechnology firm is Bayer CropScience. It is an old life science company; the original name was "Friedr. Bayer et comp." founded by Friedrich Bayer and Johann Friedrich Weskott of Wuppertal (Germany). In 1924, the Bayer Crop Protection research department was established. In 1986, Bayer acquired 40 percent of Roussel Uclaf/Procida, and continued to acquire a majority

of the company in 1978, and owned 100 percent of the company by 1997. In 1994, "Hoechst (60 percent) and Schering (40 percent) form AgrEvo, integrating the crop protection and pest control business of Roussel Uclaf into the new venture" (Bayer Milestones, 2009). In 1996, AgrEvo acquired Plan Genetics Systems, the largest plant biotechnology firm in Europe. AgrEvo acquired Cargill's U.S. seed business as well as Proagro in 1999. In 2000, Aventis CropScience was formed through the merger of AgrEvo and Rhône-Poulenc Agro.

Bayer CropScience formed in 2002 from Bayer's acquisition of Aventis CropScience. In 2004, Bayer CropScience obtained full ownership of Crompton Corporation and in 2005, it acquired Associated Farmers Delinting. In 2006, Bayer CropScience paid to use the rights to FMC Corporation's insecticide discovery pipeline; also in 2006, Bayer CropScience acquired the assets of California Planting Cotton Seed and Reliance Genetics. In 2007, Bayer CropScience acquired Stoneville Pedigreed Seed Co. (Bayer Milestones, 2009). In 2008, Bayer CropScience's sales were over €6.3 billion. Bayer CropScience offers a wide range of products and seeds with traits such as insecticide, fungicide, herbicide, and other applicable technologies (Bayer Key, 2009).

Data

According to the United States Department of Agriculture (USDA), the most rapidly growing GM crops in the U.S. are Corn HT (herbicide resistant), Soybean HT, Cotton HT, Corn IR (insect resistant), and Cotton IR. This article continues to refer to these as the "five crops". Therefore, these five crops are given specific phenotype

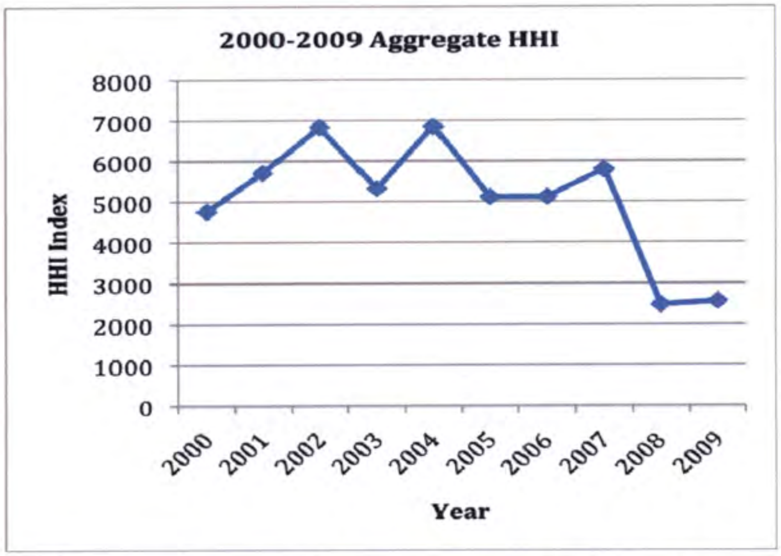
categories and are further examined to determine the concentration of the industry. In order for an institution to obtain federal authorization to test their modified seeds, permission must be granted in accordance with the Animal Plant and Health Inspection Service (APHIS) regulations. Field trial information is open to the public; APHIS has compiled the information thereby creating a dataset titled Information Systems for Biotechnology (Information, 2009). The literature provides industry concentration information from 1987 to 1998 or 1999. This paper provides an updated analysis of industry concentration using data from January 1, 2000 to December 22, 2009. Over those ten years, 40 institutions (firms, universities, government agencies) conducted field trials. Table 3 lists all involved institutions and the number of years that they actively conducted a field trial on at least one of the five crops.

Methodology and Results

Data on the five crops and phenotypes has been compiled into an aggregate dataset in order to derive the HHI, CR4, GR4, and information on the number of institutions conducting field trials. From 2000 to 2009, the aggregate HHI of the combined five crops was consistently above the Department of Justice's definition of a competitive industry (1800) as shown in Figure 9. Throughout that time period the HHI followed a cyclical movement, peaking in 2004 with an HHI of over 6,800 and dropping to its lowest level in 2008 of just under 2,500. This suggests that the decrease in the HHI was specifically caused by the 2007, government intervention when Monsanto was purchasing Delta & Pine Land Company. The cyclical pattern is

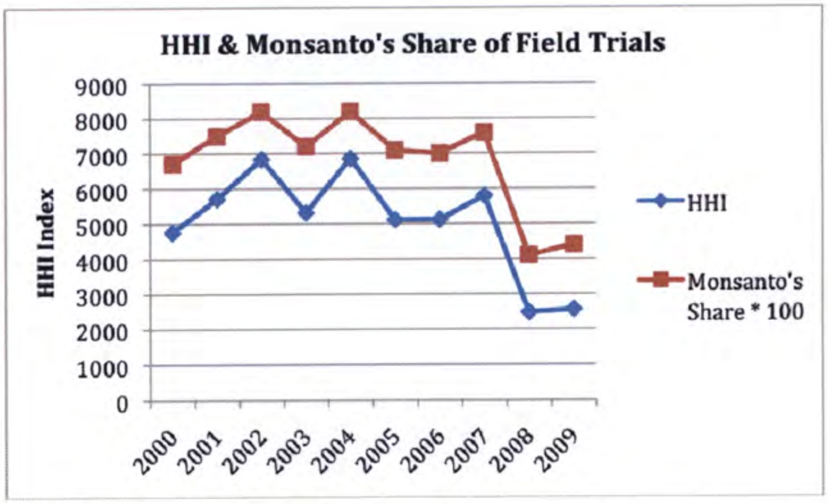
clear; periods of concentration are followed by periods of competition. The examination of field trials shows that the industry remained highly concentrated until 2008 when the concentration dropped to a relatively mild level. Figure 10 displays a strong positive correlation between the HHI and Monsanto's share of field trials. The red line graph in Figure 10 shows Monsanto's share of field trial as a percent of the market; Monsanto's percent was multiplied by 100 so that it would be more legible on the graph and better show the correlation. It is apparent that Monsanto is the driving company behind the HHI, specifically because Monsanto holds much of the market share of field trials.

Figure 9.



Aggregate HHI from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR
Source. Data from USDA APHIS (2009).

Figure10.

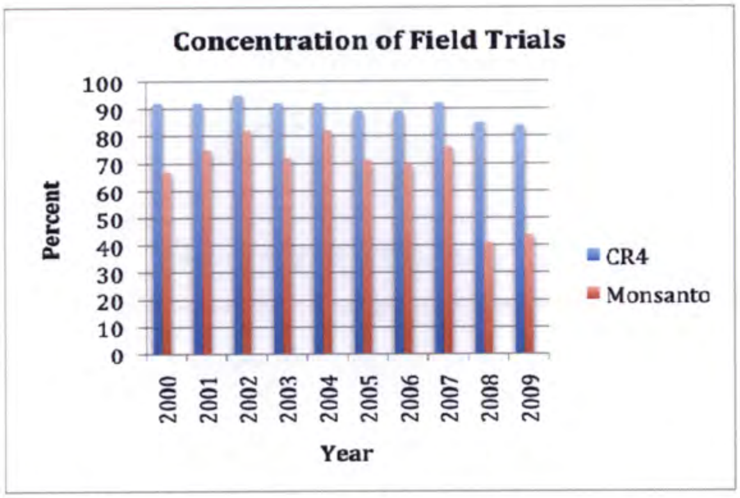


Aggregate HHI from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR

Source. Data from USDA APHIS (2009).

The CR4 generates valuable information about what percent of the market the top four institutions conducting field trials possess. The CR4 institutions have controlled about 90 percent of the field trials from 2000 to 2007, and about 85 percent from 2008 to 2009. Figure 11 illustrates Monsanto's market power by providing its share along within the CR4. Monsanto controlled an average of 70 percent of the field trials from 2000 to 2007 but only about 40 percent from 2008 to 2009. This infers that the decrease in Monsanto's share is due to the government intervention of 2007.

Figure 11.

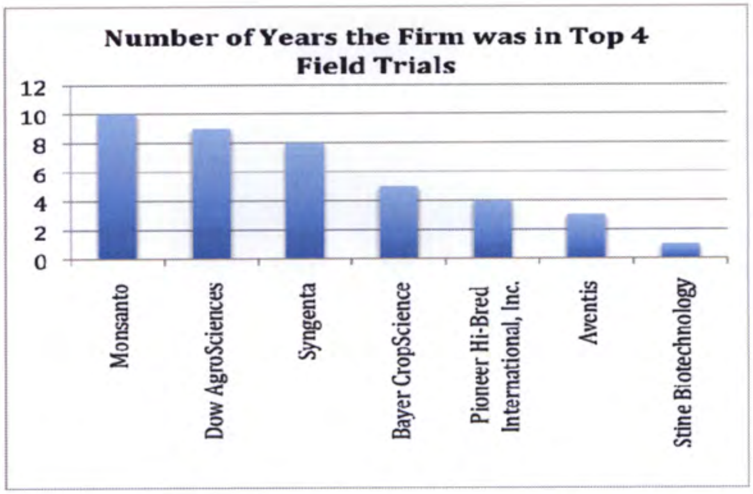


Aggregate HHI and Monsanto's Share from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR

Source. Data from USDA APHIS (2009).

The correlation between the HHI and the number of institutions conducting field trials is less stable. The relationship should in theory be inverse. The more firms conducting field trials, the smaller the HHI. But that is not shown by this data. In 2003 and 2007, there were 10 and 19 institutions conducting field trials, respectively; 10 and 19 were the outliers of number of firms in the industry, but for those years the results provided relatively moderate HHIs. The average number of firms conducting a field trial for the five crops in any given year was 15. The number of years that a firm was in a top four spot is shown in Figure 12 Monsanto, Dow AgroSciences, Syngenta, and Bayer CropScience held the CR4 positions for the most years during 2000 to 2009. The annual number of firms conducting field trials is shown for the five crops in Figure 13.

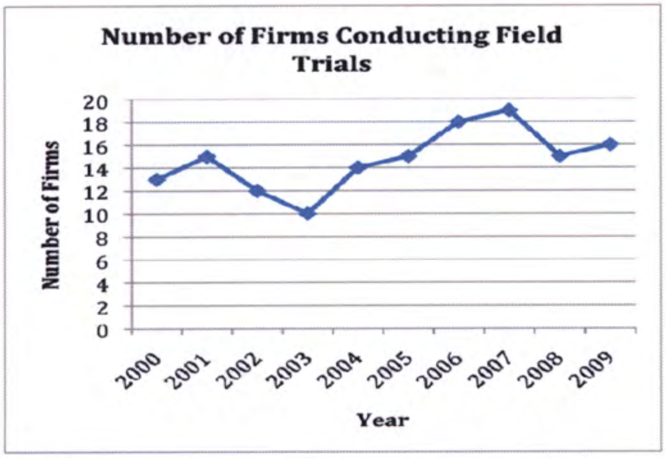
Figure 12.



Aggregate top four Positions from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR

Source. Data from USDA APHIS (2009).

Figure13.



Aggregate number of field trials from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR

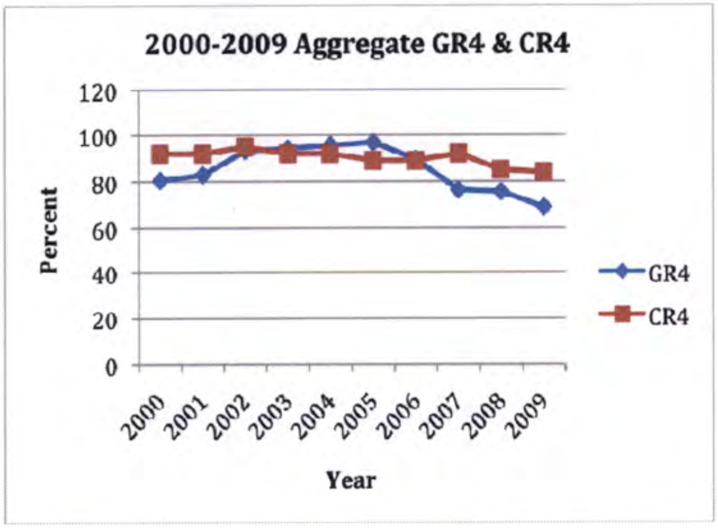
Source. Data from USDA APHIS (2009).

Extending the data from previous economic research, the GR4 has been constructed from 2000 through 2009. The GR4 helps economists understand the concentration of the most popular phenotypes. The GR4 asks the question "Of the five crops, how concentrated is the institution's use of phenotype categories?" Scientists know of an assortment of phenotype categories; economists strive to

know how many of those phenotype categories firms and other institutions are utilizing in their research. Other relevant GR4 measures are the number of firms conducting research on the same phenotype. This provides information on the disbursement of knowledge within the industry.

Figure 14 compares the aggregate CR4 ratios with the aggregate GR4 ratios. Oehmke & Wolf's work in 2003 found that the GR4 provided higher concentration than the CR4 ratios. The updated data illustrates that the CR4 is more concentrated than the GR4 only half of the time. The five-crops GR4 produces a bell shape curve across time, which peaks in 2005 with four-firm concentration accounting for 97 percent of the field trials. From 2005, the GR4 declines to the minimum level of 69 percent in 2009.

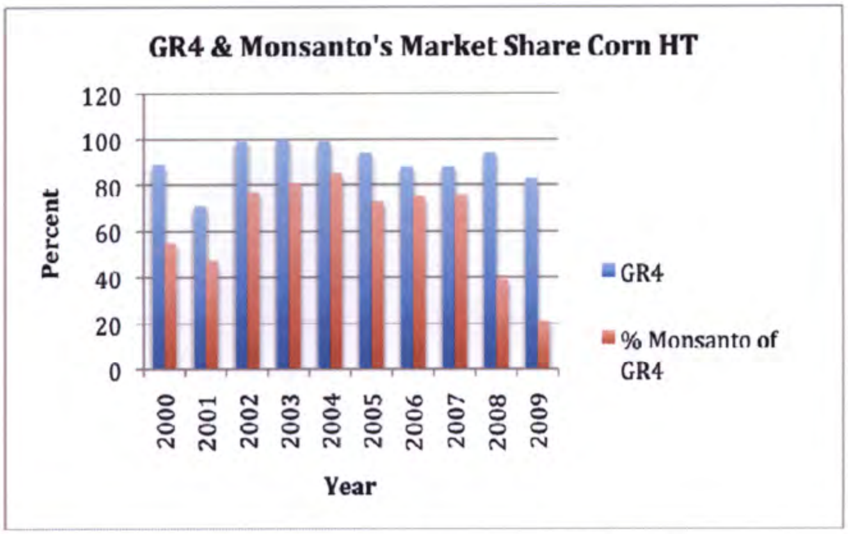
Figure 14.



Aggregate CR4 & GR4 from Corn HT, Soybean HT, Cotton HT, Corn IR, and Cotton IR
Source. Data from USDA APHIS (2009).

To create the GR4, the five crops were broken down into phenotype categories. The measure is called GR4 implying four phenotypes, but that is not always the case. The number of phenotype categories varies with the crop's specific situation. To begin, corn HT had five phenotype categories: Glyphosate Tolerant, Glyphosate Tolerance, Imidazolinone Tolerant, Phosphinothricin Tolerant, and CBI. For simplicity this study will refer to a GR4 for all five crops no matter how many phenotype categories are used. The Glyphosate Tolerant and Glyphosate Tolerance phenotypes essentially serve the same function; therefore, they were both included. The Glyphosate Tolerant phenotype had field trials in every year studied; the Glyphosate Tolerance's first field trial was in December 2006. In all ten years, field trials were conducted for Phosphinothricin Tolerant and CBI. Figure 15 reports the corn HT GR4 annual information.

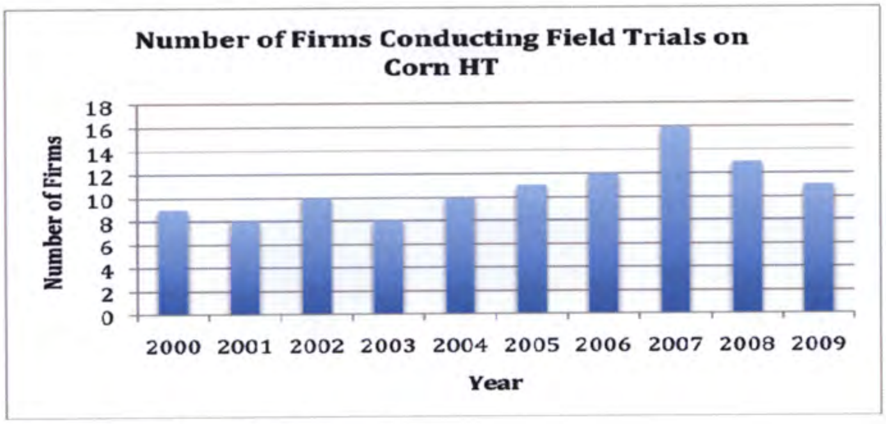
Figure 15.



Aggregate GR4 and percent of GR4 belonging to Monsanto from Corn HT
Source. Data from USDA APHIS (2009).

The number of firms conducting field trials for Corn HT peaked in 2007 with 16 firms involved. Figure 16 shows that there were only eight firms conducting field trials on in corn HT 2001 and 2003, on average 11 firms conducted these field trials.

Figure 16.

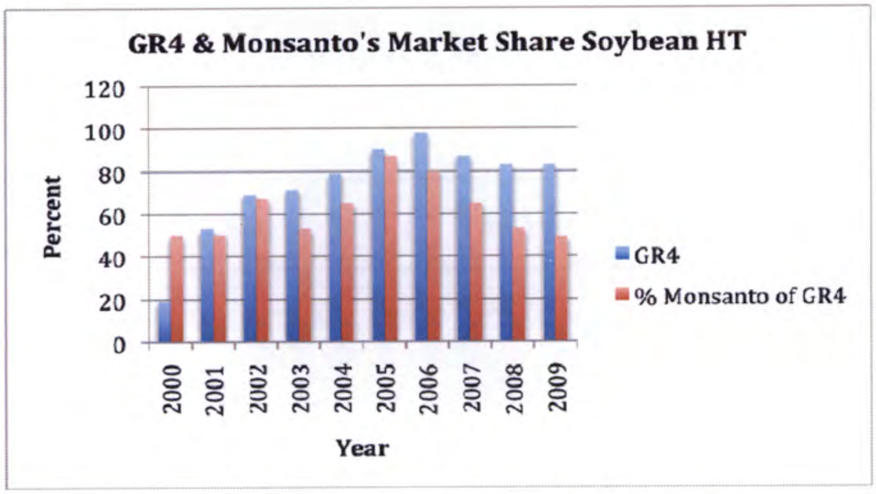


Aggregate number of firms from Corn HT

Source. Data from USDA APHIS (2009).

Soybean HT also had five phenotype categories: Glyphosate Tolerant, Glyphosate Tolerance, CBI, Dicamba Tolerant, and Als Inhibitor Tolerant. Similarly to corn, the soybean HT had field trials of the Glyphosate Tolerant phenotype for every year, and Glyphosate Tolerance starting in July 2006. CBI was tested in all years. Dicamba Tolerant was introduced in 2003 and Als Inhibitor Tolerant in 2008. Figure 17 shows the time trend of the GR4 in soybean HT. The GR4 concentration is fairly low in 2000 at 19 percent. The concentration steadily rises until reaching a turning point in 2006 with a GR4 of 98 percent, then declining to 92 percent in 2009.

Figure 17.

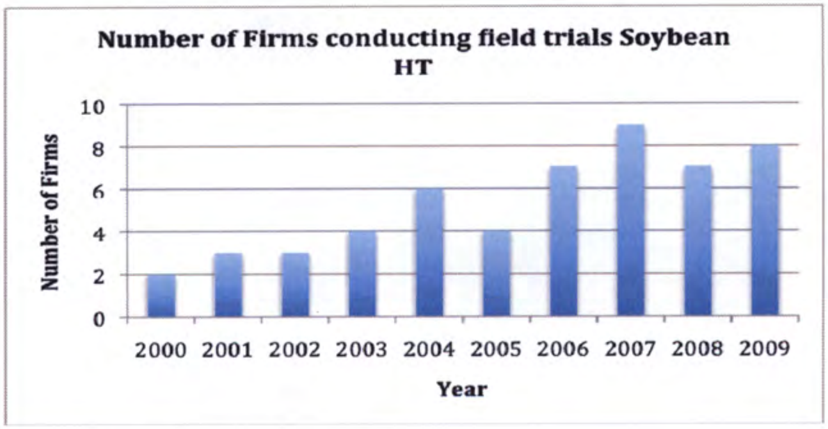


Aggregate GR4 and percent of GR4 belonging to Monsanto from Soybean HT

Source. Data from USDA APHIS (2009).

Figure 18 depicts the number of field trials for Soybean Ht using the top five phenotypes. The average number of firms conducting Soybean Ht field trials was five. In 2000, there were only two firms and only three firms in 2001 and 2002. The number of firms involved in soybean HT field trials peaked in 2007 with nine firms.

Figure 18.

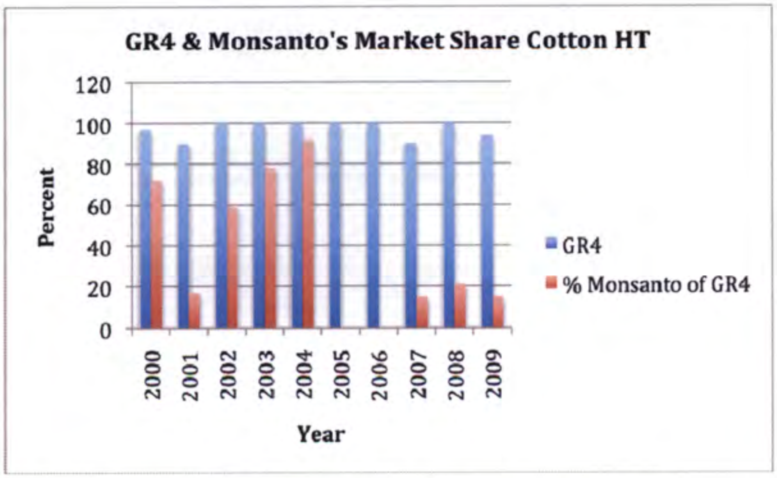


Aggregate number of firms from Soybean HT

Source. Data from USDA APHIS (2009).

Cotton HT has five phenotypes: Glyphosate Tolerant, Phosphinothricin Tolerant, CBI, Dicamba Resistance, and Dicamba Resistant. For seven of the ten years examined, there were only three firms conducting field trials on Cotton HT. Glyphosate Tolerant field trials were only conducted for cotton HT from 2000 to 2006 and Phosphinothricin Tolerant from 2000 to 2005. CBI was tested starting in 2003. Both Dicamba Resistance and Dicamba Resistant had their first field trials in 2007 and were only tested by Monsanto. The GR4 concentration levels are high ranging between 90 percent and 100 percent over the ten-year period. (Refer to Figure 19 and Figure 20.) Monsanto did not conduct any field trials in 2005 or 2006. . It may be the case that while Monsanto was in the process of acquire Delta & Pine Land Company in 2005 and 2006, Monsanto was forecasting any requirements of the Department of Justice to divest cottonseed information. Therefore, Monsanto would not want to use financial resources to develop products that could be required to be released to their competition.

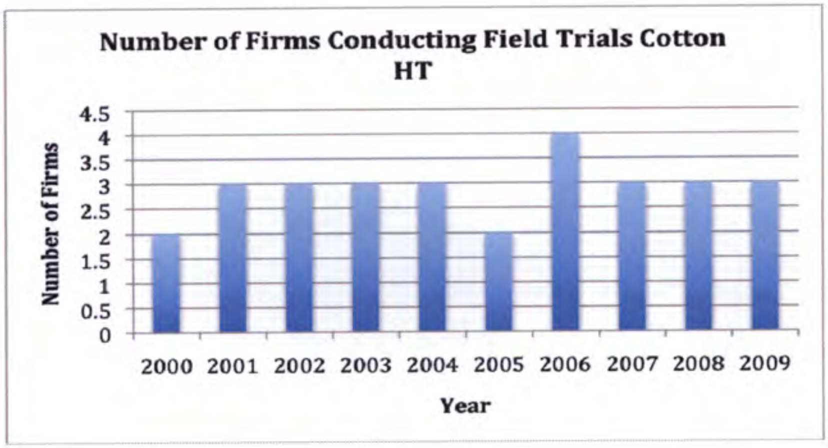
Figure 19.



Aggregate GR4 and percent of GR4 belonging to Monsanto from Cotton HT

Source. Data from USDA APHIS (2009).

Figure 20.

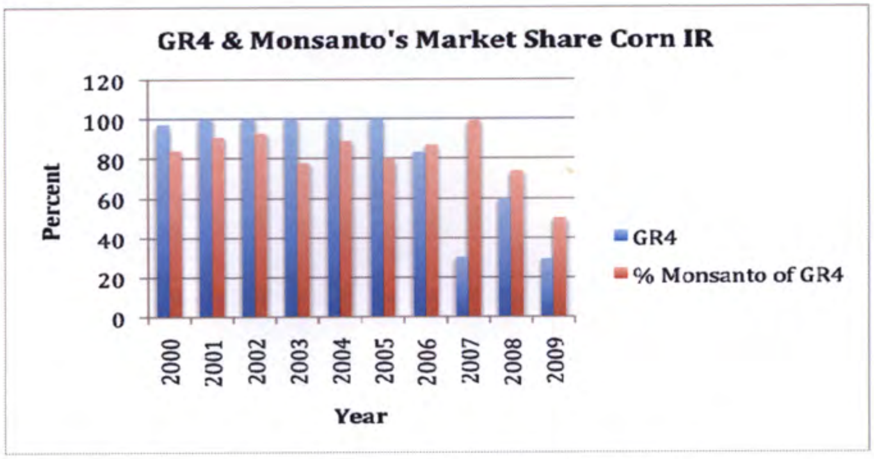


Aggregate number of firms from Cotton HT

Source. Data from USDA APHIS (2009).

Corn IR has four phenotype categories: Coleopteran Resistant, Lepidopteran Resistant, Lepidopteran Res. Coleopteran, and CBI. Coleopteran Resistant was tested by a variety of top firms, testing from 2001 through 2009. Lepidopteran Resistant was tested in all ten years, mainly by Monsanto, but also by other top firms. Lepidopteran Res. Coleopteran was only tested from 2006 to 2008, whit every field trial was conducted by Monsanto. CBI tests were conducted in all years except 2000 and 2005, with a wide array of firms were involved. Monsanto only conducted one CBI trial, which was in 2001. The GR4 levels are extremely high from 2000 to 2005 close to 100 percent. In 2006, the GR4 drops to 83 percent and again to 30 percent in 2007. Monsanto's share of the GR4 ranged around the 80 percent and 90 percent range until 2008 when it dropped to 74 percent and again in 2009 dropped to 50 percent. (Refer to Figure 21 and Figure 22.)

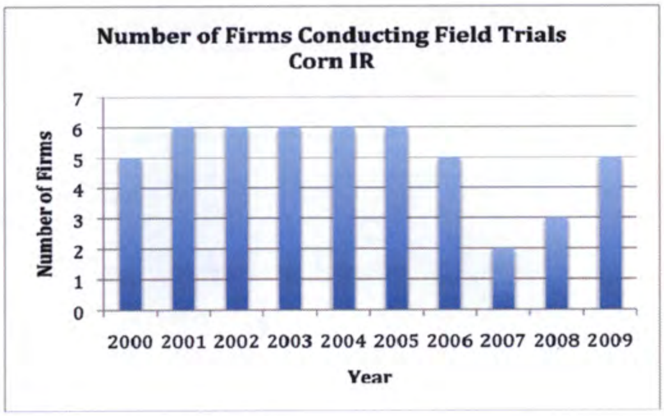
Figure 21.



Aggregate GR4 and percent of GR4 belonging to Monsanto from Corn IR

Source. Data from USDA APHIS (2009).

Figure 22.



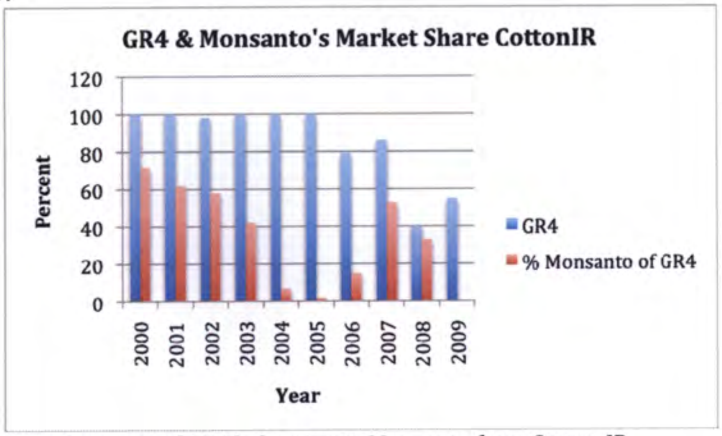
Aggregate number of firms from Corn IR

Source. Data from USDA APHIS (2009).

Cotton IR has only two phenotype categories, Lepidopteran Resistant and CBI. Lepidopteran Resistant field trials were conducted by a plethora of firms from 2000 to 2007. CBI was field tested from 2003 to 2009. Bayer CropScience, Syngenta, and Monsanto were the only firms to conduct field trials on CBI, with Bayer CropScience being the driving firm behind CBI research. The field trials were highly concentrated around these two phenotypes from 2000 to 2005 with the GR4

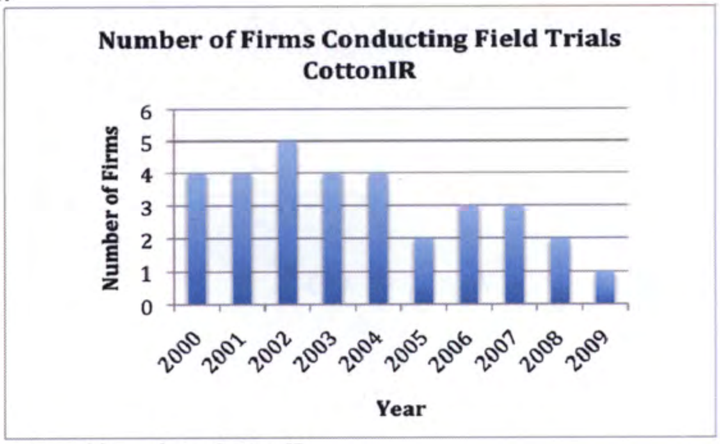
averaging 100 percent. In 2006 the GR4 dropped to 79 percent, rose a little in 2007, but by 2008 the GR4 had dropped to 40 percent. Monsanto's share of the GR4 field trials was (relative to the other five crops) low, peaking in 2000 at 72 percent and gradually declining to 42 percent in 2003. Monsanto's share of the field trials then jumped down to 7 percent and 2 percent in 2004 and 2005 respectively. Yet again the author believes that Monsanto was predicting that their information on cottonseed would have to be divested and halted research on cottonseed IR. The results are shown in Figures 23 and 24.

Figure 23.



Aggregate GR4 and percent of GR4 belonging to Monsanto from Cotton IR
Source. Data from USDA APHIS (2009).

Figure 24.



Aggregate number of firms from Cotton IR
Source. Data from USDA APHIS (2009).

Discussions and Conclusions

There are high levels of industry concentration in the plant biotechnology sector within the U.S. The industry is dynamic; key influential players are multinational firms, universities, research facilities, and governmental regulatory agencies. When top firms behave competitively such as the engagement of lawsuits against one another, society gains. When firms choose to collude, social welfare decreases. In an oligopoly or a concentrated monopolistic competition each firm pursues its best interest by innovating to increase quality or reduce costs. The result of both of these is a more abundant supply of resources that society may utilize, and thus the long-term viability of society. More resources are heavily preferred to rational actors in society, which is why creating a balance of concentration and innovation is so imperative. This innovation typically comes at a cost: reduced competition. The Federal Trade Commission and the Department of Justice should keep a close eye on this industry and be watchdogs for antitrust or anticompetitive behaviors, in order to optimize social welfare.

The bell shape HHI levels could infer that there is at least one relevant parameter omitted. From the information assessed, this parameter could be bureaucratic tolerance toward levels of monopolistic existence, or antitrust pressures. The situation appears to be that the Department of Justice has allowed most mergers, even the ones leading to increased industry concentration. In 2007, the HHI levels were relatively high, and then substantially dropped in 2008. The author believes that the regulatory actions that were taken against Monsanto in

2007 caused the decline in HHI. The decline in HHI could be considered as a positive development in the industry; by examining the situation from different perspectives it becomes apparent that the answer is not straightforward.

Recall that Monsanto was forced to divulge substantial information about cottonseed. The 2008 - 2009 data show a reduction in cottonseed field trials. It is plausible that other firms in the industry focused on the newly acquired cotton information instead of investing those resources in different technologies. If the goal is to increase innovation, then the policy was not a success. Government intervention can unintentionally influence firms in negative ways; sometimes firms associate regulation with higher costs and uncertainty. From the consumer's point of view, this type of regulation has the potential to positively affect the price in downstream markets; whereby these five crops are used in processed foods.

It is interesting to note that in 2004, Monsanto conducted 92 percent of the GR4 field trials; however, in 2005 and 2006, Monsanto did not conduct a single Cotton HT field trial. Monsanto's cotton IR field trials were few in numbers for 2004 and 2005. In 2005, Monsanto acquired Stoneville. Monsanto's 2006 investment report shows that Stoneville cotton was the top brand. Monsanto was highly active until the new technology or intellectual property had been acquired. Then, all field trials stopped. It seems reasonable that Monsanto redirected resources to further develop products that Stoneville had already created instead of investing in new research. This is a completely normative speculation; however the scenario is on par with the theory that mergers and acquisitions reduce investment in research

and development. In 2007 Monsanto was forced to divest Stoneville Pedigree Seed Company, in order for Monsanto to be allowed to acquire Delta & Pine Land. The results show a decrease in HHI after 2007; it is interesting to note that the initial transaction of acquisition, in the long run, leads to a more competitive market, through government regulation.

International data on field trials is available in the APHIS Information Systems for Biotechnology dataset. An optimal analysis would be to incorporate all major firms around the world. The U.S. is the top country developing and producing plant biotechnology, however adoption of this technology is increasing around the world. The problem with this dataset is that the data is not exclusively in English. Therefore, a translator would be necessary to incorporate multinational data. Because foreign corporations were omitted from this study, the industry concentration levels shown are overstated. Further research should encompass other industry concentration measurements such as measuring increased revenues derived from new products, or cost reduction achieved by new products or processes. Furthermore, this study did not cover product pricing. Continuing research should include an analysis of the way in which the industry sets prices; given oligopolistic competition it is possible that there is price leader setting the market price.

When comparing Oehmke's & Wolf's (2004) research to this paper, it should be noted that the CR4 and GR4 levels do not coincide. The previous work used the most common phenotypes from the 1990s and this paper uses the most common

phenotypes from the 2000s. The phenotypes used in these two works are not consistent, due to intuitional preferences. This paper's specific contribution to the field is the organization and analysis of the updated dataset.

The plant biotechnology sector has been highly concentrated in field trial research over the past two decades. The optimal level of concentration is still unknown, but the optimal level is going to be higher than other non-innovation industries. As a society we desire efficient and useful innovations form the plant biotechnology industry. Furthermore, we desire a level of competition amongst these firms to induce revolutionary design and innovation.

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Appendix

U.S. Adoption of Bioengineered Crops

Syngenta	**Aventis**	**Monsanto**	**DuPont**	**Dow**	**BASF**
Sandoz Novartis Seeds Ciba-Geigy Northrup King Rogers Rogers NK Zeneca Hilleshog Wilson - Genetics	AgrEvo Hoechst-Roussel Agritope Exelixis Limagrain PGS Plant Genetics Plant Genetic Systems Harris Moran Rhone-Poulenc	Calgene Holdens DeKalb Asgrow Upjohn Agracetus	Du Pont Pioneer	Agrigenetics Mycogen Biosource	American Cyanamid ExSeed Genetics Rohm and Haas

Table 1. Companies acquired through mergers.

Source. Data from Information Systems for Biotechnology

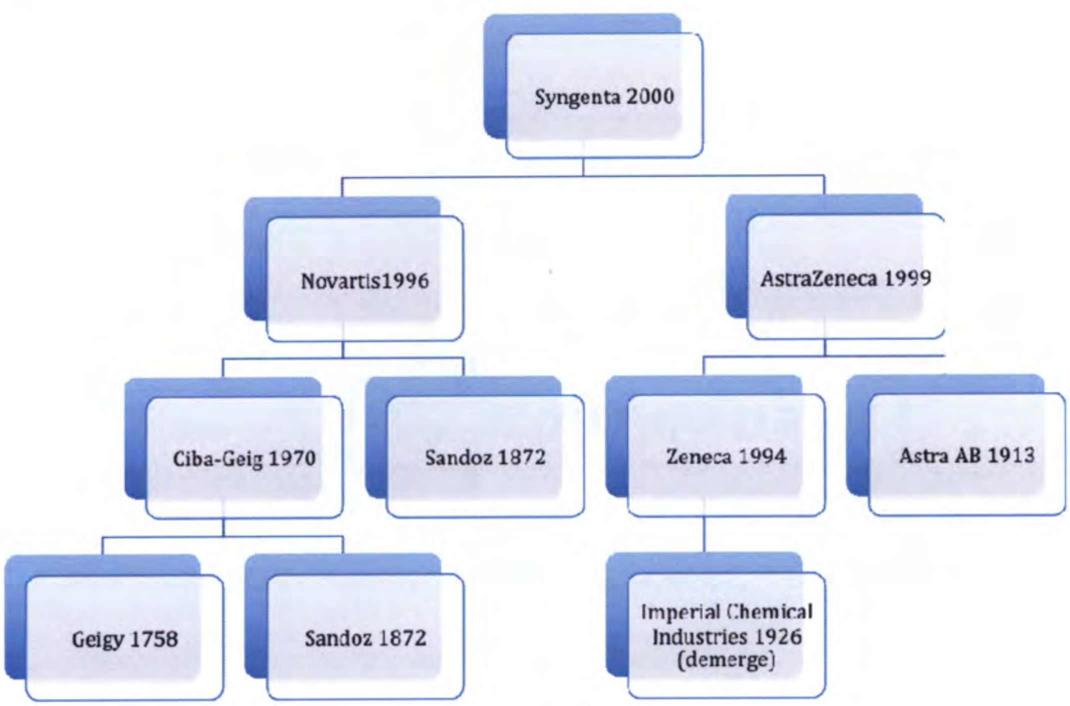

Table 2.

Historical Outline of Syngenta. (AstraZeneca, 2009).

Number of Years the Institution Conducted Field Trials	Institution		
10	Monsanto	3	Stine Seed Farm, Inc.
10	Pioneer Hi-Bred International, Inc.	3	Montana State University
10	University of Nebraska/Lincoln	2	ExSeed Genetics
10	Dow AgroSciences	2	University of Illinois
9	Syngenta	2	Zeneca
9	BASF	2	University of California/Berkeley
8	Bayer CropScience	2	Targeted Growth, Inc.
6	Athenix Corporation	1	Novartis Seeds
6	M.S. Technologies, LLC	1	Mississippi State University
5	Stine Biotechnology	1	United Agri Products
5	Southern Illinois University	1	AgReliant Genetics
5	Biogemma	1	University of California/San Diego
4	Rutgers University	1	University of Kentucky
3	Aventis	1	Benson Seed Research
3	Garst	1	Michigan State University
3	Stine Seeds	1	DeltaMax Cotton LLC
3	Midwest Research, Inc.	1	Alvey Agriculture Research
3	University of Arizona	1	Easton Agricultural Consulting, Inc.
3	Iowa State University	1	Diamond Ag Research, Inc.
3	United States Department of Agriculture/Agricultur	1	Delta and Pine Land

Table 3.

Number of Years the Institution Conducted Field Trials