BIOTECHNOLOGY R&D RACES, INDUSTRY STRUCTURE, AND PUBLIC AND PRIVATE SECTOR RESEARCH ORIENTATION

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This paper examines research and development (R&D) activity, industry structure, and public sector and private sector research orientations in two transgenic biotechnology races. Key results are: the number of R&D organizations follows a bell curve over time and universities seem to engage in R&D for smaller markets in which multinational firms do not compete.

Keywords: agricultural biotechnology; concentration; endogenous growth; herbicide-tolerance; industry structure; insect-resistance; research and development (R&D); Schumpeter.

The plant biotechnology industry is one of the most concentrated in the world. In the United States (US), only seven firms have ever successfully petitioned the government to deregulate (exempt from further review) a herbicide-tolerant (HT) variety of any crop; three of these firms have been acquired by others (Kalaitzandonakes & Hayenga, 1999), and a fourth has a licensing agreement with Monsanto (James, 2000). Barton (1998) and Brennan, Pray and Courtmanche (1999), among others, have raised the issue of whether this high level of concentration has a deleterious effect on the level of R&D activity.

This paper examines the level and nature of R&D activity in transgenic biotechnology races to develop herbicide-tolerant and insect-resistant (IR) plants, and examines potential relationships among R&D activity, concentration, and industry structure. Herbicide-tolerance and IR represent 54% of the trials conducted through 2000, and virtually all of the area planted to transgenic crops (James, 2000). The paper examines the nature of the R&D race, industry structure, and their interactions.

In looking at the agricultural R&D industry, it is important to note that this industry consists of both private sector firms and public sector institutions such as universities and experiment stations. Indeed, throughout most of the twentieth century the public sector was the primary source of agricultural R&D (Fuglie & Schimmelpfennig, 2000). In some cases, the public sector played the role of maintaining competitive forces in the face of increasing concentration (Butler & Marion, 1985), necessitating the inclusion of the public sector in any examination of the nature of R&D races and industry structure. Therefore, this paper treats both private sector firms and public sector

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institutions (universities, experiment stations, etc.) as part of the agricultural biotechnology R&D industry and structure. The paper also examines the orientation of private sector R&D activity compared to public sector activity.

A Conceptual Framework And Empirical Background For The Analysis Of R&D Activity

Following Segerstrom, Anant, and Dinopoulos (1990), Aghion and Howitt (1992), and Grossman and Helpman (1991), the recent literature on endogenous innovation characterizes an R&D race as Schumpeter's (1934) notion of creative destruction—in which the firm creating a better product destroys the market advantage of other firms and gains market power itself. Firms invest resources in R&D races with uncertain outcomes. One firm will "win" the race by becoming the first to discover or create a higher-quality product, which replaces the previously best product(s). As the sole (or even as a leading) producer of the new product, the winning firm is able to capture economic rents. These rents motivate the original R&D investment. In more detailed formulations of R&D races, firms who are unsuccessful at winning the race can earn profits if they are successful in imitating the discovery (e.g., Segerstrom, 1991), or in creating a new high-quality product which is differentiated from the original discovery (e.g., Davidson & Segerstrom, 1998).

This literature provides a conceptual framework with several implications for the examination of plant biotechnology races. First, the proximate target of R&D is a technological innovation, so that one may wish to categorize R&D activity by technology target (in addition to the final market). This paper focuses on the transgenic HT and IR traits, rather than on a particular commodity market. Second, market structure is important in the innovation market consisting of private sector firms and public sector institutions conducting R&D. In particular, a more highly concentrated structure may allow firms to capture greater profits from innovation, enticing them to increase their R&D activity (although see Barton (1998) or Brennan, Pray, and Courtmanche (2000) for an opposing viewpoint). This paper examines the relationship between concentration and R&D activity. Third, there are different kinds of R&D races. Initially the race may be to create a new innovation. Eventually, the race may be to imitate the initial discovery, or to make a similar but nonetheless differentiated product that can be sold in a different market. The application of HT or IR technology to some of the smaller crops is one example of product differentiation. Fourth, the type of organization is related to the type of research. Large multinationals with research budgets in the $100 millions specifically target the row crops that allow them to recoup their R&D investment. Smaller firms with specialized knowledge may find that their best profit opportunity lies in a differentiated market, which values their specialized knowledge and which offers less competition than do markets related to the major row crops. Organizations which have objectives other than profits or which have specialized missions, such as universities and other public sector organizations, may choose to target a set of commodities with negligible biotechnology profit potential. The commodity orientation of public and private sector R&D activities is the focus of this research.

The empirical literature on biotechnology R&D industry structure is young. Kalaitzandonakes and Bjornson (1997) examine various indicators of R&D industry structure and activity, including experiments and patents by biotechnology traits. They predict market domination by a few players, but relate this to their data on R&D activity and orientation only in passing. Hayenga (1988) reviews market shares in the insect-resistance and herbicide-tolerant seed markets, concluding that increasing domination by a few firms raises market-power and antitrust issues. However, he does not extend the analysis to look at implications for R&D activity. Brennan, Pray, and Courtmanche (2000) provide an early investigation into the relationship between concentration and R&D activity, but are unable to draw strong conclusions. Graf, Rausser, and Small (2000) explain consolidation in the biotechnology industry as attempts to merge complementary assets, suggesting that this would lead to greater returns to R&D and, hence, more R&D activity (see also Kalaitzandonakes & Hayenga, 1997). They find some empirical support for this position in looking at firm patent numbers. However, they neither explain the evolution of biotechnology races, nor consider that industry structure and consolidation may affect the level of pre- or post-patent R&D activity.

HT And IR Biotechnology R&D Activity

Data

The number of field trials of genetically modified organisms is used as the measure of R&D activity. The data are available from the Animal and Plant Health Inspection Service (APHIS), and show the organism on which the trial is to be conducted, the phenotype, the institution conducting the trial, the date at which the application was approved or rejected, and the status of the application. Attention is restricted to applications that were "issued" or "acknowledged," that is, where the field trial was allowed to go forward.

These data have both advantages and disadvantages. The major disadvantage is that they provide information on R&D activity at only one stage of the research-to-commercialization continuum, and so are not a comprehensive summary of R&D portfolios. The major advantages are that since all field trials are required to be registered, these data provide a complete census of R&D activity at the field trial stage; and that the information on the nature of the trial is sufficiently detailed so that good descriptions of the nature of the R&D activity and the industry structure affecting that activity are easily described.

Herbicide-Tolerance

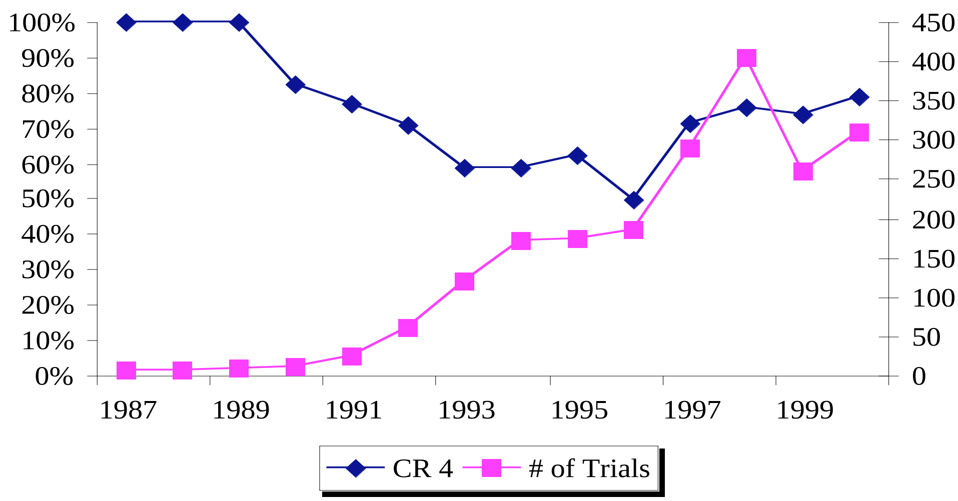
The most common field trial conducted is for crops exhibiting herbicide-tolerance characteristics: through to 2000, APHIS has permitted 2,038 field trials of transgenic, herbicide-tolerant plants. Just less than one-half of these trials were conducted on corn (967); the next two most active crops were soybean (267) and cotton (206). The number of trials grew from 6 in 1988 to a peak of 405 in 1998, before declining to 259 in 1999 and then rising to 311 in 2000 (figure 1). The four-firm concentration ratio (CR4) declined steadily from 100% in 1987 to 59% in 1993, and has fluctuated since then.

The aggregate number of private sector firms and public sector institutions conducting herbicide-tolerance trials grew slowly from two in 1987 to seven in 1992, leapt to 32 in 1993, peaked at 42 in 1996, and has declined since then. The number of private sector firms conducting herbicide-tolerance trials grew slowly until 1991, expanded rapidly to a peak of 33 firms in 1994 and again in 1996, and has declined since then (figure 2). Universities and other public sector institutions (most notably the United States Department of Agriculture (USDA)'s Agricultural Research Service) were essentially inactive until 1993; since 1994 the number of universities conducting herbicide-tolerance trials has hovered in the mid single-digits. The number of commodities on which herbicide-tolerance trials were conducted increased slowly over the sample period. Visual inspection of the number of universities conducting herbicide-tolerance trials and the number of commodities on which the trials were conducted appears to indicate co-movement of these two series, especially prior to 1999 (figure 2).

Insect-Resistance

Insect resistance is the second most researched transgenic innovation by number of field trials. Through to 2000, APHIS has permitted 1,766 field trials of plants believed to have transgenic insect-resistance characteristics. Corn accounts for 62% (or 1,103) of these trials, 17% (301) were conducted on potato, and 11% (189) on cotton. There was a steady increase in the number of insect-resistance trials from two in 1987 to 197 in 1995; since 1995 the number fluctuates but peaked in 1998 at 334 and has since fallen off that peak (figure 3). After an initial CR4 of 100% in 1987, the concentration ratio has fluctuated (figure 3). It reached a secondary peak in 1994 at 92%, declined to its nadir of 48% in 1998, and then increased to 86% in 1999. To the eye, there is no immediately apparent relationship between the number of trials and industry concentration.

Figure 1: Number of Transgenic Herbicide-Tolerance Trials and Four-Firm Concentration Ratio, 1987-2000.



The aggregate number of private sector firms and public sector institutions conducting insect-resistance trials grew from 2 in 1987 to a peak of 33 in 1996, then declined to 20 in 1998 before recovering to 26 in 1999. The number of private sector firms peaked at 27 in 1996, and has declined steadily since then to 11 in 2000 (figure 4). The number of universities engaged in transgenic IR research increased from zero in 1987 to 13 in 1999, although fluctuating significantly in the last three years. The number of commodities targeted increased from two in 1987 to 20 in 1999.

There appears to be a strong co-movement between the number of universities and the number of commodities researched. Both data series indicate upward trends over the sample period. The series move almost in tandem from 1992 onward, and follow a similar peak-trough-peak pattern from 1997-1999.

The Orientation of Public Sector Research

Examination of the field trial applications suggests that the land-grant universities are targeting their transgenic insect-resistance research to those crops in which their state specializes.[1] In 1999, for example, for nine crops, only the public sector directed research toward insect-resistance in those crops (table 1). For a tenth crop (sunflower), there were three IR trials, one each by Pioneer, the University of Nebraska, and Ohio State University. This suggests that the universities are targeting a set of crops different from the set targeted by private sector firms.

Figure 2: Number of Targeted Commodities, Universities and Other Public Sector Organizations, and Number of Private Sector Firms Engaged in Transgenic Herbicide-Tolerance Field Trials, 1986-2000.

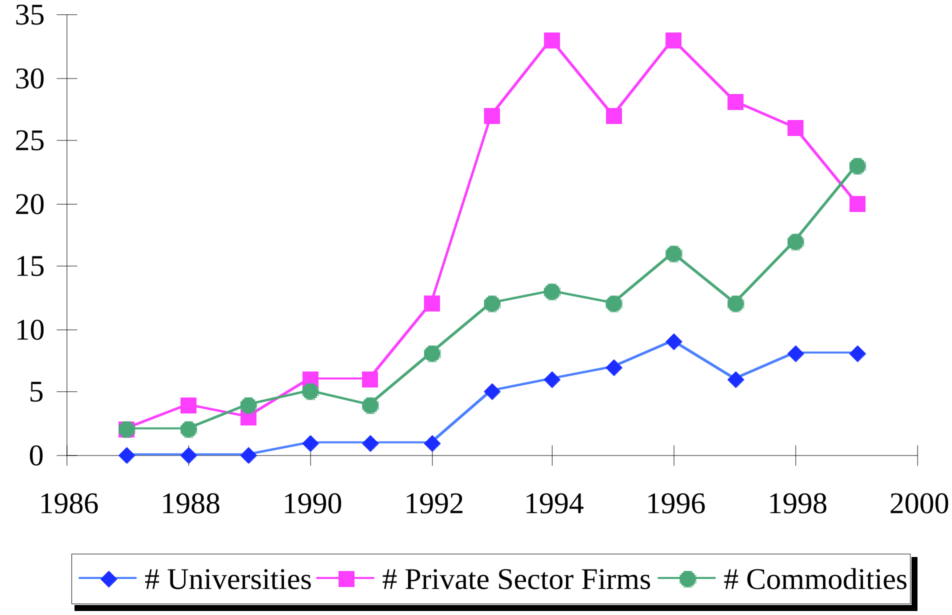


Figure 3: Number of Transgenic Insect-Resistance Field Trials, and Four-Firm Concentration Ratio, 1987-2000.

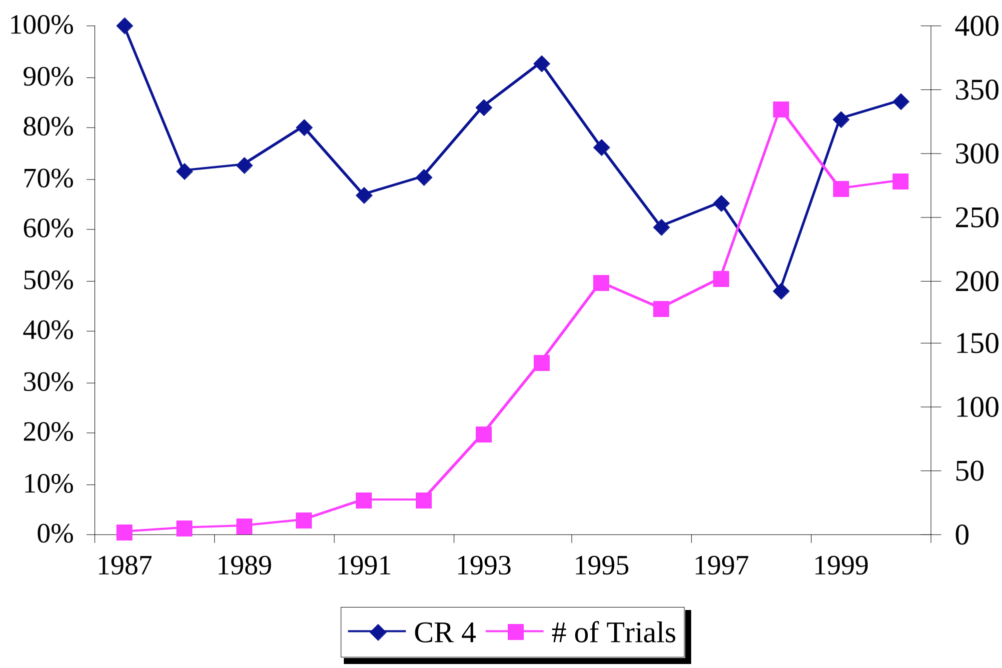
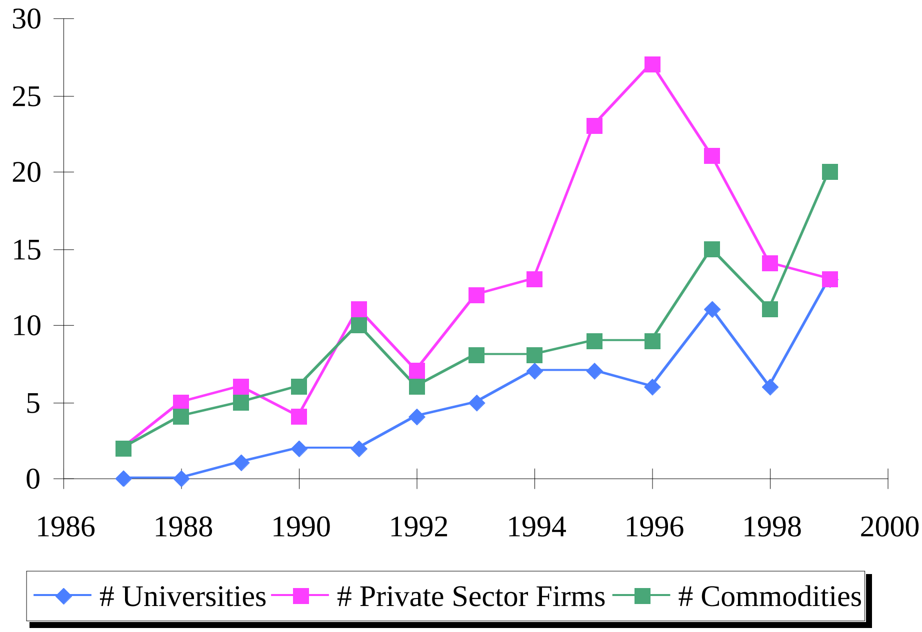


Figure 4: Number of Targeted Commodities, Number of Universities and Other Public Sector Organizations, and Number of Private Sector Firms Engaged in Transgenic Insect-Resistance Field Trials, 1986-2000.



Further evidence on the issue of different crop targets for the public and private sectors comes from a more detailed examination of public sector trials. First, through to 2000 the public sector conducted only 30(2%) of the 1,575 HT trials on corn, soybeans, and cotton. Similarly, the public sector conducted only 6 (<1%) of the 1,632 IR trials on corn, soybeans, and cotton. This indicates that at least at the trial level, the public sector is not targeting its research towards the most commercial transgenic crops.

Second, there are a number of crop-trait combinations for which the public sector is a major player in terms of being the first or only sector to conduct trials, continuing trials after the private sector has withdrawn, or simply conducting a number of trials comparable to the number conducted by the private sector (table 2). Again, land-grant universities are often conducting research targeted toward commodities grown in their state. For example, only the University of Georgia has conducted insect-resistance trials for peanut, and Oregon State University has conducted ten of the 11 IR trials for poplar (the University of Wisconsin conducted the other). This evidence suggests that the public sector is indeed targeting those commodities that are relatively neglected by the private sector but important to the mission of the public sector institution.

<u>The Relationship Between Innovation and Output Industry Structures</u>

The data provide for examination of several hypotheses about R&D activity and industry structure. However, the available information is limited both by the short sample, and by an initial period in which organizations are just getting their experiments started and are not running at full throttle. Nonetheless, we are able to provide some preliminary evidence, omitting the first three years of observations to remove the start-up period.

Table 1: Transgenic IR Plants With only one Institution Conducting Field Trials, 1999.

Plant	Research Institution
Brassica Rapa	University of North Carolina
Eggplant	Rutgers University
Grapefruit	Texas A&M University
Peanut	University of Georgia
Persimmon	University of California
Poplar	Oregon State University
Rice	Louisiana State University
Sugarcane	Agricultural Research Service (USDA)
Tobacco	University of North Carolina

Note. From APHIS database.

The first hypothesis we examine is the intuitive hypothesis that more concentrated industries are likely to contain a smaller number of organizations. The correlations between the CR4 and the number of organizations are negative for both the herbicide-tolerance (ρ = 0.75, p = 0.01) and insect-resistance races (ρ = 0.24, p = 0.48). The insect-resistance coefficient is not statistically significant at the 10% level but the herbicide-tolerance coefficient is significant at the 1% level. The evidence in support of this proposition is therefore somewhat favorable.

The second hypothesis is that there is no relationship between concentration and the level of R&D activity. The correlation between the CR4 and the number of herbicide-tolerance trials (ρ = 0.03, p = 0.94) is positive but not statistically significant. For the insect-resistance race, the correlation (ρ = -0.24, p = 0.48) is negative and not statistically significant. The data support the hypothesis.

The hypothesis that there is a positive correlation between the concentration ratios in the two races is consistent with the idea that the major plant biotechnology firms dominate the entire transgenic industry, with the additional assumption that the major firms are able to increase their dominance in the two races simultaneously. It is also consistent with the idea that there may be technological or institutional spillovers from one race to the other. There is no significant correlation between the CR4s in the two R&D activities (ρ = -0.06, p = 0.86). Thus, the data provide no support for this hypothesis. This could mean that the major firms do not dominate across the transgenic innovation industry, or it could simply mean that they do not increase their dominance of the herbicide-tolerance and insect-resistance races simultaneously.

R&D activity that duplicates private sector activity can be examined by testing to see if there is a relationship between differentiation and the level of public sector activity. The number of commodities targeted for herbicide-tolerance or insect-resistance characteristics provides a measure of differentiation. The correlations between number of commodities and number of public sector institutions conducting trials are positive and statistically significant at the 1% level for both the herbicide-tolerance race (□ = 0.80, $p > 0.0001$) and the insect-resistance race (□ = 0.87, $p > 0.0001$). This provides evidence against the idea that public sector activity duplicates private sector activity.

Table 2: Date of First Trial, Latest Trial, and Cumulative Number of Trials by Commodity, Phenotype, and Sector for Selected Commodity-Phenotype Combinations.

Commodity – Phenotype	Date of First Trial	Date of Latest Trial	Number of Trials
Brassica Rapa – Insect Resistance			
Public Sector	1999	2000	4
Private Sector			0
Creeping Bentgrass – Herbicide Tolerance			
Public Sector	1994	2001	13
Private Sector	1997	2001	24
Eggplant – Insect Resistance			
Public Sector	1994	1999	6
Private Sector			0
Grapefruit – Insect Resistance			
Public Sector	1999	1999	1
Private Sector			0
Peanut – Insect Resistance			
Public Sector	1997	2001	5
Private Sector			0
Poplar – Herbicide Tolerance			
Public Sector	1993	2001	19
Private Sector	1997	2000	5
Poplar – Insect Resistance			
Public Sector	1993	2001	13
Private Sector			0
Rapeseed – Insect Resistance			
Public Sector	1995	2000	11
Private Sector	1991	1999	5
Rice – Insect Resistance			
Public Sector	1991	1999	4
Private Sector	2000	2000	1
Sugarcane – Herbicide Tolerance			
Public Sector	1995	2001	9
Private Sector	1998	1999	4
Sugarcane – Insect Resistance			
Public Sector	1997	2001	7
Private Sector			0
Tobacco – Insect Resistance			
Public Sector	1990	2001	7
Private Sector	1988	1991	8

Conclusions

This paper has examined R&D activity in plant biotechnology from the perspective of endogenous R&D races. By focusing on the invention rather than the final commodity, this perspective differs from those based on output markets. This perspective is particularly useful in an innovation market, such as the markets for transgenic plant varieties with improved herbicide-tolerance or insect-resistance characteristics. One key empirical finding of this research are that the numbers of private sector firms and the aggregate numbers of private and public sector organizations engaged in the R&D race seem to follow a unimodal (bell-shaped) pattern over time, at least for the herbicide-tolerance and insect-resistance races examined. The number of universities and other public sector institutions conducting herbicide-tolerance or insect-resistance research has increased over the sample period. A second key finding is that there appears to be a strong correlation between the number of universities that are active in the R&D race, and the number of commodities to which the innovation is applied. The latter finding is consistent with the idea that universities are engaged in plant biotech research for important but smaller markets in which the multinational firms have little interest.

Endnote

[1] Product differentiation may also occur in a number of other dimensions, such as health, safety or ecological effect.

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